Red Hat Enterprise Linux 9

Configuring and managing networking

A guide to configuring and managing networking in Red Hat Enterprise Linux 9
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Abstract

This document describes how to manage networking on Red Hat Enterprise Linux 9.
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Red Hat is committed to replacing problematic language in our code, documentation, and web properties. We are beginning with these four terms: master, slave, blacklist, and whitelist. Because of the enormity of this endeavor, these changes will be implemented gradually over several upcoming releases. For more details, see our CTO Chris Wright’s message.
PROVIDING FEEDBACK ON RED HAT DOCUMENTATION

We appreciate your feedback on our documentation. Let us know how we can improve it.

Submitting comments on specific passages

1. View the documentation in the Multi-page HTML format and ensure that you see the Feedback button in the upper right corner after the page fully loads.
2. Use your cursor to highlight the part of the text that you want to comment on.
3. Click the Add Feedback button that appears near the highlighted text.
4. Add your feedback and click Submit.

Submitting feedback through Bugzilla (account required)

1. Log in to the Bugzilla website.
2. Select the correct version from the Version menu.
3. Enter a descriptive title in the Summary field.
4. Enter your suggestion for improvement in the Description field. Include links to the relevant parts of the documentation.
5. Click Submit Bug.
CHAPTER 1. CONSISTENT NETWORK INTERFACE DEVICE NAMING

The Linux kernel assigns names to network interfaces by combining a fixed prefix and a number that increases as the kernel initializes the network devices. For instance, `eth0` represents the first device being probed on start-up. If you add another network interface card to the system, the assignment of the kernel device names is no longer fixed. Consequently, after a reboot, the kernel can name the device differently.

To solve this problem, the `udev` device manager supports a number of different naming schemes. By default, `udev` assigns fixed names based on firmware, topology, and location information. This has the following advantages:

- Device names are fully predictable.
- Device names stay fixed even if you add or remove hardware, because no re-enumeration takes place.
- Defective hardware can be seamlessly replaced.

### WARNING
Red Hat does not support systems with consistent device naming disabled. For further details, see Is it safe to set net.ifnames=0?

#### 1.1. NETWORK INTERFACE DEVICE NAMING HIERARCHY

If consistent device naming is enabled, which is the default in Red Hat Enterprise Linux, the `udev` device manager generates device names based on the following schemes:

<table>
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<th>Scheme</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Device names incorporate firmware or BIOS-provided index numbers for onboard devices. If this information is not available or applicable, <code>udev</code> uses scheme 2.</td>
<td>eno1</td>
</tr>
<tr>
<td>2</td>
<td>Device names incorporate firmware or BIOS-provided PCI Express (PCIe) hot plug slot index numbers. If this information is not available or applicable, <code>udev</code> uses scheme 3.</td>
<td>ens1</td>
</tr>
<tr>
<td>3</td>
<td>Device names incorporate the physical location of the connector of the hardware. If this information is not available or applicable, <code>udev</code> uses scheme 5.</td>
<td>enp2s0</td>
</tr>
<tr>
<td>4</td>
<td>Device names incorporate the MAC address. Red Hat Enterprise Linux does not use this scheme by default, but administrators can optionally use it.</td>
<td>enx525400d5e0fb</td>
</tr>
<tr>
<td>Scheme</td>
<td>Description</td>
<td>Example</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>5</td>
<td>The traditional unpredictable kernel naming scheme. If udev cannot apply any of the other schemes, the device manager uses this scheme.</td>
<td>eth0</td>
</tr>
</tbody>
</table>

By default, Red Hat Enterprise Linux selects the device name based on the NamePolicy setting in the `/usr/lib/systemd/network/99-default.link` file. The order of the values in NamePolicy is important. Red Hat Enterprise Linux uses the first device name that is both specified in the file and that udev generated.

If you manually configured udev rules to change the name of kernel devices, those rules take precedence.

### 1.2. HOW THE NETWORK DEVICE RENAMING WORKS

By default, consistent device naming is enabled in Red Hat Enterprise Linux. The udev device manager processes different rules to rename the devices. The following list describes the order in which udev processes these rules and what actions these rules are responsible for:

1. The `/usr/lib/udev/rules.d/60-net.rules` file defines that the `/lib/udev/rename_device` helper utility searches for the HWADDR parameter in `/etc/sysconfig/network-scripts/ifcfg-*` files. If the value set in the variable matches the MAC address of an interface, the helper utility renames the interface to the name set in the DEVICE parameter of the file. This file only exists after installing the `initscripts` package.

2. The `/usr/lib/udev/rules.d/71-biosdevname.rules` file defines that the biosdevname utility renames the interface according to its naming policy, provided that it was not renamed in the previous step.

3. The `/usr/lib/udev/rules.d/75-net-description.rules` file defines that udev examines the network interface device and sets the properties in udev–internal variables that will be processed in the next step. Note that some of these properties might be undefined.

4. The `/usr/lib/udev/rules.d/80-net-setup-link.rules` file calls the net_setup_link udev built-in which then applies the policy. The following is the default policy that is stored in the `/usr/lib/systemd/network/99-default.link` file:

   ```
   [Link]
   NamePolicy=kernel database onboard slot path
   MACAddressPolicy=persistent
   ```

   With this policy, if the kernel uses a persistent name, udev does not rename the interface. If the kernel does not use a persistent name, udev renames the interface to the name provided by the hardware database of udev. If this database is not available, Red Hat Enterprise Linux falls back to the mechanisms described above.

   Alternatively, set the NamePolicy parameter in this file to mac for media access control (MAC) address–based interface names.

5. The `/usr/lib/udev/rules.d/80-net-setup-link.rules` file defines that udev renames the interface based on the udev–internal parameters in the following order:

   a. `ID_NET_NAME_ONBOARD`
b. ID_NET_NAME_SLOT

c. ID_NET_NAME_PATH

If one parameter is not set, udev uses the next one. If none of the parameters are set, the interface is not renamed.

Steps 3 and 4 implement the naming schemes 1 to 4 described in Network interface device naming hierarchy.

Additional resources

- Customizing the prefix of Ethernet interfaces
- For details about the NamePolicy parameter, see the systemd.link(5) man page.

1.3. PREDICTABLE NETWORK INTERFACE DEVICE NAMES ON THE X86_64 PLATFORM EXPLAINED

When the consistent network device name feature is enabled, the udev device manager creates the names of devices based on different criteria. This section describes the naming scheme when Red Hat Enterprise Linux is installed on a x86_64 platform.

The interface name starts with a two-character prefix based on the type of interface:

- en for Ethernet
- wl for wireless LAN (WLAN)
- ww for wireless wide area network (WWAN)

Additionally, one of the following is appended to one of the above-mentioned prefix based on the schema the udev device manager applies:

- o<on-board_index_number>
- s<hot_plug_slot_index_number>[f<function>][d<device_id>]
  Note that all multi-function PCI devices have the [f<function>] number in the device name, including the function 0 device.
- x<MAC_address>
- [P<domain_number>]<bus>s<slot>[f<function>][d<device_id>]
  The [P<domain_number>] part defines the PCI geographical location. This part is only set if the domain number is not 0.
- [P<domain_number>]<bus>s<slot>[f<function>][u<usb_port>][…][c<config>][<interface>]
  For USB devices, the full chain of port numbers of hubs is composed. If the name is longer than the maximum (15 characters), the name is not exported. If there are multiple USB devices in the chain, udev suppresses the default values for USB configuration descriptors (c1) and USB interface descriptors (i0).

1.4. PREDICTABLE NETWORK INTERFACE DEVICE NAMES ON THE SYSTEM Z PLATFORM EXPLAINED
When the consistent network device name feature is enabled, the udev device manager on the System z platform creates the names of devices based on the bus ID. The bus ID identifies a device in the s390 channel subsystem.

For a channel command word (CCW) device, the bus ID is the device number with a leading 0.n prefix where n is the subchannel set ID.

Ethernet interfaces are named, for example, enccw0.0.1234. Serial Line Internet Protocol (SLIP) channel-to-channel (CTC) network devices are named, for example, slccw0.0.1234.

Use the znetconf -c or the Iscss -a commands to display available network devices and their bus IDs.

### 1.5. CUSTOMIZING THE PREFIX OF ETHERNET INTERFACES

You can customize the prefix of Ethernet interface names during the Red Hat Enterprise Linux installation.

**IMPORTANT**

Red Hat does not support customizing the prefix using the prefixdevname utility on already deployed systems.

After the RHEL installation, the udev service names Ethernet devices `<prefix>..<index>`. For example, if you select the prefix net, RHEL names Ethernet interfaces net0, net1, and so on.

**Prerequisites**

- The prefix you want to set meets the following requirements:
  - It consists of ASCII characters.
  - It is an alpha-numeric string.
  - It is shorter than 16 characters.
  - It does not conflict with any other well-known prefix used for network interface naming, such as eth, eno, ens, and em.

**Procedure**

1. Boot the Red Hat Enterprise Linux installation media.

2. In the boot manager:
   a. Select the Install Red Hat Enterprise Linux `<version>` entry, and press Tab to edit the entry.
   b. Append net.ifnames.prefix=`<prefix>` to the kernel options.
   c. Press Enter to start the installer.

3. Install Red Hat Enterprise Linux.

**Verification**
After the installation, display the Ethernet interfaces:

```
# ip link show
...
2: net0: <BROADCAST, MULTICAST, UP, LOWER_UP> mtu 1500 qdisc fq_codel state UP
    mode DEFAULT group default qlen 1000
    link/ether 00:53:00:c5:98:1c brd ff:ff:ff:ff:ff:ff
3: net1: <BROADCAST, MULTICAST, UP, LOWER_UP> mtu 1500 qdisc fq_codel state UP
    mode DEFAULT group default qlen 1000
    link/ether 00:53:00:c2:39:9e brd ff:ff:ff:ff:ff:ff
...
```

1.6. ASSIGNING USER-DEFINED NETWORK INTERFACE NAMES USING UDEV RULES

The `udev` device manager supports a set of rules to customize the interface names.

**Procedure**

1. Display all network interfaces and their MAC addresses:

```
# ip link list
enp6s0f0: <BROADCAST, MULTICAST, UP, LOWER_UP> mtu 1500 qdisc fq_codel state UP
    link/ether b4:96:91:14:ae:58 brd ff:ff:ff:ff:ff:ff
enp6s0f1: <BROADCAST, MULTICAST, UP, LOWER_UP> mtu 1500 qdisc fq_codel state UP
    link/ether b4:96:91:14:ae:5a brd ff:ff:ff:ff:ff:ff
enp4s0f0: <BROADCAST, MULTICAST, UP, LOWER_UP> mtu 1500 qdisc fq_codel state UP
    link/ether 00:90:fa:6a:7d:90 brd ff:ff:ff:ff:ff:ff
```

2. Create the file `/etc/udev/rules.d/70-custom-ifnames.rules` with the following contents:

```
SUBSYSTEM="net", ACTION="add", ATTR{address}="b4:96:91:14:ae:58", ATTR{type}="1", NAME="provider0"
SUBSYSTEM="net", ACTION="add", ATTR{address}="b4:96:91:14:ae:5a", ATTR{type}="1", NAME="provider1"
SUBSYSTEM="net", ACTION="add", ATTR{address}="00:90:fa:6a:7d:90", ATTR{type}="1", NAME="dmz"
```

These rules match the MAC address of the network interfaces and rename them to the name given in the `NAME` property. In these examples, `ATTR{type}` parameter value 1 defines that the interface is of type Ethernet.

**Verification**

1. Reboot the system.

```
# reboot
```
2. Verify that interface names for each MAC address match the value you set in the `NAME` parameter of the rule file:

```
# ip link show

provider0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP mode DEFAULT group default qlen 1000
    link/ether b4:96:91:14:ae:58 brd ff:ff:ff:ff:ff:ff
    altname enp6s0f0
provider1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP mode DEFAULT group default qlen 1000
    link/ether b4:96:91:14:ae:5a brd ff:ff:ff:ff:ff:ff
    altname enp6s0f1
dmz: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP mode DEFAULT group default qlen 1000
    link/ether 00:90:fa:6a:7d:90 brd ff:ff:ff:ff:ff:ff
    altname enp4s0f0
```

Additional resources

- [udev(7)] man page
- [udevadm(8)] man page
- `/usr/src/kernels/<kernel_version>/include/uapi/linux/if_arp.h` provided by the [kernel-doc](https://www.kernel.org/pub/linux/kernel/mainline/kernel-doc) package

1.7. ASSIGNING USER-DEFINED NETWORK INTERFACE NAMES USING SYSTEMD LINK FILES

Create a naming scheme by renaming network interfaces to `provider0`.

Procedure

1. Display all interfaces names and their MAC addresses:

```
# ip link show

enp6s0f0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP mode DEFAULT group default qlen 1000
    link/ether b4:96:91:14:ae:58 brd ff:ff:ff:ff:ff:ff
enp6s0f1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP mode DEFAULT group default qlen 1000
    link/ether b4:96:91:14:ae:5a brd ff:ff:ff:ff:ff:ff
enp4s0f0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP mode DEFAULT group default qlen 1000
    link/ether 00:90:fa:6a:7d:90 brd ff:ff:ff:ff:ff:ff
```

2. For naming the interface with MAC address `b4:96:91:14:ae:58` to `provider0`, create the `/etc/systemd/network/70-custom-ifnames.link` file with following contents:

```
[Match]
MACAddress=b4:96:91:14:ae:58
```
This link file matches a MAC address and renames the network interface to the name set in the Name parameter.

Verification

1. Reboot the system:

   # reboot

2. Verify that the device with the MAC address you specified in the link file has been assigned to provider0:

   # ip link show

   provider0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP mode DEFAULT group default qlen 1000
   link/ether b4:96:91:14:ae:58 brd ff:ff:ff:ff:ff:ff

Additional resources

- systemd.link(5) man page
CHAPTER 2. GETTING STARTED WITH NETWORKMANAGER

By default, RHEL uses NetworkManager to manage the network configuration and connections.

2.1. BENEFITS OF USING NETWORKMANAGER

The main benefits of using NetworkManager are:

- Offering an API through D-Bus which allows to query and control network configuration and state. In this way, networking can be checked and configured by multiple applications ensuring a synced and up-to-date networking status. For example, the RHEL web console, which monitors and configures servers through a web browser, uses the NetworkManager D-BUS interface to configure networking, as well as the Gnome GUI, the nmcli and the nm-connection-editor tools. Each change made in one of these tools is detected by all the others.

- Making Network management easier: NetworkManager ensures that network connectivity works. When it detects that there is no network configuration in a system but there are network devices, NetworkManager creates temporary connections to provide connectivity.

- Providing easy setup of connection to the user: NetworkManager offers management through different tools – GUI, nmtui, nmcli.

- Supporting configuration flexibility. For example, configuring a WiFi interface, NetworkManager scans and shows the available wifi networks. You can select an interface, and NetworkManager displays the required credentials providing automatic connection after the reboot process. NetworkManager can configure network aliases, IP addresses, static routes, DNS information, and VPN connections, as well as many connection-specific parameters. You can modify the configuration options to reflect your needs.

- Maintaining the state of devices after the reboot process and taking over interfaces which are set into managed mode during restart.

- Handling devices which are not explicitly set unmanaged but controlled manually by the user or another network service.

Additional resources

- Managing systems using the RHEL 9 web console.

2.2. AN OVERVIEW OF UTILITIES AND APPLICATIONS YOU CAN USE TO MANAGE NETWORKMANAGER CONNECTIONS

You can use the following utilities and applications to manage NetworkManager connections:

- **nmcli**: A command-line utility to manage connections.

- **nmtui**: A curses-based text user interface (TUI). To use this application, install the NetworkManager-tui package.

- **nm-connection-editor**: A graphical user interface (GUI) for NetworkManager-related tasks. To start this application, enter nm-connection-editor in a terminal of a GNOME session.

- **control-center**: A GUI provided by the GNOME shell for desktop users. Note that this application supports less features than nm-connection-editor.
• The **network connection icon** in the GNOME shell: This icon represents network connection states and serves as visual indicator for the type of connection you are using.

**Additional resources**

• [Getting started with nmcli](#)
CHAPTER 3. CONFIGURING NETWORKMANAGER TO IGNORE CERTAIN DEVICES

By default, NetworkManager manages all devices except the lo (loopback) device. However, you can set certain devices as unmanaged to configure that NetworkManager ignores these devices. With this setting, you can manually manage these devices, for example, using a script.

3.1. PERMANENTLY CONFIGURING A DEVICE AS UNMANAGED IN NETWORKMANAGER

You can configure devices as unmanaged based on several criteria, such as the interface name, MAC address, or device type. This procedure describes how to permanently set the enp1s0 interface as unmanaged in NetworkManager.

To temporarily configure network devices as unmanaged, see Temporarily configuring a device as unmanaged in NetworkManager.

Procedure

1. Optional: Display the list of devices to identify the device you want to set as unmanaged:

```
# nmcli device status
DEVICE   TYPE      STATE         CONNECTION
enp1s0    ethernet  disconnected  -- 
...
```

2. Create the /etc/NetworkManager/conf.d/99-unmanaged-devices.conf file with the following content:

```
[keyfile]
unmanaged-devices=interface-name:enp1s0
```

To set multiple devices as unmanaged, separate the entries in the unmanaged-devices parameter with semicolon:

```
[keyfile]
unmanaged-devices=interface-name:interface_1;interface-name:interface_2;...
```

3. Reload the NetworkManager service:

```
# systemctl reload NetworkManager
```

Verification steps

- Display the list of devices:

```
# nmcli device status
DEVICE   TYPE      STATE         CONNECTION
enp1s0    ethernet  unmanaged    -- 
...
```
The unmanaged state next to the enp1s0 device indicates that NetworkManager does not manage this device.

Additional resources

- The Device List Format section in the NetworkManager.conf(5) man page.

3.2. TEMPORARILY CONFIGURING A DEVICE AS UNMANAGED IN NETWORKMANAGER

You can configure devices as unmanaged based on several criteria, such as the interface name, MAC address, or device type. This procedure describes how to temporarily set the enp1s0 interface as unmanaged in NetworkManager.

Use this method, for example, for testing purposes. To permanently configure network devices as unmanaged, see Permanently configuring a device as unmanaged in NetworkManager.

Procedure

1. Optional: Display the list of devices to identify the device you want to set as unmanaged:

```
# nmcli device status
DEVICE  TYPE      STATE         CONNECTION
enp1s0  ethernet  disconnected  --
...
```

2. Set the enp1s0 device to the unmanaged state:

```
# nmcli device set enp1s0 managed no
```

Verification steps

- Display the list of devices:

```
# nmcli device status
DEVICE  TYPE      STATE         CONNECTION
enp1s0  ethernet  unmanaged      --
...
```

The unmanaged state next to the enp1s0 device indicates that NetworkManager does not manage this device.

Additional resources

- The Device List Format section in the NetworkManager.conf(5) man page
CHAPTER 4. GETTING STARTED WITH NMCLI

This section describes general information about the nmcli utility.

4.1. THE DIFFERENT OUTPUT FORMATS OF NMCLI

The nmcli utility supports different options to modify the output of nmcli commands. Using these options, you can display only the required information. This simplifies processing the output in scripts.

By default, the nmcli utility displays its output in a table-like format:

```
# nmcli device
DEVICE  TYPE      STATE      CONNECTION
enp1s0  ethernet  connected  enp1s0
lo      loopback  unmanaged  --
```

Using the -f option, you can display specific columns in a custom order. For example, to display only the DEVICE and STATE column, enter:

```
# nmcli -f DEVICE,STATE device
DEVICE  STATE
enp1s0  connected
lo      unmanaged
```

The -t option enables you to display the individual fields of the output in a colon-separated format:

```
# nmcli -t device
enp1s0:ethernet:connected:enp1s0
lo:loopback:unmanaged:
```

Combining the -f and -t to display only specific fields in colon-separated format can be helpful when you process the output in scripts:

```
# nmcli -f DEVICE,STATE -t device
enp1s0:connected
lo:unmanaged
```

4.2. USING TAB COMPLETION IN NMCLI

If the bash-completion package is installed on your host, the nmcli utility supports tab completion. This enables you to auto-complete option names and to identify possible options and values.

For example, if you type nmcli con and press Tab, then the shell automatically completes the command to nmcli connection.

For the completion, the options or value you have typed must be unique. If it is not unique, then nmcli displays all possibilities. For example, if you type nmcli connection d and press Tab, then the command shows command delete and down as possible options.

You can also use tab completion to display all properties you can set in a connection profile. For example, if you type nmcli connection modify connection_name and press Tab, the command shows the full list of available properties.
4.3. FREQUENT NMCLI COMMANDS

The following is an overview about frequently-used **nmcli** commands.

- To display the list connection profiles, enter:

  ```bash
  # nmcli connection show
  NAME    UUID                                  TYPE      DEVICE
  enp1s0  45224a39-606f-4bf7-b3dc-d088236c15ee  ethernet  enp1s0
  ```

- To display the settings of a specific connection profile, enter:

  ```bash
  # nmcli connection show connection_name
  connection.id:             enp1s0
  connection.uuid:           45224a39-606f-4bf7-b3dc-d088236c15ee
  connection.stable-id:      --
  connection.type:           802-3-ethernet
  ...
  ```

- To modify properties of a connection, enter:

  ```bash
  # nmcli connection modify connection_name property value
  ```

  You can modify multiple properties using a single command if you pass multiple `property value` combinations to the command.

- To display the list of network devices, their state, and which connection profiles use the device, enter:

  ```bash
  # nmcli device
  DEVICE  TYPE      STATE         CONNECTION
  enp1s0  ethernet  connected     enp1s0
  enp8s0  ethernet  disconnected  --
  enp7s0  ethernet  unmanaged    --
  ...
  ```

- To activate a connection, enter:

  ```bash
  # nmcli connection up connection_name
  ```

- To deactivate a connection, enter:

  ```bash
  # nmcli connection down connection_name
  ```
CHAPTER 5. CONFIGURING AN ETHERNET CONNECTION

This section describes different ways how to configure an Ethernet connection with static and dynamic IP addresses.

5.1. CONFIGURING A STATIC ETHERNET CONNECTION USING NMCLI

This procedure describes adding an Ethernet connection with the following settings using the `nmcli` utility:

- A static IPv4 address - 192.0.2.1 with a /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with a /64 subnet mask
- An IPv4 default gateway - 192.0.2.254
- An IPv6 default gateway - 2001:db8:1::fffe
- An IPv4 DNS server - 192.0.2.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com

Procedure

1. Add a new NetworkManager connection profile for the Ethernet connection:

```bash
# nmcli connection add con-name Example-Connection ifname enp7s0 type ethernet
```

The further steps modify the `Example-Connection` connection profile you created.

2. Set the IPv4 address:

```bash
# nmcli connection modify Example-Connection ipv4.addresses 192.0.2.1/24
```

3. Set the IPv6 address:

```bash
# nmcli connection modify Example-Connection ipv6.addresses 2001:db8:1::1/64
```

4. Set the IPv4 and IPv6 connection method to `manual`:

```bash
# nmcli connection modify Example-Connection ipv4.method manual
# nmcli connection modify Example-Connection ipv6.method manual
```

5. Set the IPv4 and IPv6 default gateways:

```bash
# nmcli connection modify Example-Connection ipv4.gateway 192.0.2.254
# nmcli connection modify Example-Connection ipv6.gateway 2001:db8:1::fffe
```

6. Set the IPv4 and IPv6 DNS server addresses:
# nmcli connection modify Example-Connection ipv4.dns "192.0.2.200"
# nmcli connection modify Example-Connection ipv6.dns "2001:db8:1::ffbb"

To set multiple DNS servers, specify them space-separated and enclosed in quotes.

7. Set the DNS search domain for the IPv4 and IPv6 connection:

   # nmcli connection modify Example-Connection ipv4.dns-search example.com
   # nmcli connection modify Example-Connection ipv6.dns-search example.com

8. Activate the connection profile:

   # nmcli connection up Example-Connection
   Connection successfully activated (D-Bus active path:
   /org/freedesktop/NetworkManager/ActiveConnection/13)

Verification steps

1. Display the status of the devices and connections:

   # nmcli device status
   DEVICE      TYPE      STATE      CONNECTION
   enp7s0      ethernet  connected  Example-Connection

2. To display all settings of the connection profile:

   # nmcli connection show Example-Connection
   connection.id:     Example-Connection
   connection.uuid:    b6cdfa1c-e4ad-46e5-af8b-a75f06b79176
   connection.stable-id: --
   connection.type:    802-3-ethernet
   connection.interface-name: enp7s0
   ...

3. Use the `ping` utility to verify that this host can send packets to other hosts.

   - Ping an IP address in the same subnet.
     For IPv4:

     # ping 192.0.2.3

     For IPv6:

     # ping 2001:db8:1::2

     If the command fails, verify the IP and subnet settings.

   - Ping an IP address in a remote subnet.
     For IPv4:

     # ping 198.162.3.1

     For IPv6:
# ping 2001:db8:2::1

If the command fails, ping the default gateway to verify settings. For IPv4:

# ping 192.0.2.254

For IPv6:

# ping 2001:db8:1::fff3

4. Use the `host` utility to verify that name resolution works. For example:

# host client.example.com

If the command returns any error, such as `connection timed out` or `no servers could be reached`, verify your DNS settings.

Troubleshooting steps

1. If the connection fails or if the network interface switches between an up and down status:

- Make sure that the network cable is plugged-in to the host and a switch.
- Check whether the link failure exists only on this host or also on other hosts connected to the same switch the server is connected to.
- Verify that the network cable and the network interface are working as expected. Perform hardware diagnosis steps and replace defect cables and network interface cards.
- If the configuration on the disk does not match the configuration on the device, starting or restarting NetworkManager creates an in-memory connection that reflects the configuration of the device. For further details and how to avoid this problem, see Configuring NetworkManager to avoid using a specific profile to provide a default gateway

Additional resources

- `nm-settings(5)`, `nmcli` and `nmcli(1)` man pages
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway

5.2. CONFIGURING A STATIC ETHERNET CONNECTION USING THE NMCLI INTERACTIVE EDITOR

This procedure describes adding an Ethernet connection with the following settings using the `nmcli` interactive mode:

- A static IPv4 address - 192.0.2.1 with a /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with a /64 subnet mask
- An IPv4 default gateway - 192.0.2.254
- An IPv6 default gateway - 2001:db8:1::ffe
- An IPv4 DNS server - 192.0.2.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com

Procedure

1. To add a new NetworkManager connection profile for the Ethernet connection, and starting the interactive mode, enter:
   ```
   # nmcli connection edit type ethernet con-name Example-Connection
   ```
2. Set the network interface:
   ```
   nmcli> set connection.interface-name enp7s0
   ```
3. Set the IPv4 address:
   ```
   nmcli> set ipv4.addresses 192.0.2.1/24
   ```
4. Set the IPv6 address:
   ```
   nmcli> set ipv6.addresses 2001:db8:1::1/64
   ```
5. Set the IPv4 and IPv6 connection method to manual:
   ```
   nmcli> set ipv4.method manual
   nmcli> set ipv6.method manual
   ```
6. Set the IPv4 and IPv6 default gateways:
   ```
   nmcli> set ipv4.gateway 192.0.2.254
   nmcli> set ipv6.gateway 2001:db8:1::fffe
   ```
7. Set the IPv4 and IPv6 DNS server addresses:
   ```
   nmcli> set ipv4.dns 192.0.2.200
   nmcli> set ipv6.dns 2001:db8:1::ffbb
   ```
   To set multiple DNS servers, specify them space-separated and enclosed in quotes.
8. Set the DNS search domain for the IPv4 and IPv6 connection:
   ```
   nmcli> set ipv4.dns-search example.com
   nmcli> set ipv6.dns-search example.com
   ```
9. Save and activate the connection:
   ```
   nmcli> save persistent
   ```
   Saving the connection with 'autoconnect=yes'. That might result in an immediate activation of the connection.
   Do you still want to save? (yes/no) [yes] yes
10. Leave the interactive mode:

```
nmcli> quit
```

Verification steps

1. Display the status of the devices and connections:

```
# nmcli device status
DEVICE      TYPE      STATE      CONNECTION
enp7s0      ethernet  connected  Example-Connection
```

2. To display all settings of the connection profile:

```
# nmcli connection show Example-Connection
connection.id:       Example-Connection
connection.uuid:     b6cdfa1c-e4ad-46e5-af8b-a75f06b79f76
connection.stable-id:     --
connection.type:        802-3-ethernet
connection.interface-name: enp7s0
...
```

3. Use the `ping` utility to verify that this host can send packets to other hosts.

- Ping an IP address in the same subnet.
  For IPv4:

  ```
  # ping 192.0.2.3
  ```

  For IPv6:

  ```
  # ping 2001:db8:1::2
  ```

  If the command fails, verify the IP and subnet settings.

- Ping an IP address in a remote subnet.
  For IPv4:

  ```
  # ping 198.162.3.1
  ```

  For IPv6:

  ```
  # ping 2001:db8:2::1
  ```

  If the command fails, ping the default gateway to verify settings.
  For IPv4:

  ```
  # ping 192.0.2.254
  ```

  For IPv6:
4. Use the `host` utility to verify that name resolution works. For example:

   ```
   # host client.example.com
   ```

   If the command returns any error, such as `connection timed out` or `no servers could be reached`, verify your DNS settings.

**Troubleshooting steps**

1. If the connection fails or if the network interface switches between an up and down status:
   - Make sure that the network cable is plugged-in to the host and a switch.
   - Check whether the link failure exists only on this host or also on other hosts connected to the same switch the server is connected to.
   - Verify that the network cable and the network interface are working as expected. Perform hardware diagnosis steps and replace defect cables and network interface cards.

If the configuration on the disk does not match the configuration on the device, starting or restarting NetworkManager creates an in-memory connection that reflects the configuration of the device. For further details and how to avoid this problem, see [NetworkManager duplicates a connection after restart of NetworkManager service](#).

**Additional resources**

- `nm-settings(5)` man page
- `nmcli(1)` man page
- [Configuring NetworkManager to avoid using a specific profile to provide a default gateway](#)

### 5.3. CONFIGURING A STATIC ETHERNET CONNECTION USING NMTUI

The `nmtui` application provides a text-based user interface for NetworkManager. You can use `nmtui` to configure an Ethernet connection with a static IP address on a host without a graphical interface.

**NOTE**

In `nmtui`:

- Navigate by using the cursor keys.
- Press a button by selecting it and hitting `Enter`.
- Select and deselect checkboxes by using `Space`.

**Procedure**

1. If you do not know the network device name you want to use in the connection, display the available devices:
# nmcli device status

DEVICE     TYPE      STATE                   CONNECTION
enp7s0     ethernet  unavailable             --...

2. Start `nmtui`:

   # nmtui

3. Select **Edit a connection**, and press **Enter**.

4. Press the **Add** button.

5. Select **Ethernet** from the list of network types, and press **Enter**.

6. Optional: Enter a name for the NetworkManager profile to be created.

7. Enter the network device name into the **Device** field.

8. Configure the IPv4 and IPv6 address settings in the **IPv4 configuration** and **IPv6 configuration** areas:
   a. Press the **Automatic** button, and select **Manual** from the displayed list.
   b. Press the **Show** button next to the protocol you want to configure to display additional fields.
   c. Press the **Add** button next to **Addresses**, and enter the IP address and the subnet mask in Classless Inter-Domain Routing (CIDR) format.
      If you do not specify a subnet mask, NetworkManager sets a /32 subnet mask for IPv4 addresses and /64 for IPv6 addresses.
   d. Enter the address of the default gateway.
   e. Press the **Add** button next to **DNS servers**, and enter the DNS server address.
   f. Press the **Add** button next to **Search domains**, and enter the DNS search domain.
9. Press the OK button to create and automatically activate the new connection.

10. Press the Back button to return to the main menu.

11. Select Quit, and press Enter to close the nmtui application.

Verification

1. Display the status of the devices and connections:

```
# nmcli device status
DEVICE   TYPE     STATE    CONNECTION
enp7s0    ethernet  connected Example-Connection
```
2. Display all settings of the connection profile:

```bash
# nmcli connection show Example-Connection
connection.id:       Example-Connection
connection.uuid:     b6cd1a1c-e4ad-46e5-af8b-a75f06b79f76
connection.stable-id: --
connection.type:     802-3-ethernet
connection.interface-name: enp7s0
... 
```

5.4. CONFIGURING A STATIC ETHERNET CONNECTION USING NMSTATECTL

This procedure describes how to configure an Ethernet connection for the `enp7s0` device with the following settings using the `nmstatectl` utility:

- A static IPv4 address - 192.0.2.1 with the /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with the /64 subnet mask
- An IPv4 default gateway - 192.0.2.254
- An IPv6 default gateway - 2001:db8:1::ffe
- An IPv4 DNS server - 192.0.2.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com

The `nmstatectl` utility ensures that, after setting the configuration, the result matches the configuration file. If anything fails, `nmstatectl` automatically rolls back the changes to avoid leaving the system in an incorrect state.

The procedure defines the interface configuration in YAML format. Alternatively, you can also specify the configuration in JSON format.

Prerequisites

- The `nmstate` package is installed.

Procedure

1. Create a YAML file, for example `~/create-ethernet-profile.yml`, with the following contents:

```
---
interfaces:
  - name: enp7s0
type: ethernet
state: up
ipv4:
  enabled: true
address:
  - ip: 192.0.2.1
    prefix-length: 24
```
dhcp: false
ipv6:
  enabled: true
  address:
    - ip: 2001:db8:1::1
      prefix-length: 64
      autoconf: false
dhcp: false
routes:
  config:
    - destination: 0.0.0.0/0
      next-hop-address: 192.0.2.254
      next-hop-interface: enp7s0
    - destination: ::/0
      next-hop-address: 2001:db8:1::fffe
      next-hop-interface: enp7s0
dns-resolver:
  config:
    search:
    - example.com
    server:
      - 192.0.2.200
      - 2001:db8:1::ffbb

2. Apply the settings to the system:

   # nmstatectl apply ~/create-ethernet-profile.yml

Verification steps

1. Display the status of the devices and connections:

   # nmcli device status
   DEVICE      TYPE      STATE      CONNECTION
   enp7s0      ethernet  connected  enp7s0

2. Display all settings of the connection profile:

   # nmcli connection show enp7s0
   connection.id: enp7s0
   connection.uuid: b6cdfa1c-e4ad-46e5-af8b-a75f06b79f76
   connection.stable-id: --
   connection.type: 802-3-ethernet
   connection.interface-name: enp7s0
   ...

3. Display the connection settings in YAML format:

   # nmstatectl show enp7s0

Additional resources

- nmstatectl(8) man page
5.5. CONFIGURING A STATIC ETHERNET CONNECTION USING RHEL SYSTEM ROLES WITH THE INTERFACE NAME

This procedure describes how to use the **network** RHEL System Role to remotely add an Ethernet connection for the `enp7s0` interface with the following settings by running an Ansible playbook:

- A static IPv4 address - **192.0.2.1** with a **/24** subnet mask
- A static IPv6 address - **2001:db8:1::1** with a **/64** subnet mask
- An IPv4 default gateway - **192.0.2.254**
- An IPv6 default gateway - **2001:db8:1::ffe**
- An IPv4 DNS server - **192.0.2.200**
- An IPv6 DNS server - **2001:db8:1::ffbb**
- A DNS search domain - **example.com**

Run this procedure on the Ansible control node.

**Prerequisites**

- The **ansible-core** and **rhel-system-roles** packages are installed on the control node.
- If you use a different remote user than **root** when you run the playbook, this user has appropriate **sudo** permissions on the managed node.
- The host uses NetworkManager to configure the network.

**Procedure**

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

   ```
   node.example.com
   ```

2. Create the `-~/ethernet-static-IP.yml` playbook with the following content:

   ```yaml
   ---
   - name: Configure an Ethernet connection with static IP
     hosts: node.example.com
     become: true
     tasks:
       - include_role:
           name: rhel-system-roles.network

     vars:
       network_connections:
         - name: enp7s0
           interface_name: enp7s0
           type: ethernet
   ```
autoconnect: yes
ip:
  address:
    - 192.0.2.1/24
    - 2001:db8:1::1/64
gateway4: 192.0.2.254
gateway6: 2001:db8:1::ffe
dns:
  - 192.0.2.200
  - 2001:db8:1::ffbb
dns_search:
  - example.com
state: up

3. Run the playbook:

- To connect as root user to the managed host, enter:

  # ansible-playbook -u root ~/ethernet-static-IP.yml

- To connect as a user to the managed host, enter:

  # ansible-playbook -u user_name --ask-become-pass ~/ethernet-static-IP.yml

  The --ask-become-pass option makes sure that the ansible-playbook command prompts for the sudo password of the user defined in the -u user_name option.

  If you do not specify the -u user_name option, ansible-playbook connects to the managed host as the user that is currently logged in to the control node.

Additional resources

- /usr/share/ansible/roles/rhel-system-roles.network/README.md
- ansible-playbook(1) man page

5.6. CONFIGURING A STATIC ETHERNET CONNECTION USING RHEL SYSTEM ROLES WITH A DEVICE PATH

This procedure describes how to use RHEL System Roles to remotely add an Ethernet connection with static IP address for devices that match a specific device path by running an Ansible playbook.

You can identify the device path with the following command:

  # udevadm info /sys/class/net/<device_name> | grep ID_PATH=

This procedure sets the following settings to the device that matches the PCI ID 0000:00:0[1-3].0 expression, but not 0000:00:02.0:

- A static IPv4 address - 192.0.2.1 with a /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with a /64 subnet mask
- An IPv4 default gateway - 192.0.2.254
- An IPv6 default gateway - 2001:db8:1::fffe
- An IPv4 DNS server - 192.0.2.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com

Run this procedure on the Ansible control node.

Prerequisites

- The ansible-core and rhel-system-roles packages are installed on the control node.
- If you use a different remote user than root when you run the playbook, this user has appropriate sudo permissions on the managed node.
- The host uses NetworkManager to configure the network.

Procedure

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the /etc/ansible/hosts Ansible inventory file:

   node.example.com

2. Create the ~/ethernet-dynamic-IP.yml playbook with the following content:

```yaml
---
- name: Configure an Ethernet connection with dynamic IP
  hosts: node.example.com
  become: true
  tasks:
  - include_role:
    name: rhel-system-roles.network

  vars:
    network_connections:
    - name: example
      match:
        path:
        - pci-0000:00:0[1-3].0
        - &pci-0000:00:02.0
      type: ethernet
      autoconnect: yes
      ip:
        address:
        - 192.0.2.1/24
        - 2001:db8:1::1/64
      gateway4: 192.0.2.254
      gateway6: 2001:db8:1::fffe
      dns:
      - 192.0.2.200
      - 2001:db8:1::ffbb
```
The `match` parameter in this example defines that Ansible applies the play to devices that match PCI ID `0000:00:0[1-3].0`, but not `0000:00:02.0`. For further details about special modifiers and wild cards you can use, see the `match` parameter description in the

3. Run the playbook:
   - To connect as root user to the managed host, enter:
     ```
     # ansible-playbook -u root ~/ethernet-dynamic-IP.yml
     ```
   - To connect as a user to the managed host, enter:
     ```
     # ansible-playbook -u user_name --ask-become-pass ~/ethernet-dynamic-IP.yml
     ```
     The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

     If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

Additional resources
- `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file
- `ansible-playbook(1)` man page

5.7. CONFIGURING A DYNAMIC ETHERNET CONNECTION USING NMCLI

This procedure describes adding an dynamic Ethernet connection using the `nmcli` utility. With this setting, NetworkManager requests the IP settings for this connection from a DHCP server.

Prerequisites
- A DHCP server is available in the network.

Procedure
1. Add a new NetworkManager connection profile for the Ethernet connection:
   ```
   # nmcli connection add con-name Example-Connection ifname enp7s0 type ethernet
   ```
2. Optionally, change the host name NetworkManager sends to the DHCP server when using the `Example-Connection` profile:
   ```
   # nmcli connection modify Example-Connection ipv4.dhcp-hostname Example ipv6.dhcp-hostname Example
   ```
3. Optionally, change the client ID NetworkManager sends to an IPv4 DHCP server when using the Example-Connection profile:

```
# nmcli connection modify Example-Connection ipv4.dhcp-client-id client-ID
```

Note that there is no dhcp-client-id parameter for IPv6. To create an identifier for IPv6, configure the dhclient service.

Verification steps

1. Display the status of the devices and connections:

```
# nmcli device status
DEVICE  TYPE      STATE      CONNECTION
enp7s0   ethernet   connected  Example-Connection
```

2. To display all settings of the connection profile:

```
# nmcli connection show Example-Connection
connection.id:   Example-Connection
connection.uuid: b6cda1c-e4ad-46e5-af8b-a75f06b79f76
connection.stable-id: --
connection.type:  802-3-ethernet
connection.interface-name: enp7s0
... 
```

3. Use the `ping` utility to verify that this host can send packets to other hosts.

- Ping an IP address in the same subnet.
  For IPv4:
  
  ```
  # ping 192.0.2.3
  ```
  For IPv6:
  
  ```
  # ping 2001:db8:1::2
  ```

  If the command fails, verify the IP and subnet settings.

- Ping an IP address in a remote subnet.
  For IPv4:
  
  ```
  # ping 198.162.3.1
  ```
  For IPv6:
  
  ```
  # ping 2001:db8:2::1
  ```

  - If the command fails, ping the default gateway to verify settings.
    For IPv4:
    
    ```
    # ping 192.0.2.254
    ```
For IPv6:

```
# ping 2001:db8:1::fff3
```

4. Use the **host** utility to verify that name resolution works. For example:

```
# host client.example.com
```

If the command returns any error, such as **connection timed out** or **no servers could be reached**, verify your DNS settings.

**Additional resources**

- `dhclient(8)` man page
- `nm-settings(5)`
- `nmcli(1)` man page
- NetworkManager duplicates a connection after restart of NetworkManager service

### 5.8. CONFIGURING A DYNAMIC ETHERNET CONNECTION USING THE NMCLI INTERACTIVE EDITOR

This procedure describes adding an dynamic Ethernet connection using the interactive editor of the `nmcli` utility. With this setting, NetworkManager requests the IP settings for this connection from a DHCP server.

**Prerequisites**

- A DHCP server is available in the network.

**Procedure**

1. To add a new NetworkManager connection profile for the Ethernet connection, and starting the interactive mode, enter:

   ```
   # nmcli connection edit type ethernet con-name Example-Connection
   ```

2. Set the network interface:

   ```
   nmcli> set connection.interface-name enp7s0
   ```

3. Optionally, change the host name NetworkManager sends to the DHCP server when using the `Example-Connection` profile:

   ```
   nmcli> set ipv4.dhcp-hostname Example
   nmcli> set ipv6.dhcp-hostname Example
   ```

4. Optionally, change the client ID NetworkManager sends to an IPv4 DHCP server when using the `Example-Connection` profile:
nmcli> set ipv4.dhcp-client-id client-ID

Note that there is no dhcp-client-id parameter for IPv6. To create an identifier for IPv6, configure the dhclient service.

5. Save and activate the connection:

    nmcli> save persistent
    Saving the connection with ‘autoconnect=yes’. That might result in an immediate activation of the connection.
    Do you still want to save? (yes/no) [yes] yes

6. Leave the interactive mode:

    nmcli> quit

Verification steps

1. Display the status of the devices and connections:

    # nmcli device status
    DEVICE      TYPE      STATE      CONNECTION
    enp7s0       ethernet  connected  Example-Connection

2. To display all settings of the connection profile:

    # nmcli connection show Example-Connection
    connection.id:         Example-Connection
    connection.uuid:       b6cdfda1c-e4ad-46e5-af8b-a75f06b79176
    connection.stable-id:  --
    connection.type:       802-3-ethernet
    connection.interface-name: enp7s0
    ...

3. Use the ping utility to verify that this host can send packets to other hosts.

   - Ping an IP address in the same subnet.
     For IPv4:

     # ping 192.0.2.3

     For IPv6:

     # ping 2001:db8:1::2

     If the command fails, verify the IP and subnet settings.

   - Ping an IP address in a remote subnet.
     For IPv4:

     # ping 198.162.3.1

     For IPv6:
# ping 2001:db8:2::1

- If the command fails, ping the default gateway to verify settings.
  For IPv4:
  
  # ping 192.0.2.254

  For IPv6:
  
  # ping 2001:db8:1::fff3

4. Use the **host** utility to verify that name resolution works. For example:

   # host client.example.com

   If the command returns any error, such as **connection timed out** or **no servers could be reached**, verify your DNS settings.

Additional resources

- dhclient(8) man page
- nm-settings(5)
- nmcli(1) man page
- NetworkManager duplicates a connection after restart of NetworkManager service

## 5.9. CONFIGURING A DYNAMIC ETHERNET CONNECTION USING NMTUI

The **nmtui** application provides a text-based user interface for NetworkManager. You can use **nmtui** to configure an Ethernet connection with a dynamic IP address on a host without a graphical interface.

**NOTE**

In **nmtui**:

- Navigate by using the cursor keys.
- Press a button by selecting it and hitting **Enter**.
- Select and deselect checkboxes by using **Space**.

### Procedure

1. If you do not know the network device name you want to use in the connection, display the available devices:

   # nmcli device status

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>TYPE</th>
<th>STATE</th>
<th>CONNECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>enp7s0</td>
<td>ethernet</td>
<td>unavailable</td>
<td>--</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Start `nmtui`:

   ```
   # nmtui
   ```

3. Select **Edit a connection**, and press **Enter**.

4. Press the **Add** button.

5. Select **Ethernet** from the list of network types, and press **Enter**.

6. Optional: Enter a name for the NetworkManager profile to be created.

7. Enter the network device name into the **Device** field.

8. Press the **OK** button to create and automatically activate the new connection.

   ![Edit Connection](image)

9. Press the **Back** button to return to the main menu.

10. Select **Quit**, and press **Enter** to close the `nmtui` application.

**Verification**

1. Display the status of the devices and connections:

   ```
   # nmcli device status
   DEVICE  TYPE      STATE     CONNECTION
   enp7s0   ethernet   connected Example-Connection
   ```

2. Display all settings of the connection profile:

   ```
   # nmcli connection show Example-Connection
   connection.id:       Example-Connection
   connection.uuid:     b6cdefa1c-e4ad-46e5-af8b-a75f06b79f76
   connection.stable-id: --
   connection.type:     802-3-ethernet
   connection.interface-name: enp7s0
   ```

5.10. CONFIGURING A DYNAMIC ETHERNET CONNECTION USING NMSTATECTL
This procedure describes how to add a dynamic Ethernet for the `enp7s0` device using the `nmstatectl` utility. With the settings in this procedure, NetworkManager requests the IP settings for this connection from a DHCP server.

The `nmstatectl` utility ensures that, after setting the configuration, the result matches the configuration file. If anything fails, `nmstatectl` automatically rolls back the changes to avoid leaving the system in an incorrect state.

The procedure defines the interface configuration in YAML format. Alternatively, you can also specify the configuration in JSON format.

### Prerequisites

- The `nmstate` package is installed.

### Procedure

1. Create a YAML file, for example `~/create-ethernet-profile.yml`, with the following contents:

   ```yaml
   ---
   interfaces:
   - name: enp7s0
     type: ethernet
     state: up
     ipv4:
       enabled: true
       auto-dns: true
       auto-gateway: true
       auto-routes: true
       dhcp: true
     ipv6:
       enabled: true
       auto-dns: true
       auto-gateway: true
       auto-routes: true
       autoconf: true
       dhcp: true
   ``

2. Apply the settings to the system:

   ```bash
   # nmstatectl apply ~/create-ethernet-profile.yml
   ```

### Verification steps

1. Display the status of the devices and connections:

   ```bash
   # nmcli device status
   DEVICE   TYPE     STATE     CONNECTION
   enp7s0   ethernet  connected enp7s0
   ```

2. Display all settings of the connection profile:

   ```bash
   # nmcli connection show enp7s0
   connection.id: enp7s0
   ```
connection.uuid: b6cdfa1c-e4ad-46e5-a8b-a75f06b79f76
connection.stable-id: --
connection.type: 802-3-ethernet
connection.interface-name: enp7s0
...

3. Display the connection settings in YAML format:

```
# nmstatectl show enp7s0
```

Additional resources

- nmstatectl(8) man page
- /usr/share/doc/nmstate/examples/

5.11. CONFIGURING A DYNAMIC ETHERNET CONNECTION USING RHEL SYSTEM ROLES WITH THE INTERFACE NAME

This procedure describes how to use RHEL System Roles to remotely add a dynamic Ethernet connection for the `enp7s0` interface by running an Ansible playbook. With this setting, the network connection requests the IP settings for this connection from a DHCP server. Run this procedure on the Ansible control node.

Prerequisites

- A DHCP server is available in the network.
- The `ansible-core` and `rhel-system-roles` packages are installed on the control node.
- If you use a different remote user than `root` when you run the playbook, this user has appropriate `sudo` permissions on the managed node.
- The host uses NetworkManager to configure the network.

Procedure

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

   ```
   node.example.com
   ```

2. Create the `~/ethernet-dynamic-IP.yml` playbook with the following content:

   ```yaml
   ---
   - name: Configure an Ethernet connection with dynamic IP
     hosts: node.example.com
     become: true
     tasks:
     - include_role:
       name: rhel-system-roles.network
     vars:
       network_connections:
   ```
3. Run the playbook:

- To connect as **root** user to the managed host, enter:
  
  ```
  # ansible-playbook -u root ~/ethernet-dynamic-IP.yml
  ```

- To connect as a user to the managed host, enter:

  ```
  # ansible-playbook -u user_name --ask-become-pass ~/ethernet-dynamic-IP.yml
  ```

  The **--ask-become-pass** option makes sure that the **ansible-playbook** command prompts for the **sudo** password of the user defined in the **-u user_name** option.

If you do not specify the **-u user_name** option, **ansible-playbook** connects to the managed host as the user that is currently logged in to the control node.

### Additional resources

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file

- `ansible-playbook(1)` man page

### 5.12. CONFIGURING A DYNAMIC ETHERNET CONNECTION USING RHEL SYSTEM ROLES WITH A DEVICE PATH

This procedure describes how to use RHEL System Roles to remotely add a dynamic Ethernet connection for devices that match a specific device path by running an Ansible playbook. With dynamic IP settings, the network connection requests the IP settings for this connection from a DHCP server. Run this procedure on the Ansible control node.

You can identify the device path with the following command:

```
# udevadm info /sys/class/net/<device_name> | grep ID_PATH=
```

### Prerequisites

- A DHCP server is available in the network.

- The **ansible-core** and **rhel-system-roles** packages are installed on the control node.

- If you use a different remote user than **root** when you run the playbook, this user has appropriate **sudo** permissions on the managed node.

- The host uses NetworkManager to configure the network.
Procedure

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

   ```
   node.example.com
   ```

2. Create the `~/ethernet-dynamic-IP.yml` playbook with the following content:

   ```yaml
   ---
   - name: Configure an Ethernet connection with dynamic IP
     hosts: node.example.com
     become: true
     tasks:
     - include_role:
         name: rhel-system-roles.network
     vars:
       network_connections:
       - name: example
         match:
         type: ethernet
         autoconnect: yes
         ip:
         dhcp4: yes
         auto6: yes
         state: up
   ```

   The `match` parameter in this example defines that Ansible applies the play to devices that match PCI ID `0000:00:0[1-3].0`, but not `0000:00:02.0`. For further details about special modifiers and wildcards you can use, see the `match` parameter description in the `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file.

3. Run the playbook:

   - To connect as `root` user to the managed host, enter:
     ```
     # ansible-playbook -u root ~/ethernet-dynamic-IP.yml
     ```
   
   - To connect as a user to the managed host, enter:
     ```
     # ansible-playbook -u user_name --ask-become-pass ~/ethernet-dynamic-IP.yml
     ```

     The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

     If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

Additional resources

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file
CHAPTER 5. CONFIGURING AN ETHERNET CONNECTION

5.13. CONFIGURING AN ETHERNET CONNECTION USING CONTROL-CENTER

Ethernet connections are the most frequently used connection types in physical or virtual machines. This section describes how to configure this connection type in the GNOME control-center:

Note that control-center does not support as many configuration options as the nm-connection-editor application or the nmcli utility.

Prerequisites

- A physical or virtual Ethernet device exists in the server’s configuration.
- GNOME is installed.

Procedure

1. Press the Super key, enter Settings, and press Enter.
2. Select Network in the navigation on the left.
3. Click the + button next to the Wired entry to create a new profile.
4. Optional: Set a name for the connection on the Identity tab.
5. On the IPv4 tab, configure the IPv4 settings. For example, select method Manual, set a static IPv4 address, network mask, default gateway, and DNS server:

<table>
<thead>
<tr>
<th>Identity</th>
<th>IPv4</th>
<th>IPv6</th>
<th>Security</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPv4 Method</td>
<td>Automatic (DHCP)</td>
<td>Manual</td>
<td>Link-Local Only</td>
</tr>
<tr>
<td>Addresses</td>
<td>Address</td>
<td>Netmask</td>
<td>Gateway</td>
</tr>
<tr>
<td>192.0.2.1</td>
<td>24</td>
<td></td>
<td>192.0.2.254</td>
</tr>
<tr>
<td>DNS</td>
<td>Automatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>192.0.2.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Separate IP addresses with commas.
6. On the **IPv6** tab, configure the IPv6 settings. For example, select method **Manual**, set a static IPv6 address, network mask, default gateway, and DNS server:

   ![IPv6 Configuration Panel](image)

   - **IPv6 Method**: Manual
   - **Addresses**:
     - 2001:db8:1::1 /64
     - Default Gateway: 2001:db8:1::ff3
   - **DNS**
     - AUTO.

   - **Separate IP addresses with commas**

7. Click the **Add** button to save the connection. The GNOME **control-center** automatically activates the connection.

**Verification steps**

1. Display the status of the devices and connections:

   ```
   # nmcli device status
   DEVICE      TYPE      STATE      CONNECTION
   enp7s0      ethernet  connected  Example-Connection
   ```

2. To display all settings of the connection profile:

   ```
   # nmcli connection show Example-Connection
   connection.id:       Example-Connection
   connection.uuid:     b6c6fa1c-e4ad-46e5-a08b-a75f06b797f6
   connection.stable-id: --
   connection.type:     802-3-ethernet
   connection.interface-name: enp7s0
   ...  
   ```

3. Use the **ping** utility to verify that this host can send packets to other hosts.

   - Ping an IP address in the same subnet.
   - For IPv4:
     ```
     # ping 192.0.2.3
     ```
For IPv6:

```bash
# ping 2001:db8:1::2
```

If the command fails, verify the IP and subnet settings.

- Ping an IP address in a remote subnet.

For IPv4:

```bash
# ping 198.162.3.1
```

For IPv6:

```bash
# ping 2001:db8:2::1
```

- If the command fails, ping the default gateway to verify settings.

For IPv4:

```bash
# ping 192.0.2.254
```

For IPv6:

```bash
# ping 2001:db8:1::fffe
```

4. Use the `host` utility to verify that name resolution works. For example:

```bash
# host client.example.com
```

If the command returns any error, such as `connection timed out` or `no servers could be reached`, verify your DNS settings.

### Troubleshooting steps

1. If the connection fails or if the network interface switches between an up and down status:
   - Make sure that the network cable is plugged-in to the host and a switch.
   - Check whether the link failure exists only on this host or also on other hosts connected to the same switch the server is connected to.
   - Verify that the network cable and the network interface are working as expected. Perform hardware diagnosis steps and replace defect cables and network interface cards.

### Additional Resources

- If the connection does not have a default gateway, see Configuring NetworkManager to avoid using a specific profile to provide a default gateway.

### 5.14. Configuring an Ethernet Connection Using nm-connection-editor
Ethernet connections are the most frequently used connection types in physical or virtual servers. This section describes how to configure this connection type using the `nm-connection-editor` application.

**Prerequisites**

- A physical or virtual Ethernet device exists in the server’s configuration.
- GNOME is installed.

**Procedure**

1. Open a terminal, and enter:
   
   ```
   $ nm-connection-editor
   ```

2. Click the + button to add a new connection.

3. Select the **Ethernet** connection type, and click **Create**.

4. On the **General** tab:

   a. To automatically enable this connection when the system boots or when you restart the **NetworkManager** service:
      
      i. Select **Connect automatically with priority**.

      ii. Optional: Change the priority value next to **Connect automatically with priority**. If multiple connection profiles exist for the same device, NetworkManager enables only one profile. By default, NetworkManager activates the last-used profile that has auto-connect enabled. However, if you set priority values in the profiles, NetworkManager activates the profile with the highest priority.

   b. Clear the **All users may connect to this network** check box if the profile should be available only to the user that created the connection profile.
5. On the **Ethernet** tab, select a device and, optionally, further Ethernet-related settings.

6. On the **IPv4 Settings** tab, configure the IPv4 settings. For example, set a static IPv4 address, network mask, default gateway, and DNS server:

7. On the **IPv6 Settings** tab, configure the IPv6 settings. For example, set a static IPv6 address, network mask, default gateway, and DNS server:

8. Save the connection.
Verification steps

1. Use the ping utility to verify that this host can send packets to other hosts.
   - Ping an IP address in the same subnet.
     For IPv4:
     ```bash
     # ping 192.0.2.3
     ```
     For IPv6:
     ```bash
     # ping 2001:db8:1::2
     ```
   - If the command fails, verify the IP and subnet settings.
   - Ping an IP address in a remote subnet.
     For IPv4:
     ```bash
     # ping 198.162.3.1
     ```
     For IPv6:
     ```bash
     # ping 2001:db8:2::1
     ```
   - If the command fails, ping the default gateway to verify settings.
     For IPv4:
     ```bash
     # ping 192.0.2.254
     ```
     For IPv6:
     ```bash
     # ping 2001:db8:1::fff3
     ```
   - Use the host utility to verify that name resolution works. For example:
     ```bash
     # host client.example.com
     ```
   - If the command returns any error, such as connection timed out or no servers could be reached, verify your DNS settings.

Additional Resources

- If the connection does not have a default gateway, see Configuring NetworkManager to avoid using a specific profile to provide a default gateway.

5.15. CHANGING THE DHCP CLIENT OF NETWORKMANAGER

By default, NetworkManager uses its internal DHCP client. However, if you require a DHCP client with features that the built-in client does not provide, you can alternatively configure NetworkManager to use dhclient.
Note that RHEL does not provide `dhcpcd` and, therefore, NetworkManager cannot use this client.

**Procedure**

1. Create the `/etc/NetworkManager/conf.d/dhcp-client.conf` file with the following content:

   ```ini
   [main]
   dhcp=dhclient
   ```

   You can set the `dhcp` parameter to `internal` (default) or `dhclient`.

2. If you set the `dhcp` parameter to `dhclient`, install the `dhcpcd` package:

   ```
   # dnf install dhcpcd
   ```

3. Restart NetworkManager:

   ```
   # systemctl restart NetworkManager
   ```

   Note that the restart temporarily interrupts all network connections.

**Verification**

- Search in the `/var/log/messages` log file for an entry similar to the following:

  ```
  Apr 26 09:54:19 server NetworkManager[27748]: <info> [1650959659.8483] dhcp-init: Using DHCP client 'dhclient'
  ```

  This log entry confirms that NetworkManager uses `dhclient` as DHCP client.

**Additional resources**

- NetworkManager.conf(5) man page

### 5.16. CONFIGURING THE DHCP BEHAVIOR OF A NETWORKMANAGER CONNECTION

A Dynamic Host Configuration Protocol (DHCP) client requests the dynamic IP address and corresponding configuration information from a DHCP server each time a client connects to the network.

When you configured a connection to retrieve an IP address from a DHCP server, the NetworkManager requests an IP address from a DHCP server. By default, the client waits 45 seconds for this request to be completed. When a **DHCP** connection is started, a dhcp client requests an IP address from a **DHCP** server.

**Prerequisites**

- A connection that uses DHCP is configured on the host.

**Procedure**
1. Set the `ipv4.dhcp-timeout` and `ipv6.dhcp-timeout` properties. For example, to set both options to 30 seconds, enter:

```
# nmcli connection modify connection_name ipv4.dhcp-timeout 30 ipv6.dhcp-timeout 30
```

Alternatively, set the parameters to `infinity` to configure that NetworkManager does not stop trying to request and renew an IP address until it is successful.

2. Optional: Configure the behavior if NetworkManager does not receive an IPv4 address before the timeout:

```
# nmcli connection modify connection_name ipv4.may-fail value
```

If you set the `ipv4.may-fail` option to:

- **yes**, the status of the connection depends on the IPv6 configuration:
  - If the IPv6 configuration is enabled and successful, NetworkManager activates the IPv6 connection and no longer tries to activate the IPv4 connection.
  - If the IPv6 configuration is disabled or not configured, the connection fails.

- **no**, the connection is deactivated. In this case:
  - If the `autoconnect` property of the connection is enabled, NetworkManager retries to activate the connection as many times as set in the `autoconnect-retries` property. The default is 4.
  - If the connection still cannot acquire a DHCP address, auto-activation fails. Note that after 5 minutes, the auto-connection process starts again to acquire an IP address from the DHCP server.

3. Optional: Configure the behavior if NetworkManager does not receive an IPv6 address before the timeout:

```
# nmcli connection modify connection_name ipv6.may-fail value
```

Additional resources

- `nm-settings(5)` man page

5.17. CONFIGURING MULTIPLE ETHERNET INTERFACES USING A SINGLE CONNECTION PROFILE BY INTERFACE NAME

In most cases, one connection profile contains the settings of one network device. However, NetworkManager also supports wildcards when you set the interface name in connection profiles. If a host roams between Ethernet networks with dynamic IP address assignment, you can use this feature to create a single connection profile that you can use for multiple Ethernet interfaces.

Prerequisites

- DHCP is available in the network
- The host has multiple Ethernet adapters
No connection profile exists on the host

Procedure

1. Add a connection profile that applies to all interface names starting with `enp`:

```bash
#nmcli connection add con-name Example connection.multi-connect multiple match.interface-name enp* type ethernet
```

Verification steps

1. Display all settings of the single connection profile:

```bash
#nmcli connection show Example
```

```plaintext
collection.id:                      Example
... connection.multi-connect: 3 (multiple)
mimatch.interface-name: "enp*
```

3 indicates the number of interfaces active on the connection profile at the same time and not the number of network interfaces in the connection profile. The connection profile uses all devices that match the pattern in the `match.interface-name` parameter and, therefore, the connection profiles have the same Universally Unique Identifier (UUID).

2. Display the status of the connections:

```bash
#nmcli connection show
```

```plaintext
NAME                    UUID                    TYPE     DEVICE
... Example 6f22402e-c0cc-49cf-b702-eaf0cd5ea7d1 ethernet enp7s0
Example 6f22402e-c0cc-49cf-b702-eaf0cd5ea7d1 ethernet enp8s0
Example 6f22402e-c0cc-49cf-b702-eaf0cd5ea7d1 ethernet enp9s0
```

Additional resources

- `nmcli(1)` man page
- `nm-settings(5)` man page

5.18. CONFIGURING A SINGLE CONNECTION PROFILE FOR MULTIPLE ETHERNET INTERFACES USING PCI IDS

The PCI ID is a unique identifier of the devices connected to the system. The connection profile adds multiple devices by matching interfaces based on a list of PCI IDs. You can use this procedure to connect multiple device PCI IDs to the single connection profile.

Prerequisites

- DHCP server is available in the network
The host has multiple Ethernet adapters
No connection profile exists on system

Procedure

1. Identify the device path. For example, to display the device paths of all interfaces starting with `enp`, enter:

```bash
# udevadm info /sys/class/net/enp* | grep ID_PATH=
```

   E: ID_PATH=pci-0000:07:00.0
   E: ID_PATH=pci-0000:08:00.0

2. Add a connection profile that applies to all PCI IDs matching the `0000:00:0[7-8].0` expression:

```bash
# nmcli connection add type ethernet connection.multi-connect multiple match.path "pci-0000:07:00.0 pci-0000:08:00.0" con-name Example
```

Verification steps

1. Display the status of the connection:

```bash
# nmcli connection show
```

```
NAME   UUID     TYPE        DEVICE
...    ...      ...        ...
Example 9cee0958-512f-4203-9d3d-b57af1d88466  ethernet enp7s0
Example 9cee0958-512f-4203-9d3d-b57af1d88466  ethernet enp8s0
...    ...      ...        ...
```

2. To display all settings of the connection profile:

```bash
# nmcli connection show Example
```

```
connection.id: Example
...
connection.multi-connect: 3 (multiple)
mismatch.path: pci-0000:07:00.0,pci-0000:08:00.0
...
```

This connection profile uses all devices with a PCI ID which match the pattern in the `match.path` parameter and, therefore, the connection profiles have the same Universally Unique Identifier (UUID).

Additional resources

- `nmcli(1)` man page
- `nm-settings(5)` man page
CHAPTER 6. MANAGING WIFI CONNECTIONS

RHEL provides multiple utilities and applications to configure and connect to wifi networks, for example:

- The `nmcli` utility
- The GNOME system menu
- The GNOME Settings application
- The `nm-connection-editor` application

6.1. SUPPORTED WIFI SECURITY TYPES

Depending on the security type a wifi network supports, you can transmitted data more or less securely.

**WARNING**

Do not connect to wifi networks that do not use encryption or which support only the insecure WEP or WPA standards.

Red Hat Enterprise Linux 9 supports the following wifi security types:

- **None**: Encryption is disabled, and data is transferred in plain text over the network.
- **Enhanced Open**: With opportunistic wireless encryption (OWE), devices negotiate unique pairwise master keys (PMK) to encrypt connections in wireless networks without authentication.
- **LEAP**: The Lightweight Extensible Authentication Protocol, which was developed by Cisco, is a proprietary version of the extensible authentication protocol (EAP).
- **WPA & WPA2 Personal**: In personal mode, the Wi-Fi Protected Access (WPA) and Wi-Fi Protected Access 2 (WPA2) authentication methods use a pre-shared key.
- **WPA & WPA2 Enterprise**: In enterprise mode, WPA and WPA2 use the EAP framework and authenticate users to a remote authentication dial-in user service (RADIUS) server.
- **WPA3 Personal**: Wi-Fi Protected Access 3 (WPA3) Personal uses simultaneous authentication of equals (SAE) instead of pre-shared keys (PSK) to prevent dictionary attacks. WPA3 uses perfect forward secrecy (PFS).

6.2. CONNECTING TO A WPA2 OR WPA3 PERSONAL-PROTECTED WIFI NETWORK USING NMCLI COMMANDS

You can use the `nmcli` utility to connect to a wifi network. When you attempt to connect to a network for the first time, the utility automatically creates a NetworkManager connection profile for it. If the network requires additional settings, such as static IP addresses, you can then modify the profile after it has been automatically created.
Prerequisites

- A wifi device is installed on the host.
- The wifi device is enabled, if it has a hardware switch.

Procedure

1. If the wifi radio has been disabled in NetworkManager, enable this feature:

   ```
   # nmcli radio wifi on
   ```

2. Optional: Display the available wifi networks:

   ```
   # nmcli device wifi list
   IN-USE  BSSID              SSID          MODE   CHAN  RATE        SIGNAL  BARS  SECURITY
   00:53:00:2F:3B:08  Office        Infra  44    270 Mbit/s  57 _   _   _   WPA2 WPA3
   00:53:00:15:03:BF  --            Infra  1     130 Mbit/s  48 _   _   _   WPA2 WPA3
   ```

   The service set identifier (SSID) column contains the names of the networks. If the column shows --, the access point of this network does not broadcast an SSID.

3. Connect to the wifi network:

   ```
   # nmcli device wifi connect Office --ask
   Password: wifi-password
   ```

   If you prefer to set the password in the command instead of entering it interactively, use the `password wifi-password` option in the command instead of `--ask`:

   ```
   # nmcli device wifi connect Office wifi-password
   ```

   Note that, if the network requires static IP addresses, NetworkManager fails to activate the connection at this point. You can configure the IP addresses in later steps.

4. If the network requires static IP addresses:

   a. Configure the IPv4 address settings, for example:

      ```
      # nmcli connection modify Office ipv4.method manual ipv4.addresses 192.0.2.1/24
      ipv4.gateway 192.0.2.254 ipv4.dns 192.0.2.200 ipv4.dns-search example.com
      ```

   b. Configure the IPv6 address settings, for example:

      ```
      # nmcli connection modify Office ipv6.method manual ipv6.addresses
      2001:db8:1::1/64 ipv6.gateway 2001:db8:1::ffe ipv6.dns 2001:db8:1::ffbb ipv6.dns-search example.com
      ```

5. Re-activate the connection:

   ```
   # nmcli connection up Office
   ```

Verification
1. Display the active connections:

```
# nmcli connection show --active
NAME    ID                                    TYPE  DEVICE
  Office 2501eb7e-7b16-4dc6-97ef-7cc460139a58 wifi wlp0s20f3
```

If the output lists the wifi connection you have created, the connection is active.

2. Ping a hostname or IP address:

```
# ping -c 3 example.com
```

Additional resources

- The 802-11-wireless setting section in the nm-settings-nmcli(5) man page

### 6.3. CONFIGURING A WIFI CONNECTION USING NMTUI

The nmtui application provides a text-based user interface for NetworkManager. You can use nmtui to connect to a wifi network.

**NOTE**

In nmtui:

- Navigate by using the cursor keys.
- Press a button by selecting it and hitting Enter.
- Select and deselect checkboxes by using Space.

**Procedure**

1. If you do not know the network device name you want to use in the connection, display the available devices:

```
# nmcli device status
DEVICE    TYPE      STATE                   CONNECTION
  wlp2s0    wifi      unavailable             --
  ...  
```

2. Start nmtui:

```
# nmtui
```

3. Select Edit a connection, and press Enter.

4. Press the Add button.

5. Select Wi-Fi from the list of network types, and press Enter.

6. Optional: Enter a name for the NetworkManager profile to be created.

7. Enter the network device name into the Device field.
8. Enter the name of the Wi-Fi network, the Service Set Identifier (SSID), into the **SSID** field.

9. Leave the **Mode** field set to its default, **Client**.

10. Select the **Security** field, press **Enter**, and set the authentication type of the network from the list.
    Depending on the authentication type you have selected, **nmtui** displays different fields.

11. Fill the authentication type-related fields.

12. If the Wi-Fi network requires static IP addresses:
    a. Press the **Automatic** button next to the protocol, and select **Manual** from the displayed list.
    b. Press the **Show** button next to the protocol you want to configure to display additional fields, and fill them.

13. Press the **OK** button to create and automatically activate the new connection.

14. Press the **Back** button to return to the main menu.

15. Select **Quit**, and press **Enter** to close the **nmtui** application.

**Verification**

1. Display the active connections:

   ```
   # nmcli connection show --active
   NAME   ID                                    TYPE  DEVICE
   Office 2501eb7e-7b16-4dc6-97ef-7cc460139a58 wifi wlp0s20f3
   ```

   If the output lists the wifi connection you have created, the connection is active.
2. Ping a hostname or IP address:

```
# ping -c 3 example.com
```

### 6.4. CONNECTING TO A WIFI NETWORK USING THE GNOME SYSTEM MENU

You can use the GNOME system menu to connect to a wifi network. When you connect to a network for the first time, GNOME creates a NetworkManager connection profile for it. If you configure the connection profile to not automatically connect, you can also use the GNOME system menu to manually connect to a wifi network with an existing NetworkManager connection profile.

**NOTE**

Using the GNOME system menu to establish a connection to a wifi network for the first time has certain limitations. For example, you can not configure IP address settings. In this case first configure the connections:

- In the **GNOME settings** application
- In the **nm-connection-editor** application
- Using **nmcli** commands

**Prerequisites**

- A wifi device is installed on the host.
- The wifi device is enabled, if it has a hardware switch.

**Procedure**

1. Open the system menu on the right side of the top bar.

2. Expand the **Wi-Fi Not Connected** entry.

3. Click **Select Network**:  

![Select Network](image)

4. Select the wifi network you want to connect to.
5. Click **Connect**.

6. If this is the first time you connect to this network, enter the password for the network, and click **Connect**.

**Verification**

1. Open the system menu on the right side of the top bar, and verify that the wifi network is connected:

   ![Network icon](image)

   If the network appears in the list, it is connected.

2. Ping a hostname or IP address:

   ```
   # ping -c 3 example.com
   ```

### 6.5. CONNECTING TO A WIFI NETWORK USING THE GNOME SETTINGS APPLICATION

You can use the **GNOME settings** application, also named `gnome-control-center`, to connect to a wifi network and configure the connection. When you connect to the network for the first time, GNOME creates a NetworkManager connection profile for it.

In **GNOME settings**, you can configure wifi connections for all wifi network security types that RHEL supports.

**Prerequisites**

- A wifi device is installed on the host.
- The wifi device is enabled, if it has a hardware switch.

**Procedure**

1. Press the **Super** key, type **Wi-Fi**, and press **Enter**.

2. Click on the name of the wifi network you want to connect to.

3. Enter the password for the network, and click **Connect**.

4. If the network requires additional settings, such as static IP addresses or a security type other than WPA2 Personal:
a. Click the gear icon next to the network’s name.

b. Optional: Configure the network profile on the Details tab to not automatically connect. If you deactivate this feature, you must always manually connect to the network, for example, using GNOME settings or the GNOME system menu.


d. On the Security tab, select the authentication of the network, such as WPA3 Personal, and enter the password. Depending on the selected security, the application shows additional fields. Fill them accordingly. For details, ask the administrator of the wifi network.

e. Click Apply.

Verification

1. Open the system menu on the right side of the top bar, and verify that the wifi network is connected:

   ![Network icon]

   If the network appears in the list, it is connected.

2. Ping a hostname or IP address:

   ```
   # ping -c 3 example.com
   ```

6.6. CONFIGURING A WIFI CONNECTION USING NM-CONNECTION-EDITOR

You can use the nm-connection-editor application to create a connection profile for a wireless network. In this application you can configure all wifi network authentication types that RHEL supports.

By default, NetworkManager enables the auto-connect feature for connection profiles and automatically connects to a saved network if it is available.

Prerequisites

- A wifi device is installed on the host.
- The wifi device is enabled, if it has a hardware switch.

Procedure
1. Open a terminal and enter:

   ```
   # nm-connection-editor
   ```

2. Click the + button to add a new connection.

3. Select the Wi-Fi connection type, and click Create.

4. Optional: Set a name for the connection profile.

5. Optional: Configure the network profile on the General tab to not automatically connect. If you deactivate this feature, you must always manually connect to the network, for example, using GNOME settings or the GNOME system menu.

6. On the Wi-Fi tab, enter the service set identifier (SSID) in the SSID field.

7. On the Wi-Fi Security tab, select the authentication type for the network, such as WPA3 Personal, and enter the password. Depending on the selected security, the application shows additional fields. Fill them accordingly. For details, ask the administrator of the wifi network.


9. Click Save.

10. Close the Network Connections window.

**Verification**

1. Open the system menu on the right side of the top bar, and verify that the wifi network is connected:

   ![Wi-Fi icon with the label Office]

   If the network appears in the list, it is connected.

2. Ping a hostname or IP address:

   ```
   # ping -c 3 example.com
   ```

**6.7. CONFIGURING A WIFI CONNECTION WITH 802.1X NETWORK AUTHENTICATION USING THE RHEL SYSTEM ROLES**

Using RHEL System Roles, you can automate the creation of a wifi connection. This procedure describes how to remotely add a wireless connection profile for the wlp1s0 interface using an Ansible playbook.
The created profile uses the 802.1X standard to authenticate the client to a wifi network. The playbook configures the connection profile to use DHCP. To configure static IP settings, adapt the parameters in the `ip` dictionary accordingly.

**Prerequisites**

- You installed the ansible and rhel-system-roles packages on the control node.
- The network supports 802.1X network authentication.
- If you use a different remote user than `root` when you run the playbook, you must have appropriate `sudo` permissions on the managed node.
- You installed the `wpa_supplicant` package on the managed node.
- DHCP is available in the network of the managed node.
- The following files required for TLS authentication exist on the control node:
  - The client key is stored in the `/srv/data/client.key` file.
  - The client certificate is stored in the `/srv/data/client.crt` file.
  - The CA certificate is stored in the `/srv/data/ca.crt` file.

Perform the following procedure on the **Ansible control node**.

**Procedure**

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

   ```
   node.example.com
   ```

2. Create the `~enable-802.1x.yml` playbook with the following content:

   ```yaml
   ---
   - name: Configure a wifi connection with 802.1X authentication
     hosts: "node.example.com"
     become: true
     tasks:
       - name: Copy client key for 802.1X authentication
         copy:
           src: "/srv/data/client.key"
           dest: "/etc/pki/tls/private/client.key"
           mode: 0400

       - name: Copy client certificate for 802.1X authentication
         copy:
           src: "/srv/data/client.crt"
           dest: "/etc/pki/tls/certs/client.crt"

       - name: Copy CA certificate for 802.1X authentication
         copy:
           src: "/srv/data/ca.crt"
           dest: "/etc/pki/ca-trust/source/anchors/ca.crt"
   ```
- block:
  - import_role:
    name: linux-system-roles.network
  vars:
    network_connections:
      - name: Configure the Example-wifi profile
        interface_name: wlp1s0
        state: up
        type: wireless
        autoconnect: yes
        ip:
          dhcp4: true
          auto6: true
        wireless:
          ssid: "Example-wifi"
          key_mgmt: "wpa-eap"
          ieee802_1x:
            identity: "user_name"
            eap: tls
            private_key: "/etc/pki/tls/client.key"
            private_key_password: "password"
            private_key_password_flags: none
            client_cert: "/etc/pki/tls/client.pem"
            ca_cert: "/etc/pki/tls/cacert.pem"
            domain_suffix_match: "example.com"

3. Run the playbook:

   - To connect as a root user to the managed host, enter:

     ```
     # ansible-playbook -u root ~/enable-802.1x.yml
     ```

   - To connect as a user to the managed host, enter:

     ```
     # ansible-playbook -u user_name --ask-become-pass ~/ethernet-static-IP.yml
     ```

     The --ask-become-pass option makes sure that the ansible-playbook command prompts for the sudo password of the user defined in the -u user_name option.

     If you do not specify the -u user_name option, ansible-playbook connects to the managed host as the user that is currently logged in to the control node.

Additional resources

   - /usr/share/ansible/roles/rhel-system-roles.network/README.md file

   - ansible-playbook(1) man page

6.8. CONFIGURING 802.1X NETWORK AUTHENTICATION ON AN EXISTING WIFI CONNECTION USING NMCLI

Using the nmcli utility, you can configure the client to authenticate itself to the network. This procedure describes how to configure Protected Extensible Authentication Protocol (PEAP) authentication with
the Microsoft Challenge-Handshake Authentication Protocol version 2 (MSCHAPv2) in an existing NetworkManager wifi connection profile named **wlp1s0**.

**Prerequisites**

1. The network must have 802.1X network authentication.
2. The wifi connection profile exists in NetworkManager and has a valid IP configuration.
3. If the client is required to verify the certificate of the authenticator, the Certificate Authority (CA) certificate must be stored in the `/etc/pki/ca-trust/source/anchors/` directory.
4. The **wpa_supplicant** package is installed.

**Procedure**

1. Set the wifi security mode to **wpa-eap**, the Extensible Authentication Protocol (EAP) to **peap**, the inner authentication protocol to **mschapv2**, and the user name:

   ```
   # nmcli connection modify wlp1s0 wireless-security.key-mgmt wpa-eap 802-1x.eap peap 802-1x.phase2-auth mschapv2 802-1x.identity user_name
   ```

   Note that you must set the `wireless-security.key-mgmt`, `802-1x.eap`, `802-1x.phase2-auth`, and `802-1x.identity` parameters in a single command.

2. Optionally, store the password in the configuration:

   ```
   # nmcli connection modify wlp1s0 802-1x.password password
   ```

   **IMPORTANT**

   By default, NetworkManager stores the password in clear text in the `/etc/sysconfig/network-scripts/keys-connection_name` file, that is readable only by the root user. However, clear text passwords in a configuration file can be a security risk.

   To increase the security, set the `802-1x.password-flags` parameter to `0x1`. With this setting, on servers with the GNOME desktop environment or the **nm-applet** running, NetworkManager retrieves the password from these services. In other cases, NetworkManager prompts for the password.

3. If the client is required to verify the certificate of the authenticator, set the `802-1x.ca-cert` parameter in the connection profile to the path of the CA certificate:

   ```
   # nmcli connection modify wlp1s0 802-1x.ca-cert /etc/pki/ca-trust/source/anchors/ca.crt
   ```

   **NOTE**

   For security reasons, Red Hat recommends using the certificate of the authenticator to enable clients to validate the identity of the authenticator.

4. Activate the connection profile:
# nmcli connection up wlp1s0

Verification steps
- Access resources on the network that require network authentication.

Additional resources
- Managing wifi connections
- The 802-1x settings section in the nm-settings(5) man page
- nmcli(1) man page

6.9. MANUALLY SETTING THE WIRELESS REGULATORY DOMAIN

On RHEL, a udev rule executes the setregdomain utility to set the wireless regulatory domain. The utility then provides this information to the kernel.

By default, setregdomain attempts to determine the country code automatically. If this fails, the wireless regulatory domain setting might be wrong. To work around this problem, you can manually set the country code.

**IMPORTANT**

Manually setting the regulatory domain disables the automatic detection. Therefore, if you later use the computer in a different country, the previously configured setting might no longer be correct. In this case, remove the /etc/sysconfig/regdomain file to switch back to automatic detection or use this procedure to manually update the regulatory domain setting again.

Procedure

1. Optional: Display the current regulatory domain settings:

   ```
   # iw reg get
   global
   country US: DFS-FCC
   ...
   ```

2. Create the /etc/sysconfig/regdomain file with the following content:

   ```
   COUNTRY=<country_code>
   ```

   Set the COUNTRY variable to an ISO 3166-1 alpha2 country code, such as DE for Germany or US for the United States of America.

3. Set the regulatory domain:

   ```
   # setregdomain
   ```

Verification
• Display the regulatory domain settings:

```
# iw reg get
global
country DE: DFS-ETSI
...
```

Additional resources

• `setregdomain(1)` man page

• `iw(8)` man page

• `regulatory.bin(5)` man page

• `ISO 3166 Country Codes`
CHAPTER 7. CONFIGURING VLAN TAGGING

This section describes how to configure Virtual Local Area Network (VLAN). A VLAN is a logical network within a physical network. The VLAN interface tags packets with the VLAN ID as they pass through the interface, and removes tags of returning packets.

You create a VLAN interface on top of another interface, such as an Ethernet, bond, team, or bridge device. This interface is called the **parent interface**.

### 7.1. CONFIGURING VLAN TAGGING USING NMCLI COMMANDS

This section describes how to configure Virtual Local Area Network (VLAN) tagging using the **nmcli** utility.

**Prerequisites**

- The interface you plan to use as a parent to the virtual VLAN interface supports VLAN tags.
- If you configure the VLAN on top of a bond interface:
  - The ports of the bond are up.
  - The bond is not configured with the `fail_over_mac=follow` option. A VLAN virtual device cannot change its MAC address to match the parent’s new MAC address. In such a case, the traffic would still be sent with the incorrect source MAC address.
  - The bond is usually not expected to get IP addresses from a DHCP server or IPv6 auto-configuration. Ensure it by setting the `ipv4.method=disable` and `ipv6.method=ignore` options while creating the bond. Otherwise, if DHCP or IPv6 auto-configuration fails after some time, the interface might be brought down.
  - The switch, the host is connected to, is configured to support VLAN tags. For details, see the documentation of your switch.

**Procedure**

1. Display the network interfaces:

   ```
   # nmcli device status
   DEVICE   TYPE      STATE         CONNECTION
   enp1s0   ethernet  disconnected  enp1s0
   bridge0  bridge    connected     bridge0
   bond0    bond      connected     bond0
   ...
   ```

2. Create the VLAN interface. For example, to create a VLAN interface named `vlan10` that uses `enp1s0` as its parent interface and that tags packets with VLAN ID 10, enter:

   ```
   # nmcli connection add type vlan con-name vlan10 ifname enp1s0 vlan.parent enp1s0 vlan.id 10
   ```

   Note that the VLAN must be within the range from 0 to 4094.

3. By default, the VLAN connection inherits the maximum transmission unit (MTU) from the parent interface. Optionally, set a different MTU value:
4. Configure the IP settings of the VLAN device. Skip this step if you want to use this VLAN device as a port of other devices.

   a. Configure the IPv4 settings. For example, to set a static IPv4 address, network mask, default gateway, and DNS server to the `vlan10` connection, enter:

   ```
   # nmcli connection modify vlan10 ipv4.addresses '192.0.2.1/24'
   # nmcli connection modify vlan10 ipv4.gateway '192.0.2.254'
   # nmcli connection modify vlan10 ipv4.dns '192.0.2.253'
   # nmcli connection modify vlan10 ipv4.method manual
   ```

   b. Configure the IPv6 settings. For example, to set a static IPv6 address, network mask, default gateway, and DNS server to the `vlan10` connection, enter:

   ```
   # nmcli connection modify vlan10 ipv6.addresses '2001:db8:1::1/32'
   # nmcli connection modify vlan10 ipv6.gateway '2001:db8:1::ffe'
   # nmcli connection modify vlan10 ipv6.dns '2001:db8:1::fffd'
   # nmcli connection modify vlan10 ipv6.method manual
   ```

5. Activate the connection:

   ```
   # nmcli connection up vlan10
   ```

Verification steps

- Verify the settings:

   ```
   # ip -d addr show vlan10
   4: vlan10@enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qlen 1000
       link/ether 52:54:00:72:2f:6e brd ff:ff:ff:ff:ff:ff promiscuity 0
       vlan protocol 802.1Q id 10 <REORDER_HDR> numtxqueues 1 numrxqueues 1
       gso_max_size 65536 gso_max_segs 65535
       inet 192.0.2.1/24 brd 192.0.2.255 scope global noprefixroute vlan10
          valid_lft forever preferred_lft forever
       inet6 2001:db8:1::1/32 scope global noprefixroute
          valid_lft forever preferred_lft forever
       inet6 fe80::8dd7:9030:6f8e:89e6/64 scope link noprefixroute
          valid_lft forever preferred_lft forever
   ```

Additional resources

- Testing basic network settings.
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway.
- The `vlan setting` section in the `nm-settings(5)` man page

7.2. CONFIGURING VLAN TAGGING USING THE RHEL WEB CONSOLE

This section explains how to configure a network bridge using the RHEL web console.
Prerequisites

- The interface you plan to use as a parent to the virtual VLAN interface supports VLAN tags.
- If you configure the VLAN on top of a bond interface:
  - The ports of the bond are up.
  - The bond is not configured with the `fail_over_mac=follow` option. A VLAN virtual device cannot change its MAC address to match the parent’s new MAC address. In such a case, the traffic would still be sent with the incorrect source MAC address.
  - The bond is usually not expected to get IP addresses from a DHCP server or IPv6 auto-configuration. Ensure it by disabling the IPv4 and IPv6 protocol creating the bond. Otherwise, if DHCP or IPv6 auto-configuration fails after some time, the interface might be brought down.
- The switch, the host is connected to, is configured to support VLAN tags. For details, see the documentation of your switch.

Procedure

1. Select the **Networking** tab in the navigation on the left side of the screen.
2. Click **Add VLAN** in the **Interfaces** section.
3. Select the parent device.
4. Enter the VLAN ID.
5. Enter the name of the VLAN device or keep the automatically-generated name.
6. Click **Apply**.
7. By default, the VLAN device uses a dynamic IP address. If you want to set a static IP address:
   a. Click the name of the VLAN device in the **Interfaces** section.
   b. Click **Edit** next to the protocol you want to configure.
   c. Select **Manual** next to **Addresses**, and enter the IP address, prefix, and default gateway.
   d. In the **DNS** section, click the + button, and enter the IP address of the DNS server. Repeat this step to set multiple DNS servers.
   e. In the **DNS search domains** section, click the + button, and enter the search domain.
f. If the interface requires static routes, configure them in the **Routes** section.

![IPv4 settings](image)

- **Server**
  - 192.0.2.253

- **Search domain**
  - example.com

- **Routes**
  - Automatic

- **Apply**
  - Cancel

7. Click **Apply**

**Verification**

- Select the **Networking** tab in the navigation on the left side of the screen, and check if there is incoming and outgoing traffic on the interface:

<table>
<thead>
<tr>
<th>Interfaces</th>
<th>Add bond</th>
<th>Add team</th>
<th>Add bridge</th>
<th>Add VLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name</strong></td>
<td><strong>IP address</strong></td>
<td><strong>Sending</strong></td>
<td><strong>Receiving</strong></td>
<td></td>
</tr>
<tr>
<td>enp1s0.10</td>
<td>192.0.2/124</td>
<td>111 Mbps</td>
<td>61.2 Mbps</td>
<td></td>
</tr>
</tbody>
</table>

### 7.3. CONFIGURING VLAN TAGGING USING NMTUI

The **nmtui** application provides a text-based user interface for NetworkManager. You can use **nmtui** to configure VLAN tagging on a host without a graphical interface.
NOTE

In nmtui:

- Navigate by using the cursor keys.
- Press a button by selecting it and hitting Enter.
- Select and deselect checkboxes by using Space.

Prerequisites

- The interface you plan to use as a parent to the virtual VLAN interface supports VLAN tags.
- If you configure the VLAN on top of a bond interface:
  - The ports of the bond are up.
  - The bond is not configured with the fail_over_mac=follow option. A VLAN virtual device cannot change its MAC address to match the parent’s new MAC address. In such a case, the traffic would still be sent with the then incorrect source MAC address.
  - The bond is usually not expected to get IP addresses from a DHCP server or IPv6 auto-configuration. Ensure it by setting the ipv4.method=disable and ipv6.method=ignore options while creating the bond. Otherwise, if DHCP or IPv6 auto-configuration fails after some time, the interface might be brought down.
- The switch the host is connected to is configured to support VLAN tags. For details, see the documentation of your switch.

Procedure

1. If you do not know the network device name on which you want configure VLAN tagging, display the available devices:

   ```
   # nmcli device status
   DEVICE     TYPE      STATE                   CONNECTION
   enp1s0     ethernet  unavailable             --
   ...
   ```

2. Start nmtui:

   ```
   # nmtui
   ```

3. Select Edit a connection, and press Enter.

4. Press the Add button.

5. Select VLAN from the list of network types, and press Enter.

6. Optional: Enter a name for the NetworkManager profile to be created.

7. Enter the VLAN device name to be created into the Device field.

8. Enter the name of the device on which you want to configure VLAN tagging into the Parent field.
9. Enter the VLAN ID. The ID must be within the range from 0 to 4094.

10. Depending on your environment, configure the IP address settings in the IPv4 configuration and IPv6 configuration areas accordingly. For this, press the Automatic button, and select:

- **Disabled**, if this VLAN device does not require an IP address or you want to use it as a port of other devices.
- **Automatic**, if a DHCP server dynamically assigns an IP address to the VLAN device.
- **Manual**, if the network requires static IP address settings. In this case, you must fill further fields:
  
i. Press the Show button next to the protocol you want to configure to display additional fields.

  ii. Press the Add button next to Addresses, and enter the IP address and the subnet mask in Classless Inter-Domain Routing (CIDR) format. If you do not specify a subnet mask, NetworkManager sets a /32 subnet mask for IPv4 addresses and /64 for IPv6 addresses.

  iii. Enter the address of the default gateway.

  iv. Press the Add button next to DNS servers, and enter the DNS server address.

  v. Press the Add button next to Search domains, and enter the DNS search domain.
Figure 7.1. Example of a VLAN connection with static IP address settings

<table>
<thead>
<tr>
<th>Edit Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Profile name</strong>:</td>
</tr>
<tr>
<td><strong>Device</strong>:</td>
</tr>
<tr>
<td><strong>VLAN</strong></td>
</tr>
<tr>
<td><strong>Parent</strong>:</td>
</tr>
<tr>
<td><strong>VLAN id</strong>:</td>
</tr>
<tr>
<td><strong>Cloned MAC address</strong></td>
</tr>
<tr>
<td><strong>IPv4 CONFIGURATION</strong></td>
</tr>
<tr>
<td><strong>Addresses</strong>:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Gateway</strong>:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>DNS servers</strong>:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Search domains</strong></td>
</tr>
<tr>
<td><strong>Routing (No custom routes)</strong></td>
</tr>
<tr>
<td>[ ] Never use this network for default route</td>
</tr>
<tr>
<td>[ ] Ignore automatically obtained routes</td>
</tr>
<tr>
<td>[ ] Ignore automatically obtained DNS parameters</td>
</tr>
<tr>
<td>[ ] Require IPv4 addressing for this connection</td>
</tr>
<tr>
<td><strong>IPv6 CONFIGURATION</strong></td>
</tr>
<tr>
<td><strong>Addresses</strong>:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Gateway</strong>:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>DNS servers</strong>:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Search domains</strong></td>
</tr>
<tr>
<td><strong>Routing (No custom routes)</strong></td>
</tr>
<tr>
<td>[ ] Never use this network for default route</td>
</tr>
<tr>
<td>[ ] Ignore automatically obtained routes</td>
</tr>
<tr>
<td>[ ] Ignore automatically obtained DNS parameters</td>
</tr>
<tr>
<td>[ ] Require IPv4 addressing for this connection</td>
</tr>
</tbody>
</table>

11. Press the **OK** button to create and automatically activate the new connection.

12. Press the **Back** button to return to the main menu.

13. Select **Quit**, and press **Enter** to close the **nmtui** application.

**Verification**

- Verify the settings:
CHAPTER 7. CONFIGURING VLAN TAGGING

# ip -d addr show vlan10
4: vlan10@enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
    state UP group default qlen 1000
    link/ether 52:54:00:72:2f:6e brd ff:ff:ff:ff:ff:ff promiscuity 0
    vlan protocol 802.1Q id 10 <REORDER_HDR> numtxqueues 1 numrxqueues 1
    gso_max_size 65536 gso_max_segs 65535
    inet 192.0.2.1/24 brd 192.0.2.255 scope global noprefixroute vlan10
        valid_lft forever preferred_lft forever
    inet6 2001:db8:1::1/32 scope global noprefixroute
        valid_lft forever preferred_lft forever
    inet6 fe80::8dd7:9030:6f8e:89e6/64 scope link noprefixroute
        valid_lft forever preferred_lft forever

7.4. CONFIGURING VLAN TAGGING USING NM-CONNECTION-EDITOR

This section describes how to configure Virtual Local Area Network (VLAN) tagging using the nm-connection-editor application.

Prerequisites

- The interface you plan to use as a parent to the virtual VLAN interface supports VLAN tags.
- If you configure the VLAN on top of a bond interface:
  - The ports of the bond are up.
  - The bond is not configured with the fail_over_mac=follow option. A VLAN virtual device cannot change its MAC address to match the parent’s new MAC address. In such a case, the traffic would still be sent with the incorrect source MAC address.
- The switch, the host is connected to, is configured to support VLAN tags. For details, see the documentation of your switch.

Procedure

1. Open a terminal, and enter nm-connection-editor:

   $ nm-connection-editor

2. Click the + button to add a new connection.

3. Select the VLAN connection type, and click Create.

4. On the VLAN tab:
   a. Select the parent interface.
   b. Select the VLAN id. Note that the VLAN must be within the range from 0 to 4094.
   c. By default, the VLAN connection inherits the maximum transmission unit (MTU) from the parent interface. Optionally, set a different MTU value.
   d. Optionally, set the name of the VLAN interface and further VLAN-specific options.
5. Configure the IP settings of the VLAN device. Skip this step if you want to use this VLAN device as a port of other devices.

a. On the IPv4 Settings tab, configure the IPv4 settings. For example, set a static IPv4 address, network mask, default gateway, and DNS server:

<table>
<thead>
<tr>
<th>Address</th>
<th>Netmask</th>
<th>Gateway</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.0.2.1</td>
<td>24</td>
<td>192.0.2.254</td>
</tr>
</tbody>
</table>

b. On the IPv6 Settings tab, configure the IPv6 settings. For example, set a static IPv6 address and network mask:

<table>
<thead>
<tr>
<th>Address</th>
<th>Netmask</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.0.2.253</td>
<td></td>
</tr>
</tbody>
</table>
b. On the IPv6 Settings tab, configure the IPv6 settings. For example, set a static IPv6 address, network mask, default gateway, and DNS server.

![Editing VLAN connection 1](image)

6. Click Save to save the VLAN connection.


**Verification steps**

1. Verify the settings:

```bash
# ip -d addr show vlan10
4: vlan10@enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
state UP group default qlen 1000
   link/ether 52:54:00:d5:e0:fb brd ff:ff:ff:ff:ff:ff promiscuity 0
   vlan protocol 802.1Q id 10 <REORDER_HDR> numtxqueues 1 numrxqueues 1
   gso_max_size 65536 gso_max_segs 65535
   inet 192.0.2.1/24 brd 192.0.2.255 scope global noprefixroute vlan10
      valid_lft forever preferred_lft forever
   inet6 2001:db8:1::1/32 scope global noprefixroute
      valid_lft forever preferred_lft forever
   inet6 fe80::8dd7:9030:6f8e:89e6/64 scope link noprefixroute
      valid_lft forever preferred_lft forever
```

**Additional resources**

- Testing basic network settings.
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway.

### 7.5. CONFIGURING VLAN TAGGING USING NMSTATECTL

This section describes how to use the nmstatectl utility to configure a VLAN with ID 10 that uses an Ethernet connection. As the child device, the VLAN connection contains the IP, default gateway, and DNS configurations.
Depending on your environment, adjust the YAML file accordingly. For example, to use a bridge, or bond device in the VLAN, adapt the **base-iface** attribute and **type** attributes of the ports you use in the VLAN.

**Prerequisites**

- To use Ethernet devices as ports in the VLAN, the physical or virtual Ethernet devices must be installed on the server.

- The **nmstate** package is installed.

**Procedure**

1. Create a YAML file, for example `~/create-vlan.yml`, with the following contents:

```yaml
---
interfaces:
- name: vlan10
type: vlan
state: up
ipv4:
  enabled: true
  address:
    - ip: 192.0.2.1
      prefix-length: 24
      dhcp: false
ipv6:
  enabled: true
  address:
    - ip: 2001:db8:1::1
      prefix-length: 64
      autoconf: false
dhcp: false
vlan:
  base-iface: enp1s0
  id: 10
- name: enp1s0
type: ethernet
state: up
routes:
  config:
    - destination: 0.0.0.0/0
      next-hop-address: 192.0.2.254
      next-hop-interface: vlan10
    - destination: ::/0
      next-hop-address: 2001:db8:1::fffe
      next-hop-interface: vlan10
dns-resolver:
  config:
    search:
      - example.com
    server:
      - 192.0.2.200
      - 2001:db8:1::ffbb
```
2. Apply the settings to the system:

```
# nmstatectl apply ~/create-vlan.yml
```

**Verification steps**

1. Display the status of the devices and connections:

```
# nmcli device status
DEVICE      TYPE      STATE      CONNECTION
vlan10      vlan      connected vlan10
```

2. Display all settings of the connection profile:

```
# nmcli connection show vlan10
connection.id:      vlan10
connection.uuid:    1722970f-788e-4f81-bd7d-a86bf21c9df5
connection.stable-id: --
connection.type:     vlan
connection.interface-name: vlan10
```

3. Display the connection settings in YAML format:

```
# nmstatectl show vlan0
```

**Additional resources**

- `nmstatectl(8)` man page
- `/usr/share/doc/nmstate/examples/`

### 7.6. CONFIGURING VLAN TAGGING USING RHEL SYSTEM ROLE

You can use the `network` RHEL System Role to configure VLAN tagging. This procedure describes how to add an Ethernet connection and a VLAN with ID 10 on top of this Ethernet connection. As the child device, the VLAN connection contains the IP, default gateway, and DNS configurations.

Depending on your environment, adjust the play accordingly. For example:

- To use the VLAN as a port in other connections, such as a bond, omit the `ip` attribute, and set the IP configuration in the child configuration.

- To use team, bridge, or bond devices in the VLAN, adapt the `interface_name` and `type` attributes of the ports you use in the VLAN.

**Prerequisites**

- The `ansible-core` and `rhel-system-roles` packages are installed on the control node.

- If you use a different remote user than `root` when you run the playbook, this user has appropriate `sudo` permissions on the managed node.
Procedure

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

```
node.example.com
```

2. Create the `~/vlan-ethernet.yml` playbook with the following content:

```yaml
---
- name: Configure a VLAN that uses an Ethernet connection
  hosts: node.example.com
  become: true
  tasks:
    - include_role:
      name: rhel-system-roles.network
  vars:
    network_connections:
      # Add an Ethernet profile for the underlying device of the VLAN
      - name: enp1s0
        type: ethernet
        interface_name: enp1s0
        autoconnect: yes
        state: up
        ip:
          dhcp4: no
          auto6: no
      # Define the VLAN profile
      - name: enp1s0.10
        type: vlan
        ip:
          address:
            - "192.0.2.1/24"
            - "2001:db8:1::1/64"
        gateway4: 192.0.2.254
        gateway6: 2001:db8:1::fffe
        dns:
          - 192.0.2.200
          - 2001:db8:1::ffbb
        dns_search:
          - example.com
        vlan_id: 10
        parent: enp1s0
        state: up
```

The `parent` attribute in the VLAN profile configures the VLAN to operate on top of the `enp1s0` device.

3. Run the playbook:
   - To connect as `root` user to the managed host, enter:

```
# ansible-playbook -u root ~/vlan-ethernet.yml
```
To connect as a user to the managed host, enter:

```
# ansible-playbook -u user_name --ask-become-pass ~/vlan-ethernet.yml
```

The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

Additional resources

- /usr/share/ansible/roles/rhel-system-roles.network/README.md file
- `ansible-playbook(1)` man page
CHAPTER 8. USING A VXLAN TO CREATE A VIRTUAL LAYER-2 DOMAIN FOR VMS

A virtual extensible LAN (VXLAN) is a networking protocol that tunnels layer-2 traffic over an IP network using the UDP protocol. For example, certain virtual machines (VMs), that are running on different hosts can communicate over a VXLAN tunnel. The hosts can be in different subnets or even in different data centers around the world. From the perspective of the VMs, other VMs in the same VXLAN are within the same layer-2 domain.

This documentation describes how to configure a VXLAN on RHEL hosts, which is invisible to the VMs:

In this example, RHEL-host-A and RHEL-host-B use a bridge, `br0`, to connect the virtual network of a VM on each host with a VXLAN named `vxlan10`. Due to this configuration, the VXLAN is invisible to the VMs, and the VMs do not require any special configuration. If you later connect more VMs to the same virtual network, the VMs are automatically members of the same virtual layer-2 domain.

**IMPORTANT**

Just as normal layer-2 traffic, data in a VXLAN is not encrypted. For security reasons, use a VXLAN over a VPN or other types of encrypted connections.

### 8.1. BENEFITS OF VXLANS

A virtual extensible LAN (VXLAN) provides the following major benefits:

- VXLANs use a 24-bit ID. Therefore, you can create up to 16,777,216 isolated networks. For example, a virtual LAN (VLAN), supports only 4,096 isolated networks.

- VXLANs use the IP protocol. This enables you to route the traffic and virtually run systems in different networks and locations within the same layer-2 domain.
Unlike most tunnel protocols, a VXLAN is not only a point-to-point network. A VXLAN can learn the IP addresses of the other endpoints either dynamically or use statically-configured forwarding entries.

- Certain network cards support UDP tunnel-related offload features.

Additional resources

- `/usr/share/doc/kernel-doc-<kernel_version>/Documentation/networking/vxlan.rst` provided by the `kernel-doc` package

### 8.2. CONFIGURING THE ETHERNET INTERFACE ON THE HOSTS

To connect a RHEL VM host to the Ethernet, create a network connection profile, configure the IP settings, and activate the profile.

Run this procedure on both RHEL hosts, and adjust the IP address configuration accordingly.

**Prerequisites**

- The host is connected to the Ethernet hosts.

**Procedure**

1. Add a new Ethernet connection profile to NetworkManager:

   ```bash
   # nmcli connection add con-name Example ifname enp1s0 type ethernet
   ```

2. Configure the IPv4 settings:

   ```bash
   # nmcli connection modify Example ipv4.addresses 198.51.100.2/24 ipv4.method manual ipv4.gateway 198.51.100.254 ipv4.dns 198.51.100.200 ipv4.dns-search example.com
   ```
   
   Skip this step if the network uses DHCP.

3. Activate the `Example` connection:

   ```bash
   # nmcli connection up Example
   ```

**Verification**

1. Display the status of the devices and connections:

   ```bash
   # nmcli device status
   DEVICE   TYPE      STATE      CONNECTION
   enp1s0    ethernet  connected  Example
   ```

2. Ping a host in a remote network to verify the IP settings:

   ```bash
   # ping RHEL-host-B.example.com
   ```
Note that you cannot ping the other VM host before you have configured the network on that host as well.

Additional resources

- nm-settings(5)

8.3. CREATING A NETWORK BRIDGE WITH A VXLAN ATTACHED

To make a virtual extensible LAN (VXLAN) invisible to virtual machines (VMs), create a bridge on a host, and attach the VXLAN to the bridge. Use NetworkManager to create both the bridge and the VXLAN. You do not add any traffic access point (TAP) devices of the VMs, typically named `vnet*` on the host, to the bridge. The `libvirtd` service adds them dynamically when the VMs start.

Run this procedure on both RHEL hosts, and adjust the IP addresses accordingly.

Procedure

1. Create the bridge **br0**:

   ```
   # nmcli connection add type bridge con-name br0 ifname br0 ipv4.method disabled ipv6.method disabled
   
   This command sets no IPv4 and IPv6 addresses on the bridge device, because this bridge works on layer 2.
   ```

2. Create the VXLAN interface and attach it to **br0**:

   ```
   # nmcli connection add type vxlan slave-type bridge con-name br0-vxlan10 ifname vxlan10 id 10 local 198.51.100.2 remote 203.0.113.1 master br0
   
   This command uses the following settings:
   ```

   - **id 10**: Sets the VXLAN identifier.
   - **local 198.51.100.2**: Sets the source IP address of outgoing packets.
   - **remote 203.0.113.1**: Sets the unicast or multicast IP address to use in outgoing packets when the destination link layer address is not known in the VXLAN device forwarding database.
   - **master br0**: Sets this VXLAN connection to be created as a port in the **br0** connection.

   By default, NetworkManager uses **8472** as the destination port. If the destination port is different, additionally, pass the `destination-port <port_number>` option to the command.

3. Activate the **br0** connection profile:

   ```
   # nmcli connection up br0
   ```

4. Open port **8472** for incoming UDP connections in the local firewall:
# firewall-cmd --permanent --add-port=8472/udp
# firewall-cmd --reload

**Verification**

- Display the forwarding table:

  ```
  # bridge fdb show dev vxlan10
  2a:53:bd:d5:b3:0a master br0 permanent
  00:00:00:00:00:00 dst 203.0.113.1 self permanent
  ...
  ```

**Additional resources**

- [nm-settings(5)](nixos.org/manpage/pageweb/libnm-settings.html)

### 8.4. CREATING A VIRTUAL NETWORK IN LIBVIRT WITH AN EXISTING BRIDGE

To enable virtual machines (VM) to use the `br0` bridge with the attached virtual extensible LAN (VXLAN), first add a virtual network to the **libvirtd** service that uses this bridge.

**Prerequisites**

- You installed the [libvirt](https://libvirt.org/) package.
- You started and enabled the **libvirtd** service.
- You configured the `br0` device with the VXLAN on RHEL.

**Procedure**

1. Create the `~/vxlan10-bridge.xml` file with the following content:

   ```xml
   <network>
   <name>vxlan10-bridge</name>
   <forward mode="bridge" />
   <bridge name="br0" />
   </network>
   ```

2. Use the `~/vxlan10-bridge.xml` file to create a new virtual network in **libvirtd**:

   ```
   # virsh net-define ~/vxlan10-bridge.xml
   ```

3. Remove the `~/vxlan10-bridge.xml` file:

   ```
   # rm ~/vxlan10-bridge.xml
   ```

4. Start the `vxlan10-bridge` virtual network:

   ```
   # virsh net-start vxlan10-bridge
   ```
5. Configure the `vxlan10-bridge` virtual network to start automatically when the `libvirtd` service starts:

```
# virsh net-autostart vxlan10-bridge
```

**Verification**

- Display the list of virtual networks:

```
# virsh net-list
Name          State  Autostart Persistent
---------------------------------------
vxlan10-bridge active yes        yes ...
```

**Additional resources**

- `virsh(1)` man page

**8.5. CONFIGURING VIRTUAL MACHINES TO USE VXLAN**

To configure a VM to use a bridge device with an attached virtual extensible LAN (VXLAN) on the host, create a new VM that uses the `vxlan10-bridge` virtual network or update the settings of existing VMs to use this network.

Perform this procedure on the RHEL hosts.

**Prerequisites**

- You configured the `vxlan10-bridge` virtual network in `libvirtd`.

**Procedure**

- To create a new VM and configure it to use the `vxlan10-bridge` network, pass the `--network` option to the `virt-install` command when you create the VM:

```
# virt-install ... --network network:vxlan10-bridge
```

- To change the network settings of an existing VM:
  a. Connect the VM’s network interface to the `vxlan10-bridge` virtual network:

```
# virt-xml VM_name --edit --network network=vxlan10-bridge
```

  b. Shut down the VM, and start it again:

```
# virsh shutdown VM_name
# virsh start VM_name
```

**Verification**

1. Display the virtual network interfaces of the VM on the host:

```
-
<table>
<thead>
<tr>
<th>Interface</th>
<th>Type</th>
<th>Source</th>
<th>Model</th>
<th>MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>vnet1</td>
<td>bridge</td>
<td>vxlan10-bridge</td>
<td>virtio</td>
<td>52:54:00:c5:98:1c</td>
</tr>
</tbody>
</table>

2. Display the interfaces attached to the **vxlan10-bridge** bridge:

```
# ip link show master vxlan10-bridge
18: vxlan10: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue master
   br0 state UNKNOWN mode DEFAULT group default qlen 1000
   link/ether 2a:53:bd:d5:b3:0a brd ff:ff:ff:ff:ff:ff
19: vnet1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue master
   br0 state UNKNOWN mode DEFAULT group default qlen 1000
   link/ether 52:54:00:c5:98:1c brd ff:ff:ff:ff:ff
```

Note that the **libvirtd** service dynamically updates the bridge’s configuration. When you start a VM which uses the **vxlan10-bridge** network, the corresponding **vnet** device on the host appears as a port of the bridge.

3. Use address resolution protocol (ARP) requests to verify whether VMs are in the same VXLAN:
   a. Start two or more VMs in the same VXLAN.
   b. Send an ARP request from one VM to the other one:

```
# arping -c 1 192.0.2.2
ARPING 192.0.2.2 from 192.0.2.1 enp1s0
Unicast reply from 192.0.2.2 [52:54:00:c5:98:1c] 1.450ms
Sent 1 probe(s) (0 broadcast(s))
Received 1 response(s) (0 request(s), 0 broadcast(s))
```

If the command shows a reply, the VM is in the same layer-2 domain and, in this case in the same VXLAN.

Install the **iputils** package to use the **arping** utility.

**Additional resources**

- **virt-install(1)** man page
- **virt-xml(1)** man page
- **virsh(1)** man page
- **arping(8)** man page
CHAPTER 9. CONFIGURING A NETWORK BRIDGE

A network bridge is a link-layer device which forwards traffic between networks based on a table of MAC addresses. The bridge builds the MAC addresses table by listening to network traffic and thereby learning what hosts are connected to each network. For example, you can use a software bridge on a Red Hat Enterprise Linux host to emulate a hardware bridge or in virtualization environments, to integrate virtual machines (VM) to the same network as the host.

A bridge requires a network device in each network the bridge should connect. When you configure a bridge, the bridge is called **controller** and the devices it uses **ports**.

You can create bridges on different types of devices, such as:

- Physical and virtual Ethernet devices
- Network bonds
- Network teams
- VLAN devices

Due to the IEEE 802.11 standard which specifies the use of 3-address frames in Wi-Fi for the efficient use of airtime, you cannot configure a bridge over Wi-Fi networks operating in Ad-Hoc or Infrastructure modes.

9.1. CONFIGURING A NETWORK BRIDGE USING NMCLI COMMANDS

This section explains how to configure a network bridge using the **nmcli** utility.

**Prerequisites**

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the bridge, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bond, or VLAN devices as ports of the bridge, you can either create these devices while you create the bridge or you can create them in advance as described in:
  - Configuring a network team using nmcli commands
  - Configuring a network bond using nmcli commands
  - Configuring VLAN tagging using nmcli commands

**Procedure**

1. Create a bridge interface:

   ```
   # nmcli connection add type bridge con-name bridge0 ifname bridge0
   ```

   This command creates a bridge named **bridge0**, enter:

2. Display the network interfaces, and note the names of the interfaces you want to add to the bridge:
# nmcli device status

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>TYPE</th>
<th>STATE</th>
<th>CONNECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>enp7s0</td>
<td>ethernet</td>
<td>disconnected</td>
<td>--</td>
</tr>
<tr>
<td>enp8s0</td>
<td>ethernet</td>
<td>disconnected</td>
<td>--</td>
</tr>
<tr>
<td>bond0</td>
<td>bond</td>
<td>connected</td>
<td>bond0</td>
</tr>
<tr>
<td>bond1</td>
<td>bond</td>
<td>connected</td>
<td>bond1</td>
</tr>
</tbody>
</table>

In this example:

- **enp7s0** and **enp8s0** are not configured. To use these devices as ports, add connection profiles in the next step.
- **bond0** and **bond1** have existing connection profiles. To use these devices as ports, modify their profiles in the next step.

3. Assign the interfaces to the bridge.

a. If the interfaces you want to assign to the bridge are not configured, create new connection profiles for them:

```
# nmcli connection add type ethernet slave-type bridge con-name bridge0-port1
  ifname enp7s0 master bridge0
# nmcli connection add type ethernet slave-type bridge con-name bridge0-port2
  ifname enp8s0 master bridge0
```

These commands create profiles for **enp7s0** and **enp8s0**, and add them to the **bridge0** connection.

b. If you want to assign an existing connection profile to the bridge, set the **master** parameter of these connections to **bridge0**:

```
# nmcli connection modify bond0 master bridge0
# nmcli connection modify bond1 master bridge0
```

These commands assign the existing connection profiles named **bond0** and **bond1** to the **bridge0** connection.

4. Configure the IP settings of the bridge. Skip this step if you want to use this bridge as a ports of other devices.

a. Configure the IPv4 settings. For example, to set a static IPv4 address, network mask, default gateway, DNS server, and DNS search domain of the **bridge0** connection, enter:

```
# nmcli connection modify bridge0 ipv4.addresses '192.0.2.1/24'
# nmcli connection modify bridge0 ipv4.gateway '192.0.2.254'
# nmcli connection modify bridge0 ipv4.dns '192.0.2.253'
# nmcli connection modify bridge0 ipv4.dns-search 'example.com'
# nmcli connection modify bridge0 ipv4.method manual
```

b. Configure the IPv6 settings. For example, to set a static IPv6 address, network mask, default gateway, DNS server, and DNS search domain of the **bridge0** connection, enter:

```
# nmcli connection modify bridge0 ipv6.addresses '2001:db8:1::1/64'
# nmcli connection modify bridge0 ipv6.gateway '2001:db8:1::fffe'
# nmcli connection modify bridge0 ipv6.dns '2001:db8:1::fffd'
```
# nmcli connection modify bridge0 ipv6.dns-search 'example.com'
# nmcli connection modify bridge0 ipv6.method manual

5. Optional: Configure further properties of the bridge. For example, to set the Spanning Tree Protocol (STP) priority of bridge0 to 16384, enter:

```bash
# nmcli connection modify bridge0 bridge.priority '16384'
```

By default, STP is enabled.

6. Activate the connection:

```bash
# nmcli connection up bridge0
```

7. Verify that the ports are connected, and the CONNECTION column displays the port’s connection name:

```bash
# nmcli device
DEVICE TYPE STATE CONNECTION
...
enp7s0 ethernet connected bridge0-port1
enp8s0 ethernet connected bridge0-port2
```

When you activate any port of the connection, NetworkManager also activates the bridge, but not the other ports of it. You can configure that Red Hat Enterprise Linux enables all ports automatically when the bridge is enabled:

a. Enable the `connection.autoconnect-slaves` parameter of the bridge connection:

```bash
# nmcli connection modify bridge0 connection.autoconnect-slaves 1
```

b. Reactivate the bridge:

```bash
# nmcli connection up bridge0
```

Verification steps

- Use the `ip` utility to display the link status of Ethernet devices that are ports of a specific bridge:

```bash
# ip link show master bridge0
3: enp7s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel master bridge0 state UP mode DEFAULT group default qlen 1000
    link/ether 52:54:00:62:61:0e brd ff:ff:ff:ff:ff:ff
4: enp8s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel master bridge0 state UP mode DEFAULT group default qlen 1000
    link/ether 52:54:00:9e:f1:ce brd ff:ff:ff:ff:ff:ff
```

- Use the `bridge` utility to display the status of Ethernet devices that are ports of any bridge device:

```bash
# bridge link show
3: enp7s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge0 state forwarding priority 32 cost 100
```
4: enp8s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge0 state listening priority 32 cost 100
5: enp9s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge1 state forwarding priority 32 cost 100
6: enp11s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge1 state blocking priority 32 cost 100
...

To display the status for a specific Ethernet device, use the `bridge link show dev ethernet_device_name` command.

Additional resources

- Testing basic network settings
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway
- The `bridge settings` section in the `nm-settings(5)` man page
- The `bridge-port settings` section in the `nm-settings(5)` man page
- `bridge(8)` man page
- NetworkManager duplicates a connection after restart of NetworkManager service
- How to configure bridge with vlan information?

9.2. CONFIGURING A NETWORK BRIDGE USING THE RHEL WEB CONSOLE

This section explains how to configure a network bridge using the RHEL web console.

Prerequisites

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the bridge, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bond, or VLAN devices as ports of the bridge, you can either create these devices while you create the bridge or you can create them in advance as described in:
  - Configuring a network team using the RHEL web console
  - Configuring a network bond using the RHEL web console
  - Configuring VLAN tagging using the RHEL web console

Procedure

1. Select the **Networking** tab in the navigation on the left side of the screen.
2. Click **Add bridge** in the **Interfaces** section.
3. Enter the name of the bridge device you want to create.
4. Select the interfaces that should be ports of the bridge.

5. Optional: Enable the **Spanning tree protocol (STP)** feature to avoid bridge loops and broadcast radiation.

6. Click **Apply**.

7. By default, the bridge uses a dynamic IP address. If you want to set a static IP address:
   a. Click the name of the bridge in the **Interfaces** section.
   b. Click **Edit** next to the protocol you want to configure.
   c. Select **Manual** next to **Addresses**, and enter the IP address, prefix, and default gateway.
   d. In the **DNS** section, click the + button, and enter the IP address of the DNS server. Repeat this step to set multiple DNS servers.
   e. In the **DNS search domains** section, click the + button, and enter the search domain.
   f. If the interface requires static routes, configure them in the **Routes** section.
9.3. CONFIGURING A NETWORK BRIDGE USING NMTUI

The nmtui application provides a text-based user interface for NetworkManager. You can use nmtui to configure a network bridge on a host without a graphical interface.
**NOTE**

In `nmtui`:

- Navigate by using the cursor keys.
- Press a button by selecting it and hitting `Enter`.
- Select and deselect checkboxes by using `Space`.

**Prerequisites**

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the bridge, the physical or virtual Ethernet devices must be installed on the server.

**Procedure**

1. If you do not know the network device names on which you want configure a network bridge, display the available devices:

   ```
   # nmcli device status
   DEVICE      TYPE      STATE                   CONNECTION
   enp7s0      ethernet  unavailable             --
   enp8s0      ethernet  unavailable             --
   ...
   ```

2. Start `nmtui`:

   ```
   # nmtui
   ```


4. Press the **Add** button.

5. Select **Bridge** from the list of network types, and press **Enter**.

6. Optional: Enter a name for the NetworkManager profile to be created.

7. Enter the bridge device name to be created into the **Device** field.

8. Add ports to the bridge to be created:

   a. Press the **Add** button next to the **Slaves** list.

   b. Select the type of the interface you want to add as port to the bridge, for example, **Ethernet**.

   c. Optional: Enter a name for the NetworkManager profile to be created for this bridge port.

   d. Enter the port’s device name into the **Device** field.

   e. Press the **OK** button to return to the window with the bridge settings.
f. Repeat these steps to add more ports to the bridge.

9. Depending on your environment, configure the IP address settings in the IPv4 configuration and IPv6 configuration areas accordingly. For this, press the Automatic button, and select:

- **Disabled**, if the bridge does not require an IP address.
- **Automatic**, if a DHCP server dynamically assigns an IP address to the bridge.
- **Manual**, if the network requires static IP address settings. In this case, you must fill further fields:
  
i. Press the Show button next to the protocol you want to configure to display additional fields.

  ii. Press the Add button next to Addresses, and enter the IP address and the subnet mask in Classless Inter-Domain Routing (CIDR) format.

    If you do not specify a subnet mask, NetworkManager sets a /32 subnet mask for IPv4 addresses and /64 for IPv6 addresses.

  iii. Enter the address of the default gateway.

  iv. Press the Add button next to DNS servers, and enter the DNS server address.

  v. Press the Add button next to Search domains, and enter the DNS search domain.
10. Press the **OK** button to create and automatically activate the new connection.

11. Press the **Back** button to return to the main menu.

12. Select **Quit**, and press **Enter** to close the **nmtd** application.

**Verification**

1. Use the **ip** utility to display the link status of Ethernet devices that are ports of a specific bridge:

```
# ip link show master bridge0
3: enp7s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel master
bridge0 state UP mode DEFAULT group default qlen 1000
    link/ether 52:54:00:62:61:0e brd ff:ff:ff:ff:ff:ff
4: enp8s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel master
bridge0 state UP mode DEFAULT group default qlen 1000
    link/ether 52:54:00:9e:f1:ce brd ff:ff:ff:ff:ff:ff
```

2. Use the **bridge** utility to display the status of Ethernet devices that are ports of any bridge device:

```
# bridge link show
3: enp7s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge0 state forwarding priority 32 cost 100
```
To display the status for a specific Ethernet device, use the `bridge link show dev ethernet_device_name` command.

### 9.4. Configuring a Network Bridge Using `nm-connection-editor`

This section explains how to configure a network bridge using the `nm-connection-editor` application.

Note that `nm-connection-editor` can add only new ports to a bridge. To use an existing connection profile as a port, create the bridge using the `nmcli` utility as described in Configuring a network bridge using `nmcli` commands.

**Prerequisites**

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the bridge, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bond, or VLAN devices as ports of the bridge, ensure that these devices are not already configured.

**Procedure**

1. Open a terminal, and enter `nm-connection-editor`:

```bash
$ nm-connection-editor
```

2. Click the + button to add a new connection.

3. Select the Bridge connection type, and click Create.

4. In the Bridge tab:
   a. Optional: Set the name of the bridge interface in the Interface name field.
   b. Click the Add button to create a new connection profile for a network interface and adding the profile as a port to the bridge.
      i. Select the connection type of the interface. For example, select Ethernet for a wired connection.
      ii. Optionally, set a connection name for the port device.
      iii. If you create a connection profile for an Ethernet device, open the Ethernet tab, and select in the Device field the network interface you want to add as a port to the bridge. If you selected a different device type, configure it accordingly.
      iv. Click Save.
   c. Repeat the previous step for each interface you want to add to the bridge.
5. Optional: Configure further bridge settings, such as Spanning Tree Protocol (STP) options.

6. Configure the IP settings of the bridge. Skip this step if you want to use this bridge as a port of other devices.

   a. In the **IPv4 Settings** tab, configure the IPv4 settings. For example, set a static IPv4 address, network mask, default gateway, DNS server, and DNS search domain:

   ![IPv4 Settings](image)

   b. In the **IPv6 Settings** tab, configure the IPv6 settings. For example, set a static IPv6 address, network mask, default gateway, DNS server, and DNS search domain:
7. Save the bridge connection.


**Verification steps**

- Use the `ip` utility to display the link status of Ethernet devices that are ports of a specific bridge.

  ```
  # ip link show master bridge0
  3: enp7s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qlc qdisc fq_codel master bridge0 state UP mode DEFAULT group default qlen 1000
      link/ether 52:54:00:62:61:0e brd ff:ff:ff:ff:ff:ff
  4: enp8s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel master bridge0 state UP mode DEFAULT group default qlen 1000
      link/ether 52:54:00:9e:f1:ce brd ff:ff:ff:ff:ff:ff
  ```

- Use the `bridge` utility to display the status of Ethernet devices that are ports in any bridge device:

  ```
  # bridge link show
  3: enp7s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge0 state forwarding priority 32 cost 100
  4: enp8s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge0 state listening priority 32 cost 100
  5: enp9s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge1 state forwarding priority 32 cost 100
  6: enp11s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 master bridge1 state blocking priority 32 cost 100
  ```
To display the status for a specific Ethernet device, use the `bridge link show dev ethernet_device_name` command.

Additional resources

- Configuring a network bond using `nm-connection-editor`
- Configuring a network team using `nm-connection-editor`
- Configuring VLAN tagging using `nm-connection-editor`
- Testing basic network settings
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway
- How to configure bridge with vlan information?

9.5. CONFIGURING A NETWORK BRIDGE USING NMSTATECTL

This section describes how to use the `nmstatectl` utility to configure a Linux network bridge `bridge0` with following settings:

- Network interfaces in the bridge: `enp1s0` and `enp7s0`
- Spanning Tree Protocol (STP): Enabled
- Static IPv4 address: `192.0.2.1` with the `/24` subnet mask
- Static IPv6 address: `2001:db8:1::1` with the `/64` subnet mask
- IPv4 default gateway: `192.0.2.254`
- IPv6 default gateway: `2001:db8:1::ffe`
- IPv4 DNS server: `192.0.2.200`
- IPv6 DNS server: `2001:db8:1::ffbb`
- DNS search domain: `example.com`

Prerequisites

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports in the bridge, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bond, or VLAN devices as ports in the bridge, set the interface name in the `port` list, and define the corresponding interfaces.
- The `nmstate` package is installed.

Procedure

1. Create a YAML file, for example `~/create-bridge.yml`, with the following contents:
---

interfaces:
- name: bridge0
type: linux-bridge
state: up
ipv4:
  enabled: true
  address:
    - ip: 192.0.2.1
      prefix-length: 24
dhcp: false
ipv6:
  enabled: true
  address:
    - ip: 2001:db8:1::1
      prefix-length: 64
      autoconf: false
dhcp: false
bridge:
  options:
    stp:
      enabled: true
  port:
    - name: enp1s0
    - name: enp7s0
- name: enp1s0
type: ethernet
state: up
- name: enp7s0
type: ethernet
state: up
routes:
  config:
    - destination: 0.0.0.0/0
      next-hop-address: 192.0.2.254
      next-hop-interface: bridge0
    - destination: ::/0
      next-hop-address: 2001:db8:1::fffe
      next-hop-interface: bridge0
dns-resolver:
  config:
    search:
    - example.com
    server:
      - 192.0.2.200
      - 2001:db8:1::ffbb

2. Apply the settings to the system:

```
# nmstatectl apply ~/create-bridge.yml
```

**Verification steps**

1. Display the status of the devices and connections:
# nmcli device status

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>TYPE</th>
<th>STATE</th>
<th>CONNECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>bridge0</td>
<td>bridge</td>
<td>connected</td>
<td>bridge0</td>
</tr>
</tbody>
</table>

2. Display all settings of the connection profile:

```bash
# nmcli connection show bridge0
connection.id:        bridge0
connection.uuid:  e2cc9206-75a2-4622-89cf-1252926060a9
connection.stable-id: --
connection.type:      bridge
connection.interface-name: bridge0
...```

3. Display the connection settings in YAML format:

```bash
# nmstatectl show bridge0
```

Additional resources

- `nmstatectl(8)` man page
- `/usr/share/doc/nmstate/examples/
- How to configure bridge with vlan information?
CHAPTER 10. CONFIGURING NETWORK TEAMING

This section describes the basics of network teaming, the differences between bonding and teaming, and how to configure a network team on Red Hat Enterprise Linux.

IMPORTANT

Network teaming is deprecated in Red Hat Enterprise Linux 9. Consider using the network bonding driver as an alternative. For details, see Configuring network bonding.

You can create network teams on different types of devices, such as:

- Physical and virtual Ethernet devices
- Network bonds
- Network bridges
- VLAN devices

10.1. MIGRATING A NETWORK TEAM CONFIGURATION TO NETWORK BOND

Network teaming is deprecated in Red Hat Enterprise Linux 9. If you already have a working network team configured, for example because you upgraded from an earlier RHEL version, you can migrate the configuration to a network bond that is managed by NetworkManager.

IMPORTANT

The team2bond utility only converts the network team configuration to a bond. Afterwards, you must manually configure further settings of the bond, such as IP addresses and DNS configuration.

Prerequisites

- The team-team0 NetworkManager connection profile is configured and manages the team0 device.
- The teamd package is installed.

Procedure

1. Optional: Display the IP configuration of the team-team0 NetworkManager connection:

```
# nmcli connection show team-team0 | grep "^ip"
...
ipv4.method: manual
ipv4.dns: 192.0.2.253
ipv4.dns-search: example.com
ipv4.addresses: 192.0.2.1/24
ipv4.gateway: 192.0.2.254
...
ipv6.method: manual
```
ipv6.dns:                               2001:db8:1::fffd
ipv6.dns-search:                        example.com
ipv6.addresses:                         2001:db8:1::1/64
ipv6.gateway:                           2001:db8:1::ffe

2. Export the configuration of the team0 device to a JSON file:

   # teamdctl team0 config dump actual > /tmp/team0.json

3. Remove the network team. For example, if you configured the team in NetworkManager, remove the team-team0 connection profile and the profiles of associated ports:

   # nmcli connection delete team-team0
   # nmcli connection delete team-team0-port1
   # nmcli connection delete team-team0-port2

4. Run the team2bond utility in dry-run mode to display nmcli commands that set up a network bond with similar settings as the team device:

   # team2bond --config=/tmp/team0.json --rename=bond0
   nmcli con add type bond ifname bond0 bond.options "mode=active-backup,num_grat_arp=1,num_unsol_na=1,resend_igmp=1,miimon=100,miimon=100"
   nmcli con add type ethernet ifname enp7s0 master bond0
   nmcli con add type ethernet ifname enp8s0 master bond0

   The first command contains two miimon options because the team configuration file contained two link_watch entries. Note that this does not affect the creation of the bond.

   If you bind services to the device name of the team and want to avoid updating or breaking these services, omit the --rename=bond0 option. In this case, team2bond uses the same interface name for the bond as for the team.

5. Verify that the options for the bond the team2bond utility suggested are correct.

6. Create the bond. You can execute the suggested nmcli commands or re-run the team2bond command with the --exec-cmd option:

   # team2bond --config=/tmp/team0.json --rename=bond0 --exec-cmd
   Connection 'bond-bond0' (0241a531-0c72-4202-80df-73eadfc126b5) successfully added.
   Connection 'bond-slave-enp7s0' (38489729-b624-4606-a784-1ccf01e2f6d6) successfully added.
   Connection 'bond-slave-enp8s0' (de97ec06-7daa-4298-9a71-9d4c7909daa1) successfully added.

   You require the name of the bond connection profile (bond-bond0) in the next steps.

7. Set the IPv4 settings that were previously configured on team-team0 to the bond-bond0 connection:

   # nmcli connection modify bond-bond0 ipv4.addresses '192.0.2.1/24'
   # nmcli connection modify bond-bond0 ipv4.gateway '192.0.2.254'
   # nmcli connection modify bond-bond0 ipv4.dns '192.0.2.253'
   # nmcli connection modify bond-bond0 ipv4.dns-search 'example.com'
   # nmcli connection modify bond-bond0 ipv4.method manual
8. Set the IPv6 settings that were previously configured on `team-team0` to the `bond-bond0` connection:

```bash
# nmcli connection modify bond-bond0 ipv6.addresses '2001:db8:1::1/64'
# nmcli connection modify bond-bond0 ipv6.gateway '2001:db8:1::fffe'
# nmcli connection modify bond-bond0 ipv6.dns '2001:db8:1::fffd'
# nmcli connection modify bond-bond0 ipv6.dns-search 'example.com'
# nmcli connection modify bond-bond0 ipv6.method manual
```

9. Activate the connection:

```bash
# nmcli connection up bond-bond0
```

**Verification**

1. Display the IP configuration of the `bond-bond0` NetworkManager connection:

```bash
# nmcli connection show bond-bond0 | egrep "^ip"
```

```
...  
ipv4.method: manual
ipv4.dns: 192.0.2.253
ipv4.dns-search: example.com
ipv4.addresses: 192.0.2.1/24
ipv4.gateway: 192.0.2.254
...
ipv6.method: manual
ipv6.dns: 2001:db8:1::fffd
ipv6.dns-search: example.com
ipv6.addresses: 2001:db8:1::1/64
ipv6.gateway: 2001:db8:1::fffe
...
```

2. Display the status of the bond:

```bash
# cat /proc/net/bonding/bond0
```

```
Ethernet Channel Bonding Driver: v5.13.0-0.rc7.51.el9.x86_64

Bonding Mode: fault-tolerance (active-backup)
Primary Slave: None
Currently Active Slave: enp7s0
MII Status: up
MII Polling Interval (ms): 100
Up Delay (ms): 0
Down Delay (ms): 0
Peer Notification Delay (ms): 0

Slave Interface: enp7s0
MII Status: up
Speed: Unknown
Duplex: Unknown
Link Failure Count: 0
Permanent HW addr: 52:54:00:bf:b1:a9
Slave queue ID: 0
```
Slave Interface: enp8s0
MII Status: up
Speed: Unknown
Duplex: Unknown
Link Failure Count: 0
Permanent HW addr: 52:54:00:04:36:0f
Slave queue ID: 0

In this example, both ports are up.

3. To verify that bonding failover works:
   a. Temporarily remove the network cable from the host. Note that there is no method to properly test link failure events using the command line.
   b. Display the status of the bond:

      # cat /proc/net/bonding/bond0

10.2. UNDERSTANDING NETWORK TEAMING

Network teaming is a feature that combines or aggregates network interfaces to provide a logical interface with higher throughput or redundancy.

Network teaming uses a kernel driver to implement fast handling of packet flows, as well as user-space libraries and services for other tasks. This way, network teaming is an easily extensible and scalable solution for load-balancing and redundancy requirements.

IMPORTANT

Certain network teaming features, such as the fail-over mechanism, do not support direct cable connections without a network switch. For further details, see Is bonding supported with direct connection using crossover cables?

10.3. UNDERSTANDING THE DEFAULT BEHAVIOR OF CONTROLLER AND PORT INTERFACES

Consider the following default behavior of, when managing or troubleshooting team or bond port interfaces using the NetworkManager service:

- Starting the controller interface does not automatically start the port interfaces.
- Starting a port interface always starts the controller interface.
- Stopping the controller interface also stops the port interface.
- A controller without ports can start static IP connections.
- A controller without ports waits for ports when starting DHCP connections.
- A controller with a DHCP connection waiting for ports completes when you add a port with a carrier.
• A controller with a DHCP connection waiting for ports continues waiting when you add a port without carrier.

10.4. UNDERSTANDING THE TEAMD SERVICE, RUNNERS, AND LINK-WATCHERS

The team service, teamd, controls one instance of the team driver. This instance of the driver adds instances of a hardware device driver to form a team of network interfaces. The team driver presents a network interface, for example team0, to the kernel.

The teamd service implements the common logic to all methods of teaming. Those functions are unique to the different load sharing and backup methods, such as round-robin, and implemented by separate units of code referred to as runners. Administrators specify runners in JavaScript Object Notation (JSON) format, and the JSON code is compiled into an instance of teamd when the instance is created. Alternatively, when using NetworkManager, you can set the runner in the team.runner parameter, and NetworkManager auto-creates the corresponding JSON code.

The following runners are available:

- broadcast: Transmits data over all ports.
- roundrobin: Transmits data over all ports in turn.
- activebackup: Transmits data over one port while the others are kept as a backup.
- loadbalance: Transmits data over all ports with active Tx load balancing and Berkeley Packet Filter (BPF)-based Tx port selectors.
- random: Transmits data on a randomly selected port.
- lacp: Implements the 802.3ad Link Aggregation Control Protocol (LACP).

The teamd services uses a link watcher to monitor the state of subordinate devices. The following link-watchers are available:

- ethtool: The libteam library uses the ethtool utility to watch for link state changes. This is the default link-watcher.
- arp_ping: The libteam library uses the arp_ping utility to monitor the presence of a far-end hardware address using Address Resolution Protocol (ARP).
- nsna_ping: On IPv6 connections, the libteam library uses the Neighbor Advertisement and Neighbor Solicitation features from the IPv6 Neighbor Discovery protocol to monitor the presence of a neighbor’s interface.

Each runner can use any link watcher, with the exception of lacp. This runner can only use the ethtool link watcher.

10.5. INSTALLING THE TEAMD SERVICE

To configure a network team in NetworkManager, you require the teamd service and the team plug-in for NetworkManager. Both are installed on Red Hat Enterprise Linux by default. This section describes how you install the required packages in case that you remove them.

Prerequisites
An active Red Hat subscription is assigned to the host.

Procedure

- Install the `teamd` and `NetworkManager-team` packages:

  ```bash
  # dnf install teamd NetworkManager-team
  ```

10.6. CONFIGURING A NETWORK TEAM USING NMCLI COMMANDS

This section describes how to configure a network team using `nmcli` utility.

**IMPORTANT**

Network teaming is deprecated in Red Hat Enterprise Linux 9. Consider using the network bonding driver as an alternative. For details, see Configuring network bonding.

Prerequisites

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the team, the physical or virtual Ethernet devices must be installed on the server and connected to a switch.
- To use bond, bridge, or VLAN devices as ports of the team, you can either create these devices while you create the team or you can create them in advance as described in:
  - Configuring a network bond using nmcli commands
  - Configuring a network bridge using nmcli commands
  - Configuring VLAN tagging using nmcli commands

Procedure

1. Create a team interface:

   ```bash
   # nmcli connection add type team con-name team0 ifname team0 team.runner activebackup
   ```

   This command creates a network team named `team0` that uses the `activebackup` runner.

2. Optionally, set a link watcher. For example, to set the `ethtool` link watcher in the `team0` connection profile:

   ```bash
   # nmcli connection modify team0 team.link-watchers "name=ethtool"
   ```

   Link watchers support different parameters. To set parameters for a link watcher, specify them space-separated in the `name` property. Note that the name property must be surrounded by quotes. For example, to use the `ethtool` link watcher and set its `delay-up` parameter to 2500 milliseconds (2.5 seconds):

   ```bash
   # nmcli connection modify team0 team.link-watchers "name=ethtool delay-up=2500"
   ```
To set multiple link watchers and each of them with specific parameters, the link watchers must be separated by a comma. The following example sets the `ethtool` link watcher with the `delay-up` parameter and the `arp_ping` link watcher with the `source-host` and `target-host` parameter:

```bash
# nmcli connection modify team0 team.link-watchers "name=ethtool delay-up=2,
name=arp_ping source-host=192.0.2.1 target-host=192.0.2.2"
```

3. Display the network interfaces, and note the names of the interfaces you want to add to the team:

```bash
# nmcli device status
DEVICE  TYPE      STATE         CONNECTION
enp7s0  ethernet  disconnected  --
enp8s0  ethernet  disconnected  --
bond0   bond      connected bond0
bond1   bond      connected bond1
...
```

In this example:

- `enp7s0` and `enp8s0` are not configured. To use these devices as ports, add connection profiles in the next step. Note that you can only use Ethernet interfaces in a team that are not assigned to any connection.
- `bond0` and `bond1` have existing connection profiles. To use these devices as ports, modify their profiles in the next step.

4. Assign the port interfaces to the team:

   a. If the interfaces you want to assign to the team are not configured, create new connection profiles for them:

   ```bash
   # nmcli connection add type ethernet slave-type team con-name team0-port1
   ifname enp7s0 master team0
   # nmcli connection add type ethernet slave-type team con-name team0-port2
   ifname enp8s0 master team0
   ```

   These commands create profiles for `enp7s0` and `enp8s0`, and add them to the `team0` connection.

   b. To assign an existing connection profile to the team, set the `master` parameter of these connections to `team0`:

   ```bash
   # nmcli connection modify bond0 master team0
   # nmcli connection modify bond1 master team0
   ```

   These commands assign the existing connection profiles named `bond0` and `bond1` to the `team0` connection.

5. Configure the IP settings of the team. Skip this step if you want to use this team as a ports of other devices:

   a. Configure the IPv4 settings. For example, to set a static IPv4 address, network mask, default gateway, DNS server, and DNS search domain the `team0` connection, enter:
# Configure the IPv4 settings. For example, to set a static IPv4 address, network mask, default gateway, DNS server, and DNS search domain of the team0 connection, enter:

```bash
# nmcli connection modify team0 ipv4.addresses '192.0.2.1/24'
# nmcli connection modify team0 ipv4.gateway '192.0.2.254'
# nmcli connection modify team0 ipv4.dns '192.0.2.253'
# nmcli connection modify team0 ipv4.dns-search 'example.com'
# nmcli connection modify team0 ipv4.method manual
```

b. Configure the IPv6 settings. For example, to set a static IPv6 address, network mask, default gateway, DNS server, and DNS search domain of the team0 connection, enter:

```bash
# nmcli connection modify team0 ipv6.addresses '2001:db8:1::1/64'
# nmcli connection modify team0 ipv6.gateway '2001:db8:1::ffe'
# nmcli connection modify team0 ipv6.dns '2001:db8:1::fffd'
# nmcli connection modify team0 ipv6.dns-search 'example.com'
# nmcli connection modify team0 ipv6.method manual
```

6. Activate the connection:

```bash
# nmcli connection up team0
```

**Verification steps**

- Display the status of the team:

```bash
# teamdctl team0 state
setup:
 runner: activebackup
ports:
 enp7s0
  link watches:
   link summary: up
   instance[link_watch_0]:
    name: ethtool
    link: up
    down count: 0
  enp8s0
  link watches:
   link summary: up
   instance[link_watch_0]:
    name: ethtool
    link: up
    down count: 0
runner:
 active port: enp7s0
```

In this example, both ports are up.

**Additional resources**

- Testing basic network settings
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway
- Understanding the teamd service, runners, and link-watchers
10.7. CONFIGURING A NETWORK TEAM USING THE RHEL WEB CONSOLE

This section describes how to configure a network team using the RHEL web console.

IMPORTANT

Network teaming is deprecated in Red Hat Enterprise Linux 9. Consider using the network bonding driver as an alternative. For details, see Configuring network bonding.

Prerequisites

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the team, the physical or virtual Ethernet devices must be installed on the server and connected to a switch.
- To use bond, bridge, or VLAN devices as ports of the team, create them in advance as described in:
  - Configuring a network bond using the RHEL web console
  - Configuring a network bridge using the RHEL web console
  - Configuring VLAN tagging using the RHEL web console

Procedure

1. Select the Networking tab in the navigation on the left side of the screen.
2. Click Add team in the Interfaces section.
3. Enter the name of the team device you want to create.
4. Select the interfaces that should be ports of the team.
5. Select the runner of the team.
   If you select Load balancing or 802.3ad LACP, the web console shows the additional field Balancer.
6. Set the link watcher:
   - If you select Ethtool, additionally, set a link up and link down delay.
   - If you set ARP ping or NSNA ping, additionally, set a ping interval and ping target.
7. Click **Apply**.

8. By default, the team uses a dynamic IP address. If you want to set a static IP address:
   a. Click the name of the team in the **Interfaces** section.
   b. Click **Edit** next to the protocol you want to configure.
   c. Select **Manual** next to **Addresses**, and enter the IP address, prefix, and default gateway.
   d. In the **DNS** section, click the **+** button, and enter the IP address of the DNS server. Repeat this step to set multiple DNS servers.
   e. In the **DNS search domains** section, click the **+** button, and enter the search domain.
   f. If the interface requires static routes, configure them in the **Routes** section.
g. Click **Apply**

**Verification**

1. Select the **Networking** tab in the navigation on the left side of the screen, and check if there is incoming and outgoing traffic on the interface.

<table>
<thead>
<tr>
<th>Interfaces</th>
<th>Add bond</th>
<th>Add team</th>
<th>Add bridge</th>
<th>Add VLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>IP address</td>
<td>Sending</td>
<td>Receiving</td>
<td></td>
</tr>
<tr>
<td>team0</td>
<td>192.0.2/24</td>
<td>1.11 Mbps</td>
<td>612 Mbps</td>
<td></td>
</tr>
</tbody>
</table>

2. Display the status of the team:

```
# teamdctl team0 state
setup:
  runner: activebackup
ports:
  enp7s0
    link watches:
      link summary: up
instance[link_watch_0]:
  name: ethtool
  link: up
```
In this example, both ports are up.

Additional resources

- Network team runners

### 10.8. Configuring a Network Team Using nm-connection-editor

This section describes how you configure a network team using the `nm-connection-editor` application.

Note that `nm-connection-editor` can add only new ports to a team. To use an existing connection profile as a port, create the team using the `nmcli` utility as described in Configuring a network team using `nmcli` commands.

**IMPORTANT**

Network teaming is deprecated in Red Hat Enterprise Linux 9. Consider using the network bonding driver as an alternative. For details, see Configuring network bonding.

**Prerequisites**

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the team, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bond, or VLAN devices as ports of the team, ensure that these devices are not already configured.

**Procedure**

1. Open a terminal, and enter `nm-connection-editor`:

   ```
   $ nm-connection-editor
   ```

2. Click the + button to add a new connection.

3. Select the **Team** connection type, and click **Create**.

4. In the **Team** tab:
   a. Optional: Set the name of the team interface in the **Interface name** field.
b. Click the **Add** button to add a new connection profile for a network interface and adding the profile as a port to the team.

   i. Select the connection type of the interface. For example, select **Ethernet** for a wired connection.

   ii. Optional: Set a connection name for the port.

   iii. If you create a connection profile for an Ethernet device, open the **Ethernet** tab, and select in the **Device** field the network interface you want to add as a port to the team. If you selected a different device type, configure it accordingly. Note that you can only use Ethernet interfaces in a team that are not assigned to any connection.

   iv. Click **Save**.

c. Repeat the previous step for each interface you want to add to the team.

   ![Editing Team connection 1](image)

   d. Click the **Advanced** button to set advanced options to the team connection.

      i. In the **Runner** tab, select the runner.

      ii. In the **Link Watcher** tab, set the link watcher and its optional settings.

      iii. Click **OK**.

5. Configure the IP settings of the team. Skip this step if you want to use this team as a port of other devices.
a. In the **IPv4 Settings** tab, configure the IPv4 settings. For example, set a static IPv4 address, network mask, default gateway, DNS server, and DNS search domain:

![IPv4 Settings](image)

b. In the **IPv6 Settings** tab, configure the IPv6 settings. For example, set a static IPv6 address, network mask, default gateway, DNS server, and DNS search domain:

![IPv6 Settings](image)

6. Save the team connection.

Verification steps

- Display the status of the team:

```
# teamdctl team0 state
setup:
  runner: activebackup
ports:
  enp7s0
    link watches:
      link summary: up
      instance[link_watch_0]:
        name: ethtool
        link: up
        down count: 0
  enp8s0
    link watches:
      link summary: up
      instance[link_watch_0]:
        name: ethtool
        link: up
        down count: 0
runner:
  active port: enp7s0
```

Additional resources

- Configuring a network bond using nm-connection-editor
- Configuring a network team using nm-connection-editor
- Configuring VLAN tagging using nm-connection-editor
- Testing basic network settings
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway
- Understanding the teamd service, runners, and link-watchers
- NetworkManager duplicates a connection after restart of NetworkManager service
CHAPTER 11. CONFIGURING NETWORK BONDING

This section describes the basics of network bonding, the differences between bonding and teaming, and how to configure a network bond on Red Hat Enterprise Linux.

You can create bonds on different types of devices, such as:

- Physical and virtual Ethernet devices
- Network bridges
- Network teams
- VLAN devices

11.1. UNDERSTANDING NETWORK BONDING

Network bonding is a method to combine or aggregate network interfaces to provide a logical interface with higher throughput or redundancy.

The active-backup, balance-tlb, and balance-alb modes do not require any specific configuration of the network switch. However, other bonding modes require configuring the switch to aggregate the links. For example, Cisco switches require EtherChannel for modes 0, 2, and 3, but for mode 4, the Link Aggregation Control Protocol (LACP) and EtherChannel are required.

For further details, see the documentation of your switch and Linux Ethernet Bonding Driver HOWTO.

**IMPORTANT**

Certain network bonding features, such as the fail-over mechanism, do not support direct cable connections without a network switch. For further details, see the Is bonding supported with direct connection using crossover cables? KCS solution.

11.2. UNDERSTANDING THE DEFAULT BEHAVIOR OF CONTROLLER AND PORT INTERFACES

Consider the following default behavior of, when managing or troubleshooting team or bond port interfaces using the NetworkManager service:

- Starting the controller interface does not automatically start the port interfaces.
- Starting a port interface always starts the controller interface.
- Stopping the controller interface also stops the port interface.
- A controller without ports can start static IP connections.
- A controller without ports waits for ports when starting DHCP connections.
- A controller with a DHCP connection waiting for ports completes when you add a port with a carrier.
- A controller with a DHCP connection waiting for ports continues waiting when you add a port without carrier.
11.3. UPSTREAM SWITCH CONFIGURATION DEPENDING ON THE BONDING MODES

The following table describes which settings you must apply to the upstream switch depending on the bonding mode:

<table>
<thead>
<tr>
<th>Bonding mode</th>
<th>Configuration on the switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - balance-rr</td>
<td>Requires static Etherchannel enabled (not LACP-negotiated)</td>
</tr>
<tr>
<td>1 - active-backup</td>
<td>Requires autonomous ports</td>
</tr>
<tr>
<td>2 - balance-xor</td>
<td>Requires static Etherchannel enabled (not LACP-negotiated)</td>
</tr>
<tr>
<td>3 - broadcast</td>
<td>Requires static Etherchannel enabled (not LACP-negotiated)</td>
</tr>
<tr>
<td>4 - 802.3ad</td>
<td>Requires LACP-negotiated Etherchannel enabled</td>
</tr>
<tr>
<td>5 - balance-tlb</td>
<td>Requires autonomous ports</td>
</tr>
<tr>
<td>6 - balance-alb</td>
<td>Requires autonomous ports</td>
</tr>
</tbody>
</table>

For configuring these settings on your switch, see the switch documentation.

11.4. CONFIGURING A NETWORK BOND USING NMCLI COMMANDS

This section describes how to configure a network bond using nmcli commands.

Prerequisites

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the bond, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bridge, or VLAN devices as ports of the bond, you can either create these devices while you create the bond or you can create them in advance as described in:
  - Configuring a network team using nmcli commands
  - Configuring a network bridge using nmcli commands
  - Configuring VLAN tagging using nmcli commands

Procedure

1. Create a bond interface:

   ```bash
   # nmcli connection add type bond con-name bond0 ifname bond0 bond.options "mode=active-backup"
   ```
This command creates a bond named `bond0` that uses the `active-backup` mode.

To additionally set a Media Independent Interface (MII) monitoring interval, add the `miimon=interval` option to the `bond.options` property. For example, to use the same command but, additionally, set the MII monitoring interval to 1000 milliseconds (1 second), enter:

```
# nmcli connection add type bond con-name bond0 ifname bond0 bond.options "mode=active-backup,miimon=1000"
```

2. Display the network interfaces, and note names of interfaces you plan to add to the bond:

```
# nmcli device status

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>TYPE</th>
<th>STATE</th>
<th>CONNECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>enp7s0</td>
<td>ethernet</td>
<td>disconnected</td>
<td>--</td>
</tr>
<tr>
<td>enp8s0</td>
<td>ethernet</td>
<td>disconnected</td>
<td>--</td>
</tr>
<tr>
<td>bridge0</td>
<td>bridge</td>
<td>connected</td>
<td>bridge0</td>
</tr>
<tr>
<td>bridge1</td>
<td>bridge</td>
<td>connected</td>
<td>bridge1</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

In this example:

- `enp7s0` and `enp8s0` are not configured. To use these devices as ports, add connection profiles in the next step.
- `bridge0` and `bridge1` have existing connection profiles. To use these devices as ports, modify their profiles in the next step.

3. Assign interfaces to the bond:
   a. If the interfaces you want to assign to the bond are not configured, create new connection profiles for them:

```
# nmcli connection add type ethernet slave-type bond con-name bond0-port1
ifname enp7s0 master bond0

# nmcli connection add type ethernet slave-type bond con-name bond0-port2
ifname enp8s0 master bond0
```

These commands create profiles for `enp7s0` and `enp8s0`, and add them to the `bond0` connection.

b. To assign an existing connection profile to the bond, set the `master` parameter of these connections to `bond0`:

```
# nmcli connection modify bridge0 master bond0
# nmcli connection modify bridge1 master bond0
```

These commands assign the existing connection profiles named `bridge0` and `bridge1` to the `bond0` connection.

4. Configure the IP settings of the bond. Skip this step if you want to use this bond as a port of other devices.
   a. Configure the IPv4 settings. For example, to set a static IPv4 address, network mask, default gateway, DNS server, and DNS search domain to the `bond0` connection, enter:
Configure the IPv6 settings. For example, to set a static IPv6 address, network mask, default gateway, DNS server, and DNS search domain to the `bond0` connection, enter:

```
# nmcli connection modify bond0 ipv6.addresses '2001:db8:1::1/64'
# nmcli connection modify bond0 ipv6.gateway '2001:db8:1::fffe'
# nmcli connection modify bond0 ipv6.dns '2001:db8:1::fffd'
# nmcli connection modify bond0 ipv6.dns-search 'example.com'
# nmcli connection modify bond0 ipv6.method manual
```

5. Activate the connection:

```
# nmcli connection up bond0
```

6. Verify that the ports are connected, and the `CONNECTION` column displays the port’s connection name:

```
# nmcli device
DEVICE   TYPE      STATE      CONNECTION
...      enp7s0   ethernet  connected bond0-port1
       enp8s0   ethernet  connected bond0-port2
```

When you activate any port of the connection, NetworkManager also activates the bond, but not the other ports of it. You can configure that Red Hat Enterprise Linux enables all ports automatically when when the bond is enabled:

a. Enable the `connection.autoconnect-slaves` parameter of the bond’s connection:

```
# nmcli connection modify bond0 connection.autoconnect-slaves 1
```

b. Reactivate the bridge:

```
# nmcli connection up bond0
```

**Verification steps**

1. Temporarily remove the network cable from the host.
   Note that there is no method to properly test link failure events using software utilities. Tools that deactivate connections, such as `nmcli`, show only the bonding driver’s ability to handle port configuration changes and not actual link failure events.

2. Display the status of the bond:

```
# cat /proc/net/bonding/bond0
```

**Additional resources**
11.5. CONFIGURING A NETWORK BOND USING THE RHEL WEB CONSOLE

This section describes how to configure a network bond using the RHEL web console.

Prerequisites

- You are logged in to the RHEL web console.
- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as members of the bond, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bridge, or VLAN devices as members of the bond, create them in advance as described in:
  - Configuring a network team using the RHEL web console
  - Configuring a network bridge using the RHEL web console
  - Configuring VLAN tagging using the RHEL web console

Procedure

1. Select the Networking tab in the navigation on the left side of the screen.
2. Click Add bond in the Interfaces section.
3. Enter the name of the bond device you want to create.
4. Select the interfaces that should be members of the bond.
5. Select the mode of the bond.
   - If you select Active backup, the web console shows the additional field Primary in which you can select the preferred active device.
6. Set the link monitoring mode. For example, when you use the Adaptive load balancing mode, set it to ARP.
7. Optional: Adjust the monitoring interval, link up delay, and link down delay settings. Typically, you only change the defaults for troubleshooting purposes.
8. Click **Apply**.

9. By default, the bond uses a dynamic IP address. If you want to set a static IP address:
   
   a. Click the name of the bond in the **Interfaces** section.

   b. Click **Edit** next to the protocol you want to configure.

   c. Select **Manual** next to **Addresses**, and enter the IP address, prefix, and default gateway.

   d. In the **DNS** section, click the † button, and enter the IP address of the DNS server. Repeat this step to set multiple DNS servers.

   e. In the **DNS search domains** section, click the † button, and enter the search domain.
f. If the interface requires static routes, configure them in the **Routes** section.

![IPv4 settings](image)

- **Addresses**
  - **Address**: 192.0.2.1, Prefix length or netmask: 24, Gateway: 192.0.2.254

- **DNS**
  - **Server**: 192.0.2.253

- **DNS search domains**
  - **Search domain**: example.com

- **Routes**
  - **Automatic**

Click **Apply**

**Verification**

1. Select the **Networking** tab in the navigation on the left side of the screen, and check if there is incoming and outgoing traffic on the interface:

![Interfaces](image)

- **Name**: bond0, IP address: 192.0.2.1/24, Sending: 1.11 Mbps, Receiving: 61.2 Mbps

2. Temporarily remove the network cable from the host.
   Note that there is no method to properly test link failure events using software utilities. Tools that deactivate connections, such as the web console, show only the bonding driver’s ability to handle member configuration changes and not actual link failure events.

3. Display the status of the bond:

```
# cat /proc/net/bonding/bond0
```
11.6. CONFIGURING A NETWORK BOND USING NMTUI

The nmtui application provides a text-based user interface for NetworkManager. You can use nmtui to configure a network bond on a host without a graphical interface.

**NOTE**

In nmtui:

- Navigate by using the cursor keys.
- Press a button by selecting it and hitting Enter.
- Select and deselect checkboxes by using Space.

**Prerequisites**

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports of the bond, the physical or virtual Ethernet devices must be installed on the server.

**Procedure**

1. If you do not know the network device names on which you want configure a network bond, display the available devices:

   ```
   # nmcli device status
   DEVICE     TYPE      STATE                   CONNECTION
   enp7s0     ethernet  unavailable             --
   enp8s0     ethernet  unavailable             --
   ...  
   ```

2. Start nmtui:

   ```
   # nmtui
   ```


4. Press the Add button.

5. Select **Bond** from the list of network types, and press Enter.

6. Optional: Enter a name for the NetworkManager profile to be created.

7. Enter the bond device name to be created into the **Device** field.

8. Add ports to the bond to be created:

   a. Press the Add button next to the Slaves list.
   b. Select the type of the interface you want to add as port to the bond, for example, Ethernet.
   c. Optional: Enter a name for the NetworkManager profile to be created for this bond port.
d. Enter the port’s device name into the **Device** field.

e. Press the **OK** button to return to the window with the bond settings.

**Figure 11.1. Adding an Ethernet device as port to a bond**

![Image of bond configuration settings]

f. Repeat these steps to add more ports to the bond.

9. Set the bond mode. Depending on the value you set, `nmtui` displays additional fields for settings that are related to the selected mode.

10. Depending on your environment, configure the IP address settings in the **IPv4 configuration** and **IPv6 configuration** areas accordingly. For this, press the **Automatic** button, and select:

   - **Disabled**, if the bond does not require an IP address.
   - **Automatic**, if a DHCP server dynamically assigns an IP address to the bond.
   - **Manual**, if the network requires static IP address settings. In this case, you must fill further fields:

     i. Press the **Show** button next to the protocol you want to configure to display additional fields.

     ii. Press the **Add** button next to **Addresses**, and enter the IP address and the subnet mask in Classless Inter-Domain Routing (CIDR) format. If you do not specify a subnet mask, NetworkManager sets a /32 subnet mask for IPv4 addresses and /64 for IPv6 addresses.

iii. Enter the address of the default gateway.

iv. Press the **Add** button next to **DNS servers**, and enter the DNS server address.

v. Press the **Add** button next to **Search domains**, and enter the DNS search domain.
Figure 11.2. Example of a bond connection with static IP address settings

11. Press the OK button to create and automatically activate the new connection.
12. Press the Back button to return to the main menu.

13. Select Quit, and press Enter to close the nmtui application.

Verification

1. Temporarily remove the network cable from the host.
   Note that there is no method to properly test link failure events using software utilities. Tools that deactivate connections, such as nmcli, show only the bonding driver’s ability to handle port configuration changes and not actual link failure events.

2. Display the status of the bond:

   # cat /proc/net/bonding/bond0

11.7. CONFIGURING A NETWORK BOND USING NM-CONNECTION-EDITOR

This section describes how to configure a network bond using the nm-connection-editor application.

Note that nm-connection-editor can add only new ports to a bond. To use an existing connection profile as a port, create the bond using the nmcli utility as described in Configuring a network bond using nmcli commands.

Prerequisites

- Two or more physical or virtual network devices are installed on the server.

- To use Ethernet devices as ports of the bond, the physical or virtual Ethernet devices must be installed on the server.

- To use team, bond, or VLAN devices as ports of the bond, ensure that these devices are not already configured.

Procedure

1. Open a terminal, and enter nm-connection-editor:

   $ nm-connection-editor

2. Click the + button to add a new connection.

3. Select the Bond connection type, and click Create.

4. In the Bond tab:

   a. Optional: Set the name of the bond interface in the Interface name field.

   b. Click the Add button to add a network interface as a port to the bond.

      i. Select the connection type of the interface. For example, select Ethernet for a wired connection.

      ii. Optional: Set a connection name for the port.
iii. If you create a connection profile for an Ethernet device, open the Ethernet tab, and select in the **Device** field the network interface you want to add as a port to the bond. If you selected a different device type, configure it accordingly. Note that you can only use Ethernet interfaces in a bond that are not configured.

iv. Click **Save**.

c. Repeat the previous step for each interface you want to add to the bond:

<table>
<thead>
<tr>
<th>Bonded connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>bond0-port1</td>
</tr>
<tr>
<td>bond0-port2</td>
</tr>
</tbody>
</table>


d. Optional: Set other options, such as the Media Independent Interface (MII) monitoring interval.

5. Configure the IP settings of the bond. Skip this step if you want to use this bond as a port of other devices.

a. In the **IPv4 Settings** tab, configure the IPv4 settings. For example, set a static IPv4 address, network mask, default gateway, DNS server, and DNS search domain:

<table>
<thead>
<tr>
<th>Addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
</tr>
<tr>
<td>192.0.2.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DNS servers</th>
<th>Search domains</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.0.2.253</td>
<td>example.com</td>
</tr>
</tbody>
</table>
b. In the **IPv6 Settings** tab, configure the IPv6 settings. For example, set a static IPv6 address, network mask, default gateway, DNS server, and DNS search domain:

![Editing Bond connection 1](image)

<table>
<thead>
<tr>
<th>Address</th>
<th>Prefix</th>
<th>Gateway</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001:db8:1::1</td>
<td>64</td>
<td>2001:db8:1::fff3</td>
</tr>
</tbody>
</table>

**DNS servers**: 2001:db8:1::fffd
**Search domains**: example.com

6. Click **Save** to save the bond connection.

7. Close **nm-connection-editor**.

**Verification steps**

1. Temporarily remove the network cable from the host.
   Note that there is no method to properly test link failure events using software utilities. Tools that deactivate connections, such as **nmcli**, show only the bonding driver’s ability to handle port configuration changes and not actual link failure events.

2. Display the status of the bond:

   ```
   # cat /proc/net/bonding/bond0
   ```

**Additional resources**

- Testing basic network settings.
- Configuring NetworkManager to avoid using a specific profile to provide a default gateway.
- Configuring a network team using **nm-connection-editor**
- Configuring a network bridge using **nm-connection-editor**
- Configuring VLAN tagging using **nm-connection-editor**

### 11.8. CONFIGURING A NETWORK BOND USING NMSTATECTL
This section describes how to use the `nmstatectl` utility to configure a network bond, `bond0`, with the following settings:

- Network interfaces in the bond: `enp1s0` and `enp7s0`
- Mode: `active-backup`
- Static IPv4 address: `192.0.2.1` with a `/24` subnet mask
- Static IPv6 address: `2001:db8:1::1` with a `/64` subnet mask
- IPv4 default gateway: `192.0.2.254`
- IPv6 default gateway: `2001:db8:1::ffe`
- IPv4 DNS server: `192.0.2.200`
- IPv6 DNS server: `2001:db8:1::ffbb`
- DNS search domain: `example.com`

**Prerequisites**

- Two or more physical or virtual network devices are installed on the server.
- To use Ethernet devices as ports in the bond, the physical or virtual Ethernet devices must be installed on the server.
- To use team, bridge, or VLAN devices as ports in the bond, set the interface name in the `port` list, and define the corresponding interfaces.
- The `nmstate` package is installed.

**Procedure**

1. Create a YAML file, for example `~/create-bond.yml`, with the following contents:

```yaml
---
interfaces:
- name: bond0
type: bond
state: up
ipv4:
  enabled: true
  address:
  - ip: 192.0.2.1
    prefix-length: 24
dhcp: false
ipv6:
  enabled: true
  address:
  - ip: 2001:db8:1::1
    prefix-length: 64
autoconf: false
dhcp: false
link-aggregation:
```

---

CHAPTER 11. CONFIGURING NETWORK BONDING
mode: active-backup
port:
- enp1s0
- enp7s0
- name: enp1s0
type: ethernet
state: up
- name: enp7s0
type: ethernet
state: up

routes:
config:
- destination: 0.0.0.0/0
  next-hop-address: 192.0.2.254
  next-hop-interface: bond0
- destination: ::/0
  next-hop-address: 2001:db8:1::fffe
  next-hop-interface: bond0

dns-resolver:
config:
  search:
  - example.com
  server:
  - 192.0.2.200
  - 2001:db8:1::ffbb

2. Apply the settings to the system:

```bash
# nmstatectl apply ~/create-bond.yml
```

Verification steps

1. Display the status of the devices and connections:

```bash
# nmcli device status
DEVICE  TYPE      STATE  CONNECTION
bond0    bond      connected bond0
```

2. Display all settings of the connection profile:

```bash
# nmcli connection show bond0
connection.id: bond0
connection.uuid: 79cbc3bd-302e-4b1f-ad89-f12533b818ee
connection.stable-id: --
connection.type: bond
connection.interface-name: bond0
...```

3. Display the connection settings in YAML format:

```bash
# nmstatectl show bond0
```
11.9. CONFIGURING A NETWORK BOND USING RHEL SYSTEM ROLES

You can use the `network` RHEL System Role to configure a network bond. This procedure describes how to configure a bond in active-backup mode that uses two Ethernet devices, and sets an IPv4 and IPv6 addresses, default gateways, and DNS configuration.

**NOTE**

Set the IP configuration on the bond and not on the ports of the Linux bond.

**Prerequisites**

- The `ansible-core` package and `rhel-system-roles` packages are installed on the control node.
- If you use a different remote user than `root` when you run the playbook, this user has appropriate `sudo` permissions on the managed node.
- Two or more physical or virtual network devices are installed on the server.

**Procedure**

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

```
node.example.com
```

2. Create the `~/bond-ethernet.yml` playbook with the following content:

```yaml
---
- name: Configure a network bond that uses two Ethernet ports
  hosts: node.example.com
  become: true
  tasks:
    - include_role:
        name: rhel-system-roles.network
        vars:
          network_connections:
            # Define the bond profile
            - name: bond0
              type: bond
              interface_name: bond0
              ip:
                address:
                  - "192.0.2.1/24"
                  - "2001:db8:1::1/64"
              gateway4: 192.0.2.254
              gateway6: 2001:db8:1::fffe
              dns:
```

Additional resources

- `nmstatectl(8)` man page
- `/usr/share/doc/nmstate/examples/`
3. Run the playbook:

- To connect as **root** user to the managed host, enter:
  
  ```bash
  # ansible-playbook -u root ~/bond-ethernet.yml
  ```

- To connect as a user to the managed host, enter:
  
  ```bash
  # ansible-playbook -u user_name --ask-become-pass ~/bond-ethernet.yml
  ```

The **--ask-become-pass** option makes sure that the **ansible-playbook** command prompts for the **sudo** password of the user defined in the **-u** **user_name** option.

If you do not specify the **-u** **user_name** option, **ansible-playbook** connects to the managed host as the user that is currently logged in to the control node.

**Additional resources**

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file
- **ansible-playbook**(1) man page

**11.10. CREATING A NETWORK BOND TO ENABLE SWITCHING BETWEEN AN ETHERNET AND WIRELESS CONNECTION WITHOUT INTERRUPTING THE VPN**

RHEL users who connect their workstation to their company’s network typically use a VPN to access remote resources. However, if the workstation switches between an Ethernet and Wi-Fi connection, for example, if you release a laptop from a docking station with an Ethernet connection, the VPN connection is interrupted. To avoid this problem, you can create a network bond that uses the Ethernet and Wi-Fi connection in **active-backup** mode.
Prerequisites

- The host contains an Ethernet and a Wi-Fi device.
- An Ethernet and Wi-Fi NetworkManager connection profile has been created and both connections work independently.

This procedure uses the following connection profiles to create a network bond named \texttt{bond0}:

- Docking\_station associated with the \texttt{enp11s0u1} Ethernet device
- Wi-Fi associated with the \texttt{wlp1s0} Wi-Fi device

Procedure

1. Create a bond interface in \texttt{active-backup} mode:

   ```
   # nmcli connection add type bond con-name bond0 ifname bond0 bond.options "mode=active-backup"
   ```

   This command names both the interface and connection profile \texttt{bond0}.

2. Configure the IPv4 settings of the bond:

   - If a DHCP server in your network assigns IPv4 addresses to hosts, no action is required.
   - If your local network requires static IPv4 addresses, set the address, network mask, default gateway, DNS server, and DNS search domain to the \texttt{bond0} connection:

     ```
     # nmcli connection modify bond0 ipv4.addresses '192.0.2.1/24'
     # nmcli connection modify bond0 ipv4.gateway '192.0.2.254'
     # nmcli connection modify bond0 ipv4.dns '192.0.2.253'
     # nmcli connection modify bond0 ipv4.dns-search 'example.com'
     # nmcli connection modify bond0 ipv4.method manual
     ```

3. Configure the IPv6 settings of the bond:

   - If your router or a DHCP server in your network assigns IPv6 addresses to hosts, no action is required.
   - If your local network requires static IPv6 addresses, set the address, network mask, default gateway, DNS server, and DNS search domain to the \texttt{bond0} connection:

     ```
     # nmcli connection modify bond0 ipv6.addresses '2001:db8:1::1/64'
     # nmcli connection modify bond0 ipv6.gateway '2001:db8:1::ffe'
     # nmcli connection modify bond0 ipv6.dns '2001:db8:1::fffd'
     # nmcli connection modify bond0 ipv6.dns-search 'example.com'
     # nmcli connection modify bond0 ipv6.method manual
     ```

4. Display the connection profiles:

   ```
   # nmcli connection show
   NAME             UUID                                  TYPE      DEVICE
   Docking\_station 256dd073-fecc-339d-91ae-9834a0407f9   ethernet enp11s0u1
   Wi-Fi            f1f531c7-8737-4c60-91af-2d21164417e8   wifi     wlp1s0
   ...
You require the names of the connection profiles and the Ethernet device name in the next steps.

5. Assign the connection profile of the Ethernet connection to the bond:

   ```shell
   # nmcli connection modify Docking_station master bond0
   ```

6. Assign the connection profile of the Wi-Fi connection to the bond:

   ```shell
   # nmcli connection modify Wi-Fi master bond0
   ```

7. If your Wi-Fi network uses MAC filtering to allow only MAC addresses on a allow list to access the network, configure that NetworkManager dynamically assigns the MAC address of the active port to the bond:

   ```shell
   # nmcli connection modify bond0 +bond.options fail_over_mac=1
   ```

   With this setting, you must set only the MAC address of the Wi-Fi device to the allow list instead of the MAC address of both the Ethernet and Wi-Fi device.

8. Set the device associated with the Ethernet connection as primary device of the bond:

   ```shell
   # nmcli con modify bond0 +bond.options "primary=enp11s0u1"
   ```

   With this setting, the bond always uses the Ethernet connection if it is available.

9. Configure that NetworkManager automatically activates ports when the `bond0` device is activated:

   ```shell
   # nmcli connection modify bond0 connection.autoconnect-slaves 1
   ```

10. Activate the `bond0` connection:

    ```shell
    # nmcli connection up bond0
    ```

**Verification steps**

- Display the currently active device, the status of the bond and its ports:

  ```shell
  # cat /proc/net/bonding/bond0
  Ethernet Channel Bonding Driver: v3.7.1 (April 27, 2011)
  
  Bonding Mode: fault-tolerance (active-backup) (fail_over_mac active)
  Primary Slave: enp11s0u1 (primary_reselect always)
  Currently Active Slave: enp11s0u1
  
  MII Status: up
  MII Polling Interval (ms): 1
  Up Delay (ms): 0
  Down Delay (ms): 0
  Peer Notification Delay (ms): 0
  
  Slave Interface: enp11s0u1
  MII Status: up
  Speed: 1000 Mbps
  ```
CHAPTER 11. CONFIGURING NETWORK BONDING

The Linux bonding driver provides link aggregation. It is the process of aggregating multiple network interfaces in parallel to provide a single logical bonded interface. The actions of a bonded interface depend on the bonding policy that is also known as mode. Mode provides either load-balancing service or hot standby.

Balance-rr (Mode 0)

Balance-rr uses the round-robin algorithm that sequentially transmits packets from the first available port to the last one. This mode provides fault tolerance and load balancing.

To set up an Etherchannel, this mode requires a switch configuration. An Etherchannel is a port link aggregation technology to group multiple physical Ethernet links to one logical Ethernet link, or similar port grouping.

The drawback of this mode is that it is not suitable for heavy workloads or if TCP throughput or ordered packet delivery is essential.

Active-backup (Mode 1)

Active-backup uses the policy that determines that only one port is active in the bond. This mode provides fault tolerance and does not require any switch configuration.

If the active port fails, an alternate port becomes active. The bond sends a gratuitous address resolution protocol (ARP) to the network. The gratuitous ARP forces the receiver of the ARP frame to update their forwarding table. The Active-backup mode transmits a gratuitous ARP to announce the new path to maintain connectivity for the host.

The primary option defines the preferred port of the bonding interface.

Balance-xor (Mode 2)

Balance-xor uses the selected transmit hash policy to transmit packets. This mode provides load balancing, fault tolerance, and requires a switch configuration to set up an Etherchannel or similar port grouping.
To alter packet transmission, use the `xmit_hash_policy` option. Depending on the source or destination of traffic on the interface, the interface requires an additional load-balancing configuration.

**Broadcast (Mode 3)**

- **Broadcast** uses a broadcast policy that transmits every packet on all agent interfaces. This mode provides fault tolerance.
  - In this mode, a switch configuration is required to establish an EtherChannel or similar port grouping.
  - The drawback of this mode is that it is not suitable for heavy workloads, or if TCP throughput or ordered packet delivery is essential.

**802.3ad (Mode 4)**

- **802.3ad** uses the IEEE standard 802.3ad or IEEE standard 802.1ax-2008 dynamic link aggregation policy. This mode provides fault tolerance.
  - This mode creates aggregation groups that share the same speed and duplex settings and utilizes all ports in the active aggregator. Depending on the source or destination of traffic on the interface, this mode requires an additional load-balancing configuration.
  - By default, the port selection for outgoing traffic depends on the transmit hash policy. Use the `xmit_hash_policy` option of the transmit hash policy to change the port selection.
  - The difference between **802.3ad** and **Balance-xor** policy is compliance. Not all transmit policies are **802.3ad** compliant. Using different policies on ports have different fault tolerance rates.

**Balance-tlb (Mode 5)**

- **Balance-tlb** uses the adaptive transmit load balancing policy. This mode provides fault tolerance, load balancing, and establishes channel bonding that does not require any switch support.
  - The active port receives the incoming traffic. In case of failure of the active port, another one takes over the MAC address of the failed port.

  - To decide which interface processes the outgoing traffic, use one of the following modes: value 1 distributes traffic to each port using load balancing and value 0 uses the hash distribution policy to distribute traffic without load balancing.

  - The `primary` option defines the preferred port of the bonding interface.

**Balance-alb (Mode 6)**

- **Balance-alb** mode uses an adaptive load balancing policy. This mode provides fault tolerance, load balancing, and does not require any special switch support.
  - This mode includes balance-transmit load balancing (balance-tlb) and receive-load balancing for IPv4 and IPv6 traffic. The bonding intercepts ARP replies sent by the local system and overwrites the source hardware address of one of the ports in the bond. ARP negotiation manages the receive-load balancing. Thus, different ports use different hardware addresses for the server.

  - The `primary` option defines the preferred port of the bonding interface.

**Additional resources**

- `/usr/share/doc/kernel-doc-<version>/Documentation/networking/bonding.rst` provided by the `kernel-doc` package
• Which bonding modes work when used with a bridge that virtual machine guests or containers connect to
CHAPTER 12. SETTING UP A WIREGUARD VPN

WireGuard is a high-performance VPN solution that runs in the Linux kernel. It uses modern cryptography and is easier to configure than many other VPN solutions. Additionally, WireGuard’s small codebase reduces the surface for attacks and, therefore, improves security. For authentication and encryption, WireGuard uses keys similar to SSH.

IMPORTANT

WireGuard is provided as a Technology Preview only. Technology Preview features are not supported with Red Hat production Service Level Agreements (SLAs), might not be functionally complete, and Red Hat does not recommend using them for production. These previews provide early access to upcoming product features, enabling customers to test functionality and provide feedback during the development process.

See Technology Preview Features Support Scope on the Red Hat Customer Portal for information about the support scope for Technology Preview features.

To set up a WireGuard VPN, you must complete the following steps. You can perform each step by using different options:

1. Create public and private keys for every host in the VPN.

2. Configure the WireGuard server by using `nmcli`, `nmtui`, `nm-connection-editor`, or the `wg-quick` service.

3. Configure firewalld on the WireGuard server by using the command line or graphical interface.

4. Configure the WireGuard client by using `nmcli`, `nm-connection-editor`, or the `wg-quick` service.

WireGuard operates on the network layer (layer 3). Therefore, you cannot use DHCP and must assign static IP addresses or IPv6 link-local addresses to the tunnel devices on both the server and clients.

IMPORTANT

You can use WireGuard only if the Federal Information Processing Standard (FIPS) mode in RHEL is disabled.

Note that all hosts that participate in a WireGuard VPN are peers. This documentation uses the terms `client` to describe hosts that establish a connection and `server` to describe the host with the fixed hostname or IP address that the clients connect to and optionally route all traffic through this server.

12.1. PROTOCOLS AND PRIMITIVES USED BY WIREGUARD

WireGuard uses the following protocols and primitives:

- ChaCha20 for symmetric encryption, authenticated with Poly1305, using Authenticated Encryption with Associated Data (AEAD) construction as described in RFC7539
- Curve25519 for Elliptic-curve Diffie–Hellman (ECDH) key exchange
- BLAKE2s for hashing and keyed hashing, as described in RFC7693
- SipHash24 for hash table keys
HKDF for key derivation, as described in RFC5869

12.2. HOW WIREGUARD USES TUNNEL IP ADDRESSES, PUBLIC KEYS, AND REMOTE ENDPOINTS

When WireGuard sends a network packet to a peer:

1. WireGuard reads the destination IP from the packet and compares it to the list of allowed IP addresses in the local configuration. If the peer is not found, WireGuard drops the packet.

2. If the peer is valid, WireGuard encrypts the packet using the peer’s public key.

3. The sending host looks up the most recent Internet IP address of the host and sends the encrypted packet to it.

When WireGuard receives a packet:

1. WireGuard decrypts the packet using private key of the remote host.

2. WireGuard reads the internal source address from the packet and looks up whether the IP is configured in the list of allowed IP addresses in the settings for the peer on the local host. If the source IP is on the allowlist, WireGuard accepts the packet. If the IP address is not on the list, WireGuard drops the packet.

The association of public keys and allowed IP addresses is called Cryptokey Routing Table. This means that the list of IP addresses behaves similar to a routing table when sending packets, and as a kind of access control list when receiving packets.

12.3. USING A WIREGUARD CLIENT BEHIND NAT AND FIREWALLS

WireGuard uses the UDP protocol and transmits data only when a peer sends packets. Stateful firewalls and network address translation (NAT) on routers track connections to enable a peer behind NAT or a firewall to receive packets.

To keep the connection active, WireGuard supports persistent keepalives. This means you can set an interval at which WireGuard sends keepalive packets. By default, the persistent keep-alive feature is disabled to reduce network traffic. Enable this feature on the client if you use the client in a network with NAT or if a firewall closes the connection after some time of inactivity.

12.4. CREATING PRIVATE AND PUBLIC KEYS TO BE USED IN WIREGUARD CONNECTIONS

WireGuard uses base64-encoded private and public keys to authenticate hosts to each other. Therefore, you must create the keys on each host that participates in the WireGuard VPN.

IMPORTANT

For secure connections, create different keys for each host, and ensure that you only share the public key with the remote WireGuard host. Do not use the example keys used in this documentation.

Procedure

1. Install the wireguard-tools package:
# dnf install wireguard-tools

2. Create a private key and a corresponding public key for the host:

```bash
# wg genkey | tee /etc/wireguard/$HOSTNAME.private.key | wg pubkey > /etc/wireguard/$HOSTNAME.public.key
```

You will need the content of the key files, but not the files themselves. However, Red Hat recommends keeping the files in case that you need to remember the keys in future.

3. Set secure permissions on the key files:

```bash
# chmod 600 /etc/wireguard/$HOSTNAME.private.key /etc/wireguard/$HOSTNAME.public.key
```

4. Display the private key:

```bash
# cat /etc/wireguard/$HOSTNAME.private.key
YFAnE0psgIdiAF7XR4abxiwVRnlMfeltxu10s/c4JXg=
```

You will need the private key to configure the WireGuard connection on the local host. Do not share the private key.

5. Display the public key:

```bash
# cat /etc/wireguard/$HOSTNAME.public.key
UtjqCJ57DeAscYKRfp7cFGiQqdONRn69u249Fa4O6BE=
```

You will need the public key to configure the WireGuard connection on the remote host.

Additional resources

- The `wg(8)` man page

12.5. CONFIGURING A WIREGUARD SERVER USING NMCLI

You can configure the WireGuard server by creating a connection profile in NetworkManager. Use this method to let NetworkManager manage the WireGuard connection.

This procedure assumes the following settings:

- **Server:**
  - Private key: `YFAnE0psgIdiAF7XR4abxiwVRnlMfeltxu10s/c4JXg=
  - Tunnel IPv4 address: `192.0.2.1/24`
  - Tunnel IPv6 address: `2001:db8:1::1/32`

- **Client:**
  - Public key: `bnwfQcC8/g2i4vvEqcRUM2e6Hi3Nskk6G9t4r26nFVM=
  - Tunnel IPv4 address: `192.0.2.2/24`
Tunnel IPv6 address: 2001:db8:1::2/32

Prerequisites

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the server
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the client
  - The static tunnel IP addresses and subnet masks of the server

Procedure

1. Add a NetworkManager WireGuard connection profile:

   ```
   # nmcli connection add type wireguard con-name server-wg0 ifname wg0 autoconnect no
   ```

   This command creates a profile named `server-wg0` and assigns the virtual interface `wg0` to it. To prevent the connection from starting automatically after you add it without finalizing the configuration, disable the `autoconnect` parameter.

2. Set the tunnel IPv4 address and subnet mask of the server:

   ```
   # nmcli connection modify server-wg0 ipv4.method manual ipv4.addresses 192.0.2.1/24
   ```

3. Set the tunnel IPv6 address and subnet mask of the server:

   ```
   # nmcli connection modify server-wg0 ipv6.method manual ipv6.addresses 2001:db8:1::1/32
   ```

4. Add the server’s private key to the connection profile:

   ```
   # nmcli connection modify server-wg0 wireguard.private-key "YFAnE0psgliAF7XR4abxiwVRnIMfeItxu10s/c4JXg="
   ```

5. Set the port for incoming WireGuard connections:

   ```
   # nmcli connection modify server-wg0 wireguard.listen-port 51820
   ```

   Always set a fixed port number on hosts that receive incoming WireGuard connections. If you do not set a port, WireGuard uses a random free port each time you activate the `wg0` interface.

6. Add peer configurations for each client that you want to allow to communicate with this server. You must add these settings manually, because the `nmcli` utility does not support setting the corresponding connection properties.

   a. Edit the `/etc/NetworkManager/system-connections/server-wg0.nmconnection` file, and append:
The [wireguard-peer.<public_key_of_the_client>] entry defines the peer section of the client, and the section name contains the public key of the client.

- The `allowed-ips` parameter sets the tunnel IP addresses of the client that are allowed to send data to this server.
  Add a section for each client.

b. Reload the `server-wg0` connection profile:

```
# nmcli connection load /etc/NetworkManager/system-connections/server-wg0.nmconnection
```

7. Optional: Configure the connection to start automatically, enter:

```
# nmcli connection modify server-wg0 autoconnect yes
```

8. Reactivate the `server-wg0` connection:

```
# nmcli connection up server-wg0
```

Next steps

- Configure the firewalld service on the WireGuard server.

Verification

1. Display the interface configuration of the `wg0` device:

```
# wg show wg0
interface: wg0
  public key: UtjqCJ57DeAscYKRIp7cFGiQqdONRn69u249Fa4O6BE=
  private key: (hidden)
  listening port: 51820

  peer: bwnfQcC8/g2i4vvEqcRUM2e6Hi3Nskk6G9t4r26nFVM=
  allowed ips: 192.0.2.2/32, 2001:db8:1::2/128
```

To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.

2. Display the IP configuration of the `wg0` device:

```
# ip address show wg0
20: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state
UNKNOWN group default qlen 1000
  link/none
    inet 192.0.2.1/24 brd 192.0.2.255 scope global noprefixroute wg0
      valid_lft forever preferred_lft forever
    inet6 2001:db8:1::1/32 scope global noprefixroute
```
Additional resources

- The `wg(8)` man page
- The `WireGuard setting` section in the `nm-settings(5)` man page

12.6. CONFIGURING A WIREGUARD SERVER USING NMTUI

You can configure the WireGuard server by creating a connection profile in NetworkManager. Use this method to let NetworkManager manage the WireGuard connection.

This procedure assumes the following settings:

- **Server:**
  - Private key: `YFAnE0psgIdiAF7XR4abxiwVRnlMfeltxu10s/c4JXg=`
  - Tunnel IPv4 address: `192.0.2.1/24`
  - Tunnel IPv6 address: `2001:db8:1::1/32`

- **Client:**
  - Public key: `bnwfQcC8/g2i4vvEqcRUM2e6Hi3Nskk6G9t4r26nFVM=`
  - Tunnel IPv4 address: `192.0.2.2/24`
  - Tunnel IPv6 address: `2001:db8:1::2/32`

**Prerequisites**

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the server
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the client
  - The static tunnel IP addresses and subnet masks of the server
- You installed the `NetworkManager-tui` package.

**Procedure**

1. Start the `nmtui` application:

   ```
   # nmtui
   ```

2. Select **Edit a connection**, and press **Enter**.
3. Select **Add**, and press **Enter**.

4. Select the **WireGuard** connection type in the list, and press **Enter**.

5. In the **Edit connection** window:
   
a. Enter the name of the connection and the virtual interface, such as **wg0**, that NetworkManager should assign to the connection.

b. Enter the private key of the server.

c. Set the listen port number, such as **51820**, for incoming WireGuard connections. Always set a fixed port number on hosts that receive incoming WireGuard connections. If you do not set a port, WireGuard uses a random free port each time you activate the interface.

d. Click **Add** next to the **Peers** pane:
   
i. Enter the public key of the client.

ii. Set the **Allowed IPs** field to the tunnel IP addresses of the client that are allowed to send data to this server.

iii. Select **OK**, and press **Enter**.

6. Select **Show** next to **IPv4 Configuration**, and press **Enter**.
   
i. Select the IPv4 configuration method **Manual**.

ii. Enter the tunnel IPv4 address and the subnet mask. Leave the **Gateway** field empty.

7. Select **Show** next to **IPv6 Configuration**, and press **Enter**.
   
i. Select the IPv6 configuration method **Manual**.

ii. Enter the tunnel IPv6 address and the subnet mask. Leave the **Gateway** field empty.
6. In the window with the list of connections, select **Back**, and press **Enter**.

7. In the **NetworkManager TUI** main window, select **Quit**, and press **Enter**.

**Next steps**

- Configure the firewalld service on the WireGuard server.

**Verification**

1. Display the interface configuration of the **wg0** device:

   ```
   # wg show wg0
   interface: wg0
   public key: UtjqCJ57DeAscYKRfp7cFGiQqdONRn69u249Fa4O6BE=
   private key: (hidden)
   listening port: 51820
   peer: bnwfQcC8/g24vvEgcRUM2e6Hi3Nskk6G9t4r26nFVM=
   allowed ips: 192.0.2.2/32, 2001:db8:1::2/128
   ```

   To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.

2. Display the IP configuration of the **wg0** device:
# ip address show wg0
20: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state UNKNOWN group default qlen 1000
   link/none
   inet 192.0.2.1/24 brd 192.0.2.255 scope global noprefixroute wg0
      valid_lft forever preferred_lft forever
   inet6 2001:db8:1::1/32 scope global noprefixroute
      valid_lft forever preferred_lft forever
   inet6 fe80::3ef:8863:1ce2:844/64 scope link noprefixroute
      valid_lft forever preferred_lft forever

Additional resources

- The `wg(8)` man page

## 12.7. CONFIGURING A WIREGUARD SERVER USING NM-CONNECTION-EDITOR

You can configure the WireGuard server by creating a connection profile in NetworkManager. Use this method to let NetworkManager manage the WireGuard connection.

### Prerequisites

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the server
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the client
  - The static tunnel IP addresses and subnet masks of the server

### Procedure

1. Open a terminal, and enter:

   ```
   # nm-connection-editor
   ```

2. Add a new connection by clicking the `+` button.

3. Select the **WireGuard** connection type, and click **Create**.

4. Optional: Update the connection name.

5. On the **General** tab, select **Connect automatically with priority**. Optionally, set a priority value.

6. On the **WireGuard** tab:
   a. Enter the name of the virtual interface, such as `wg0`, that NetworkManager should assign to the connection.
   b. Enter the private key of the server.
c. Set the listen port number, such as 51820, for incoming WireGuard connections. Always set a fixed port number on hosts that receive incoming WireGuard connections. If you do not set a port, WireGuard uses a random free port each time you activate the interface.

d. Click Add to add peers:
   i. Enter the public key of the client.
   ii. Set the Allowed IPs field to the tunnel IP addresses of the client that are allowed to send data to this server.
   iii. Click Apply.

7. On the IPv4 Settings tab:
   b. Click Add to enter the tunnel IPv4 address and the subnet mask. Leave the Gateway field empty.

8. On the IPv6 Settings tab:
   b. Click Add to enter the tunnel IPv6 address and the subnet mask. Leave the Gateway field empty.

9. Click Save to store the connection profile.

Next steps

- Configure the firewalld service on the WireGuard server.

Verification

1. Display the interface configuration of the wg0 device:

   ```bash
   # wg show wg0
   interface: wg0
   public key: UtjqCJ57DeAscYKRlfp7cFGiQqdONRn69u249Fa4O6BE=
   private key: (hidden)
   listening port: 51820
   peer: bnwfQcC8/g2/4vvEeqcRUM2e6Hi3Nskk6G9t4r26nFVM=
   allowed ips: 192.0.2.2/32, 2001:db8:1::2/128
   ``

   To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.

2. Display the IP configuration of the wg0 device:

   ```bash
   # ip address show wg0
   20: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state
   UNKNOWN group default qlen 1000
   link/none
   ```
inet 192.0.2.1/24 brd 192.0.2.255 scope global noprefixroute wg0  
valid_lft forever preferred_lft forever
inet6 2001:db8:1::1/32 scope global noprefixroute  
valid_lft forever preferred_lft forever
inet6 fe80::3ef:8863:1ce2:844/64 scope link noprefixroute  
valid_lft forever preferred_lft forever

Additional resources

- The **wg(8)** man page

### 12.8. CONFIGURING A WIREGUARD SERVER USING THE WG-QUICK SERVICE

You can configure the WireGuard server by creating a configuration file in the `/etc/wireguard/` directory. Use this method to configure the service independently from NetworkManager.

This procedure assumes the following settings:

- **Server:**
  - Private key: YFAnE0psgIdiAF7XR4abxiwVRnlMfetxu10s/c4JXg=
  - Tunnel IPv4 address: 192.0.2.1/24
  - Tunnel IPv6 address: 2001:db8:1::1/32

- **Client:**
  - Public key: bnwfQcC8/g2i4vvcRUM2e6Hi3Nskk6G9t4r26nFVM=  
  - Tunnel IPv4 address: 192.0.2.2/24
  - Tunnel IPv6 address: 2001:db8:1::2/32

**Prerequisites**

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the server
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the client
  - The static tunnel IP addresses and subnet masks of the server

**Procedure**

1. Install the **wireguard-tools** package:

   ```bash
   # dnf install wireguard-tools
   ```
2. Create the /etc/wireguard/wg0.conf file with the following content:

```
[Interface]
Address = 192.0.2.1/24, 2001:db8:1::1/32
ListenPort = 51820
PrivateKey = YFAnE0psgIdiAF7XR4abxiwVRnlMfetxu10s/c4JXg=

[Peer]
PublicKey = bnwfQcC8/g2i4vvEqcRUM2e6Hi3Nsok6G9t4r26nFVM=
AllowedIPs = 192.0.2.2, 2001:db8:1::2
```

- The [Interface] section describes the WireGuard settings of the interface on the server:
  - **Address**: A comma-separated list of the server’s tunnel IP addresses.
  - **PrivateKey**: The private key of the server.
  - **ListenPort**: The port on which WireGuard listens for incoming UDP connections.
    - Always set a fixed port number on hosts that receive incoming WireGuard connections.
    - If you do not set a port, WireGuard uses a random free port each time you activate the `wg0` interface.

- Each [Peer] section describes the settings of one client:
  - **PublicKey**: The public key of the client.
  - **AllowedIPs**: The tunnel IP addresses of the client that are allowed to send data to this server.

3. Enable and start the WireGuard connection:

```
# systemctl enable --now wg-quick@wg0
```

The systemd instance name must match the name of the configuration file in the /etc/wireguard/ directory without the .conf suffix. The service also uses this name for the virtual network interface.

**Next steps**

- Configure the firewall service on the WireGuard server.

**Verification**

1. Display the interface configuration of the `wg0` device:

```
# wg show wg0
interface: wg0
  public key: UtjqCJ57DeAscYKRfp7cFGiQqdONRn69u249Fa4O6BE=
  private key: (hidden)
  listening port: 51820

peer: bnwfQcC8/g2i4vvEqcRUM2e6Hi3Nsok6G9t4r26nFVM=
  allowed ips: 192.0.2.2/32, 2001:db8:1::2/128
```

To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.
2. Display the IP configuration of the \texttt{wg0} device:

```
# ip address show wg0
20: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state
UNKNOWN group default qlen 1000
  link/no
  inet 192.0.2.1/24 scope global wg0
    valid_lft forever preferred_lft forever
  inet6 2001:db8:1::1/32 scope global
    valid_lft forever preferred_lft forever
```

Additional resources

- The \texttt{wg(8)} man page
- The \texttt{wg-quick(8)} man page

12.9. CONFIGURING FIREWALLD ON A WIREGUARD SERVER USING THE COMMAND LINE

You must configure the \texttt{firewalld} service on the WireGuard server to allow incoming connections from clients. Additionally, if clients should be able to use the WireGuard server as the default gateway and route all traffic through the tunnel, you must enable masquerading.

Procedure

1. Open the WireGuard port for incoming connections in the \texttt{firewalld} service:

   ```
   # firewall-cmd --permanent --add-port=51820/udp --zone=public
   ```

2. If clients should route all traffic through the tunnel and use the WireGuard server as the default gateway, enable masquerading for the \texttt{public} zone:

   ```
   # firewall-cmd --permanent --zone=public --add-masquerade
   ```

3. Reload the \texttt{firewalld} rules.

   ```
   # firewall-cmd --reload
   ```

Verification

- Display the configuration of the \texttt{public} zone:

   ```
   # firewall-cmd --list-all
   public (active)
   ...  
   ports: 51820/udp
   masquerade: yes
   ...  
   ```

Additional resources
12.10. CONFIGURING FIREWALLD ON A WIREGUARD SERVER USING THE GRAPHICAL INTERFACE

You must configure the `firewalld` service on the WireGuard server to allow incoming connections from clients. Additionally, if clients should be able to use the WireGuard server as the default gateway and route all traffic through the tunnel, you must enable masquerading.

Procedure

1. Press the Super key, enter `firewall`, and select the Firewall application from the results.
2. Select Permanent in the Configuration list.
3. Select the public zone.
4. Allow incoming connections to the WireGuard port:
   a. On the Ports tab, click Add.
   b. Enter the port number you set for incoming WireGuard connections:
   c. Select udp from the Protocol list.
   d. Click OK.
5. If clients should route all traffic through the tunnel and use the WireGuard server as the default gateway:
   a. Navigate to the Masquerading tab of the public zone.
   b. Select Masquerade zone.
6. Select Options → Reload Firewalld.

Verification

- Display the configuration of the public zone:

  ```
  # firewall-cmd --list-all
  public (active)
  ... ports: 51820/udp masquerade: yes ...
  ```

12.11. CONFIGURING A WIREGUARD CLIENT USING NMCLI

You can configure a WireGuard client by creating a connection profile in NetworkManager. Use this method to let NetworkManager manage the WireGuard connection.

This procedure assumes the following settings:

- Client:
- Private key: aPUcp5vHz8yMLrzk8SsDyYnV33IhE/k20e52lKJFV0A=
- Tunnel IPv4 address: 192.0.2.2/24
- Tunnel IPv6 address: 2001:db8:1::2/32

- Server:
  - Public key: UtjqCJ57DeAscYKRfp7cFGiQqdONRn69u249Fa4O6BE=
  - Tunnel IPv4 address: 192.0.2.1/24
  - Tunnel IPv6 address: 2001:db8:1::1/32

**Prerequisites**

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the client
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the server
  - The static tunnel IP addresses and subnet masks of the server

**Procedure**

1. Add a NetworkManager WireGuard connection profile:

   ```
   # nmcli connection add type wireguard con-name client-wg0 ifname wg0 autoconnect no
   ```

   This command creates a profile named `client-wg0` and assigns the virtual interface `wg0` to it. To prevent the connection from starting automatically after you add it without finalizing the configuration, disable the `autoconnect` parameter.

2. Optional: Configure NetworkManager so that it does not automatically start the `client-wg` connection:

   ```
   # nmcli connection modify client-wg0 autoconnect no
   ```

3. Set the tunnel IPv4 address and subnet mask of the client:

   ```
   # nmcli connection modify client-wg0 ipv4.method manual ipv4.addresses 192.0.2.2/24
   ```

4. Set the tunnel IPv6 address and subnet mask of the client:

   ```
   # nmcli connection modify client-wg0 ipv6.method manual ipv6.addresses 2001:db8:1::2/32
   ```

5. If you want to route all traffic through the tunnel, set the tunnel IP addresses of the server as the default gateway:
6. Add the server’s private key to the connection profile:

```
# nmcli connection modify client-wg0 wireguard.private-key "aPUcp5vHz2yMLrzk8SsDyYnV33IhE/k20e52IkJFV0A="
```

a. Edit the `/etc/NetworkManager/system-connections/client-wg0.nmconnection` file, and append:

```
[wireguard-peer.<public_key_of_the_server>]
endpoint=server.example.com:51820
allowed-ips=192.0.2.1;2001:db8:1::1;
persistent-keepalive=20
```

- The `[wireguard-peer.<public_key_of_the_server>]` entry defines the peer section of the server, and the section name contains the public key of the server.

- The `endpoint` parameter sets the hostname or IP address and the port of the server. The client uses this information to establish the connection.

- The `allowed-ips` parameter sets a list of IP addresses that are allowed to send data to this client. For example, set the parameter to:
  - The tunnel IP addresses of the server to allow only the server to communicate with this client. The value in the example above configures this scenario.
  - `0.0.0.0/0;::/0;` to allow any remote IPv4 and IPv6 address to communicate with this client. Use this setting to route all traffic through the tunnel and use the WireGuard server as default gateway.

- The optional `persistent-keepalive` parameter defines an interval in seconds in which WireGuard sends a keepalive packet to the server. Set this parameter if you use the client in a network with network address translation (NAT) or if a firewall closes the UDP connection after some time of inactivity.

b. Reload the `client-wg0` connection profile:

```
# nmcli connection load /etc/NetworkManager/system-connections/client-wg0.nmconnection
```

7. Reactivate the `client-wg0` connection:

```
# nmcli connection up client-wg0
```

Verification

1. Ping the IP addresses of the server:

```
# ping 192.0.2.1
# ping6 2001:db8:1::1
```

2. Display the interface configuration of the `wg0` device:
To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.

Note that the output contains only the latest handshake and transfer entries if you have already sent traffic through the VPN tunnel.

3. Display the IP configuration of the `wg0` device:

```bash
# ip address show wg0
10: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state unknown group default qlen 1000
    link/none
    inet 192.0.2.2/24 brd 192.0.2.255 scope global noprefixroute wg0
        valid_lft forever preferred_lft forever
    inet6 2001:db8:1::2/32 scope global noprefixroute
        valid_lft forever preferred_lft forever
    inet6 fe80::73d9:6f51:ea6f:863e/64 scope link noprefixroute
        valid_lft forever preferred_lft forever
```

Additional resources

- The `wg(8)` man page
- The `WireGuard setting` section in the `nm-settings(5)` man page

### 12.12. CONFIGURING A WIREGUARD CLIENT USING NMTUI

You can configure a WireGuard client by creating a connection profile in NetworkManager. Use this method to let NetworkManager manage the WireGuard connection.

This procedure assumes the following settings:

- Client:
  - Private key: `aPUcp5vHz8yMLrzk8SsDyYnV33IhE/k20e52iKJFV0A=`
  - Tunnel IPv4 address: `192.0.2.2/24`
  - Tunnel IPv6 address: `2001:db8:1::2/32`
- Server:
Prerequisites

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the client
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the server
  - The static tunnel IP addresses and subnet masks of the server
- You installed the **NetworkManager-tui** package

Procedure

1. Start the `nmtui` application:

   ```
   # nmtui
   ```

2. Select **Edit a connection**, and press **Enter**.

3. Select **Add**, and press **Enter**.

4. Select the **WireGuard** connection type in the list, and press **Enter**.

5. In the **Edit connection** window:

   a. Enter the name of the connection and the virtual interface, such as **wg0**, that NetworkManager should assign to the connection.

   b. Enter the private key of the client.

   ![Edit Connection Window]

   c. Click **Add** next to the **Peers** pane:

      i. Enter the public key of the server.

      ii. Set the **Allowed IPs** field. For example, set it to:
- The tunnel IP addresses of the server to allow only the server to communicate with this client.

- 0.0.0.0/0,::/0 to allow any remote IPv4 and IPv6 address to communicate with this client. Use this setting to route all traffic through the tunnel and use the WireGuard server as default gateway.

iii. Enter the host name or IP address and port of the WireGuard server into the **Endpoint** field. Use the following format: *hostname_or_IP:port_number*

iv. Optional: If you use the client in a network with network address translation (NAT) or if a firewall closes the UDP connection after some time of inactivity, set a persistent keep alive interval in seconds. In this interval, the client sends a keepalive packet to the server.

v. Select **OK**, and press **Enter**.

![](image)

- Select **Show** next to **IPv4 Configuration**, and press **Enter**.
  
i. Select the IPv4 configuration method **Manual**.

  ii. Enter the tunnel IPv4 address and the subnet mask. Leave the **Gateway** field empty.

- Select **Show** next to **IPv6 Configuration**, and press **Enter**.
  
i. Select the IPv6 configuration method **Manual**.

  ii. Enter the tunnel IPv6 address and the subnet mask. Leave the **Gateway** field empty.

- Optional: Select **Automatically connect**.

- Select **OK**, and press **Enter**
6. In the window with the list of connections, select **Back**, and press **Enter**.

7. In the **NetworkManager TUI** main window, select **Quit**, and press **Enter**.

**Verification**

1. Ping the IP addresses of the server:

   ```
   # ping 192.0.2.1
   # ping6 2001:db8:1::1
   ```

2. Display the interface configuration of the **wg0** device:

   ```
   # wg show wg0
   interface: wg0
   public key: bnwfOcC8/g2i4vvEqcRUM2e6Hi3Nskk6G9t4r26nFVM=
   private key: (hidden)
   listening port: 51820
   peer: UtjqCJ57DeAsYK7Rh7cFGiQqONRn69u249Fa406BE=
   endpoint: server.example.com:51820
   allowed ips: 192.0.2.1/32, 2001:db8:1::1/128
   latest handshake: 1 minute, 41 seconds ago
   transfer: 824 B received, 1.01 KiB sent
   persistent keepalive: every 20 seconds
   ```
To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.

Note that the output contains only the latest handshake and transfer entries if you have already sent traffic through the VPN tunnel.

3. Display the IP configuration of the `wg0` device:

```shell
# ip address show wg0
10: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state UNKNOWN group default qlen 1000
link/none
inet 192.0.2.2/24 brd 192.0.2.255 scope global noprefixroute wg0
   valid_lft forever preferred_lft forever
inet6 2001:db8:1::2/32 scope global noprefixroute
   valid_lft forever preferred_lft forever
inet6 fe80::73d9:6f51:ea6f:863e/64 scope link noprefixroute
   valid_lft forever preferred_lft forever
```

Additional resources

- The `wg(8)` man page

12.13. CONFIGURING A WIREGUARD CLIENT USING NM-CONNECTION-EDITOR

You can configure a WireGuard client by creating a connection profile in NetworkManager. Use this method to let NetworkManager manage the WireGuard connection.

Prerequisites

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the client
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the server
  - The static tunnel IP addresses and subnet masks of the server

Procedure

1. Open a terminal, and enter:

```
# nm-connection-editor
```

2. Add a new connection by clicking the `+` button.

3. Select the WireGuard connection type, and click Create.

4. Optional: Update the connection name.
5. Optional: On the **General** tab, select **Connect automatically with priority**.

6. On the **WireGuard** tab:
   a. Enter the name of the virtual interface, such as **wg0**, that NetworkManager should assign to the connection.
   b. Enter client’s private key.
   c. Click **Add** to add peers:
      i. Enter the public key of the server.
      ii. Set the **Allowed IPs** field. For example, set it to:
         - The tunnel IP addresses of the server to allow only the server to communicate with this client.
         - **0.0.0.0/0::/0**; to allow any remote IPv4 and IPv6 address to communicate with this client. Use this setting to route all traffic through the tunnel and use the WireGuard server as default gateway.
      iii. Enter the hostname or IP address and port of the WireGuard server into the **Endpoint** field. Use the following format: **hostname_or_IP:port_number**
      iv. Optional: If you use the client in a network with network address translation (NAT) or if a firewall closes the UDP connection after some time of inactivity, set a persistent keep alive interval in seconds. In this interval, the client sends a keepalive packet to the server.
   v. Click **Apply**.

7. On the **IPv4 Settings** tab:
   a. Select **Manual** in the **Method** list.
   b. Click **Add** to enter the tunnel IPv4 address and the subnet mask.
   c. If you want to route all traffic through the tunnel, set the tunnel IPv4 address of the server in the **Gateway** field. Otherwise, leave the field empty.

8. On the **IPv6 Settings** tab:
   a. Select **Manual** in the **Method** list.
   b. Click **Add** to enter the tunnel IPv6 address and the subnet mask.
   c. If you want to route all traffic through the tunnel, set the tunnel IPv6 address of the server in the **Gateway** field. Otherwise, leave the field empty.

9. Click **Save** to store the connection profile.

**Verification**

1. Ping the IP addresses of the server:

   ```
   # ping 192.0.2.1
   # ping6 2001:db8:1::1
   ```
2. Display the interface configuration of the `wg0` device:

```
# wg show wg0
interface: wg0
   public key: bnwfQcC8/g2i4vvEqcRUM2e6Hi3Nskk6G9t4r26nFVM=
   private key: (hidden)
   listening port: 51820

peer: UtjqCJ57DeAscYKRtp7cFGiQqdONRn69u249Fa4O6BE=
   endpoint: server.example.com:51820
allowed ips: 192.0.2.1/32, 2001:db8:1::1/128
latest handshake: 1 minute, 41 seconds ago
transfer: 824 B received, 1.01 KiB sent
persistent keepalive: every 20 seconds
```

To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.

Note that the output only contains the latest handshake and transfer entries if you have already sent traffic through the VPN tunnel.

3. Display the IP configuration of the `wg0` device:

```
# ip address show wg0
10: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state UNKNOWN group default qlen 1000
   link/none
   inet 192.0.2.2/24 brd 192.0.2.255 scope global noprefixroute wg0
      valid_lft forever preferred_lft forever
   inet6 2001:db8:1::2/32 scope global noprefixroute
      valid_lft forever preferred_lft forever
   inet6 fe80::73d9:6f51:ea6f:863e/64 scope link noprefixroute
      valid_lft forever preferred_lft forever
```

Additional resources

- The `wg(8)` man page

### 12.14. CONFIGURING A WIREGUARD CLIENT USING THE WG-QUICK SERVICE

You can configure a WireGuard client by creating a configuration file in the `/etc/wireguard/` directory. Use this method to configure the service independently from NetworkManager.

This procedure assumes the following settings:

- **Client:**
  - Private key: `aPUcp5vHtz8yMLrzk8SsDyYnV33IhE/k20e52iKJFV0A=
  - Tunnel IPv4 address: `192.0.2.2/24`
  - Tunnel IPv6 address: `2001:db8:1::2/32`

- **Server:**
- Public key: `UtjqCJ57DeAscYKRfp7cFGiQqdONRn69u249Fa4O6BE=`
- Tunnel IPv4 address: `192.0.2.1/24`
- Tunnel IPv6 address: `2001:db8:1::1/32`

**Prerequisites**

- You have generated the public and private key for both the server and client.
- You know the following information:
  - The private key of the client
  - The static tunnel IP addresses and subnet masks of the client
  - The public key of the server
  - The static tunnel IP addresses and subnet masks of the server

**Procedure**

1. Install the `wireguard-tools` package:

   ```bash
   # dnf install wireguard-tools
   ```

2. Create the `/etc/wireguard/wg0.conf` file with the following content:

   ```
   [Interface]
   Address = 192.0.2.2/24, 2001:db8:1::2/32
   PrivateKey = aPUcp5vHz8yMLrzk8SsDyYnV33ihE/k20e52iKJFV0A=

   [Peer]
   PublicKey = UtjqCJ57DeAscYKRfp7cFGiQqdONRn69u249Fa4O6BE=
   AllowedIPs = 192.0.2.1, 2001:db8:1::1
   Endpoint = server.example.com:51820
   PersistentKeepalive = 20
   ```

- The `[Interface]` section describes the WireGuard settings of the interface on the client:
  - **Address**: A comma-separated list of the client’s tunnel IP addresses.
  - **PrivateKey**: The private key of the client.

- The `[Peer]` section describes the settings of the server:
  - **PublicKey**: The public key of the server.
  - **AllowedIPs**: The IP addresses that are allowed to send data to this client. For example, set the parameter to:
    - The tunnel IP addresses of the server to allow only the server to communicate with this client. The value in the example above configures this scenario.
- **0.0.0.0/0, ::/0** to allow any remote IPv4 and IPv6 address to communicate with this client. Use this setting to route all traffic through the tunnel and use the WireGuard server as default gateway.

- **Endpoint**: Sets the hostname or IP address and the port of the server. The client uses this information to establish the connection.

- The optional **persistent-keepalive** parameter defines an interval in seconds in which WireGuard sends a keepalive packet to the server. Set this parameter if you use the client in a network with network address translation (NAT) or if a firewall closes the UDP connection after some time of inactivity.

3. Enable and start the WireGuard connection:

   ```
   # systemctl enable --now wg-quick@wg0
   ```

   The systemd instance name must match the name of the configuration file in the `/etc/wireguard/` directory without the `.conf` suffix. The service also uses this name for the virtual network interface.

**Verification**

1. Ping the IP addresses of the server:

   ```
   # ping 192.0.2.1
   # ping6 2001:db8:1::1
   ```

2. Display the interface configuration of the `wg0` device:

   ```
   # wg show wg0
   interface: wg0
   public key: bnfWQcC8/g2i4vvEqcRUM2e6Hl3Nskk6G9t4r26nFVM=
   private key: (hidden)
   listening port: 51820
   peer: UtjqCJ57DeAscYKRfp7cFGiQqdONRn69u249Fa4O6BE=
   endpoint: server.example.com:51820
   allowed ips: 192.0.2.1/32, 2001:db8:1::1/128
   latest handshake: 1 minute, 41 seconds ago
   transfer: 824 B received, 1.01 KiB sent
   persistent keepalive: every 20 seconds
   ```

   To display the private key in the output, use the `WG_HIDE_KEYS=never wg show wg0` command.

   Note that the output contains only the **latest handshake** and **transfer** entries if you have already sent traffic through the VPN tunnel.

3. Display the IP configuration of the `wg0` device:

   ```
   # ip address show wg0
   10: wg0: <POINTOPOINT,NOARP,UP,LOWER_UP> mtu 1420 qdisc noqueue state
   UNKNOWN group default qlen 1000
   link/none
   inet 192.0.2.2/24 scope global wg0
   ```
Valid LFT forever Preferred LFT forever
inet6 2001:db8:1::2/32__ scope global
Valid LFT forever Preferred LFT forever

Additional resources

- The `wg(8)` man page
- The `wg-quick(8)` man page
CHAPTER 13. CONFIGURING A VPN CONNECTION

This section explains how to configure a virtual private network (VPN) connection.

A VPN is a way of connecting to a local network over the Internet. **IPsec** provided by **Libreswan** is the preferred method for creating a VPN. **Libreswan** is a user-space **IPsec** implementation for VPN. A VPN enables the communication between your LAN, and another, remote LAN by setting up a tunnel across an intermediate network such as the Internet. For security reasons, a VPN tunnel always uses authentication and encryption. For cryptographic operations, **Libreswan** uses the **NSS** library.

13.1. CONFIGURING A VPN CONNECTION WITH CONTROL-CENTER

This procedure describes how to configure a VPN connection using **control-center**.

**Prerequisites**

- The **NetworkManager-libreswan-gnome** package is installed.

**Procedure**

1. Press the **Super** key, type **Settings**, and press **Enter** to open the **control-center** application.

2. Select the **Network** entry on the left.

3. Click the + icon.

4. Select **VPN**.

5. Select the **Identity** menu entry to see the basic configuration options:
   - **General**

   **Gateway** – The name or **IP** address of the remote VPN gateway.

   **Authentication**

   **Type**

   - **IKEv2 (Certificate)** - client is authenticated by certificate. It is more secure (default).

   - **IKEv1 (XAUTH)** - client is authenticated by user name and password, or a pre-shared key (PSK).

   The following configuration settings are available under the **Advanced** section:
Figure 13.1. Advanced options of a VPN connection

<table>
<thead>
<tr>
<th>IPsec Advanced Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identification</strong></td>
</tr>
<tr>
<td>Domain:</td>
</tr>
<tr>
<td><strong>Security</strong></td>
</tr>
<tr>
<td>Phase1 Algorithms:</td>
</tr>
<tr>
<td>Phase2 Algorithms:</td>
</tr>
<tr>
<td>Disable PFS</td>
</tr>
<tr>
<td>Phase1 Lifetime:</td>
</tr>
<tr>
<td>Phase2 Lifetime:</td>
</tr>
<tr>
<td>Disable rekeying</td>
</tr>
<tr>
<td><strong>Connectivity</strong></td>
</tr>
<tr>
<td>Remote Network:</td>
</tr>
<tr>
<td>narrowing</td>
</tr>
<tr>
<td>Enable fragmentation:  yes</td>
</tr>
<tr>
<td>Enable MOBIKE:         no</td>
</tr>
</tbody>
</table>

Apply
WARNING

When configuring an IPsec-based VPN connection using the `gnome-control-center` application, the `Advanced` dialog displays the configuration, but it does not allow any changes. As a consequence, users cannot change any advanced IPsec options. Use the `nm-connection-editor` or `nmcli` tools instead to perform configuration of the advanced properties.

Identification

- **Domain** – If required, enter the Domain Name.

Security

- **Phase1 Algorithms** – corresponds to the `ike` Libreswan parameter – enter the algorithms to be used to authenticate and set up an encrypted channel.

- **Phase2 Algorithms** – corresponds to the `esp` Libreswan parameter – enter the algorithms to be used for the IPsec negotiations. Check the `Disable PFS` field to turn off Perfect Forward Secrecy (PFS) to ensure compatibility with old servers that do not support PFS.

- **Phase1 Lifetime** – corresponds to the `ikelifetime` Libreswan parameter – how long the key used to encrypt the traffic will be valid.

- **Phase2 Lifetime** – corresponds to the `salifetime` Libreswan parameter – how long a particular instance of a connection should last before expiring. Note that the encryption key should be changed from time to time for security reasons.

- **Remote network** – corresponds to the `rightsubnet` Libreswan parameter – the destination private remote network that should be reached through the VPN. Check the `narrowing` field to enable narrowing. Note that it is only effective in IKEv2 negotiation.

- **Enable fragmentation** – corresponds to the `fragmentation` Libreswan parameter – whether or not to allow IKE fragmentation. Valid values are `yes` (default) or `no`.

- **Enable Mobike** – corresponds to the `mobike` Libreswan parameter – whether to allow Mobility and Multihoming Protocol (MOBIKE, RFC 4555) to enable a connection to migrate its endpoint without needing to restart the connection from scratch. This is used on mobile devices that switch between wired, wireless, or mobile data connections. The values are `no` (default) or `yes`.

6. Select the **IPv4** menu entry:

   **IPv4 Method**

   - **Automatic (DHCP)** – Choose this option if the network you are connecting to uses a DHCP server to assign dynamic IP addresses.

   - **Link-Local Only** – Choose this option if the network you are connecting to does not have a DHCP server and you do not want to assign IP addresses manually. Random addresses will be assigned as per RFC 3927 with prefix 169.254/16.
• **Manual** – Choose this option if you want to assign IP addresses manually.

• **Disable** – IPv4 is disabled for this connection.

**DNS**

In the DNS section, when **Automatic** is **ON**, switch it to **OFF** to enter the IP address of a DNS server you want to use separating the IPs by comma.

**Routes**

Note that in the Routes section, when **Automatic** is **ON**, routes from DHCP are used, but you can also add additional static routes. When **OFF**, only static routes are used.

• **Address** – Enter the IP address of a remote network or host.

• **Netmask** – The netmask or prefix length of the IP address entered above.

• **Gateway** – The IP address of the gateway leading to the remote network or host entered above.

• **Metric** – A network cost, a preference value to give to this route. Lower values will be preferred over higher values.

**Use this connection only for resources on its network**

Select this check box to prevent the connection from becoming the default route. Selecting this option means that only traffic specifically destined for routes learned automatically over the connection or entered here manually is routed over the connection.

7. To configure IPv6 settings in a VPN connection, select the IPv6 menu entry:

**IPv6 Method**

• **Automatic** – Choose this option to use IPv6 Stateless Address AutoConfiguration (SLAAC) to create an automatic, stateless configuration based on the hardware address and Router Advertisements (RA).

• **Automatic, DHCP only** – Choose this option to not use RA, but request information from DHCPv6 directly to create a stateful configuration.

• **Link-Local Only** – Choose this option if the network you are connecting to does not have a DHCP server and you do not want to assign IP addresses manually. Random addresses will be assigned as per **RFC 4862** with prefix **FE80::0**.

• **Manual** – Choose this option if you want to assign IP addresses manually.

• **Disable** – IPv6 is disabled for this connection.

Note that DNS, Routes, **Use this connection only for resources on its network** are common to IPv4 settings.

8. Once you have finished editing the VPN connection, click the **Add** button to customize the configuration or the **Apply** button to save it for the existing one.

9. Switch the profile to **ON** to activate the VPN connection.

**Additional resources**

• **nm-settings-libreswan(5)**
13.2. CONFIGURING A VPN CONNECTION USING NM-CONNECTION-EDITOR

This procedure describes how to configure a VPN connection using **nm-connection-editor**.

**Prerequisites**

- The **NetworkManager-libreswan-gnome** package is installed.
- If you configure an Internet Key Exchange version 2 (IKEv2) connection:
  - The certificate is imported into the IPsec network security services (NSS) database.
  - The nickname of the certificate in the NSS database is known.

**Procedure**

1. Open a terminal, and enter:

```
$ nm-connection-editor
```

2. Click the **+** button to add a new connection.

3. Select the **IPsec based VPN** connection type, and click **Create**.

4. On the **VPN** tab:

   a. Enter the host name or IP address of the VPN gateway into the **Gateway** field, and select an authentication type. Based on the authentication type, you must enter different additional information:

      - **IKEv2 (Certificate)** authenticates the client by using a certificate, which is more secure. This setting requires the nickname of the certificate in the IPsec NSS database.
      - **IKEv1 (XAUTH)** authenticates the user by using a user name and password (pre-shared key). This setting requires that you enter the following values:
        - User name
        - Password
        - Group name
        - Secret

   b. If the remote server specifies a local identifier for the IKE exchange, enter the exact string in the **Remote ID** field. In the remote server runs Libreswan, this value is set in the server’s **leftid** parameter.
c. Optionally, configure additional settings by clicking the Advanced button. You can configure the following settings:

- Identification
  - Domain – If required, enter the domain name.

- Security
  - Phase 1 Algorithms corresponds to the ike Libreswan parameter. Enter the algorithms to be used to authenticate and set up an encrypted channel.
  
  - Phase 2 Algorithms corresponds to the esp Libreswan parameter. Enter the algorithms to be used for the IPsec negotiations. Check the Disable PFS field to turn off Perfect Forward Secrecy (PFS) to ensure compatibility with old servers that do not support PFS.

  - Phase 1 Lifetime corresponds to the ike lifetime Libreswan parameter. This parameter defines how long the key used to encrypt the traffic is valid.

  - Phase 2 Lifetime corresponds to the salifetime Libreswan parameter. This parameter defines how long a security association is valid.

- Connectivity
- **Remote network** corresponds to the `rightsubnet` Libreswan parameter and defines the destination private remote network that should be reached through the VPN. Check the narrowing field to enable narrowing. Note that it is only effective in the IKEv2 negotiation.

- **Enable fragmentation** corresponds to the `fragmentation` Libreswan parameter and defines whether or not to allow IKE fragmentation. Valid values are **yes** (default) or **no**.

- **Enable Mobike** corresponds to the `mobike` Libreswan parameter. The parameter defines whether to allow Mobility and Multihoming Protocol (MOBIKE) (RFC 4555) to enable a connection to migrate its endpoint without needing to restart the connection from scratch. This is used on mobile devices that switch between wired, wireless or mobile data connections. The values are **no** (default) or **yes**.

5. On the **IPv4 Settings** tab, select the IP assignment method and, optionally, set additional static addresses, DNS servers, search domains, and routes.

6. Save the connection.

7. Close *nm-connection-editor*.

**NOTE**

When you add a new connection by clicking the + button, *NetworkManager* creates a new configuration file for that connection and then opens the same dialog that is used for editing an existing connection. The difference between these dialogs is that an existing connection profile has a **Details** menu entry.

Additional resources

- *nm-settings-libreswan(5)* man page
13.3. CONFIGURING AUTOMATIC DETECTION AND USAGE OF ESP HARDWARE OFFLOAD TO ACCELERATE AN IPSEC CONNECTION

Offloading Encapsulating Security Payload (ESP) to the hardware accelerates IPsec connections over Ethernet. By default, Libreswan detects if hardware supports this feature and, as a result, enables ESP hardware offload. This procedure describes how to enable the automatic detection in case that the feature was disabled or explicitly enabled.

Prerequisites

- The network card supports ESP hardware offload.
- The network driver supports ESP hardware offload.
- The IPsec connection is configured and works.

Procedure

1. Edit the Libreswan configuration file in the `/etc/ipsec.d/` directory of the connection that should use automatic detection of ESP hardware offload support.

2. Ensure the `nic-offload` parameter is not set in the connection’s settings.

3. If you removed `nic-offload`, restart the `ipsec` service:

```
# systemctl restart ipsec
```

Verification

If the network card supports ESP hardware offload support, following these steps to verify the result:

1. Display the `tx_ipsec` and `rx_ipsec` counters of the Ethernet device the IPsec connection uses:

```
# ethtool -S enp1s0 | egrep "_ipsec"
  tx_ipsec: 10
  rx_ipsec: 10
```

2. Send traffic through the IPsec tunnel. For example, ping a remote IP address:

```
# ping -c 5 remote_ip_address
```

3. Display the `tx_ipsec` and `rx_ipsec` counters of the Ethernet device again:

```
# ethtool -S enp1s0 | egrep "_ipsec"
  tx_ipsec: 15
  rx_ipsec: 15
```

If the counter values have increased, ESP hardware offload works.

Additional resources

- Configuring a VPN with IPsec
13.4. CONFIGURING ESP HARDWARE OFFLOAD ON A BOND TO ACCELERATE AN IPSEC CONNECTION

Offloading Encapsulating Security Payload (ESP) to the hardware accelerates IPsec connections. If you use a network bond for fail-over reasons, the requirements and the procedure to configure ESP hardware offload are different from those using a regular Ethernet device. For example, in this scenario, you enable the offload support on the bond, and the kernel applies the settings to the ports of the bond.

Prerequisites

- All network cards in the bond support ESP hardware offload.
- The network driver supports ESP hardware offload on a bond device. In RHEL, only the ixgbe driver supports this feature.
- The bond is configured and works.
- The bond uses the active-backup mode. The bonding driver does not support any other modes for this feature.
- The IPsec connection is configured and works.

Procedure

1. Enable ESP hardware offload support on the network bond:
   
   ```bash
   # nmcli connection modify bond0 ethtool.feature-esp-hw-offload on
   ```
   
   This command enables ESP hardware offload support on the bond0 connection.

2. Reactivate the bond0 connection:
   
   ```bash
   # nmcli connection up bond0
   ```

3. Edit the Libreswan configuration file in the `/etc/ipsec.d/` directory of the connection that should use ESP hardware offload, and append the `nic-offload=yes` statement to the connection entry:
   
   ```
   conn example
   ...
   nic-offload=yes
   ```

4. Restart the ipsec service:
   
   ```bash
   # systemctl restart ipsec
   ```

Verification

1. Display the active port of the bond:
   
   ```bash
   # grep "Currently Active Slave" /proc/net/bonding/bond0
   Currently Active Slave: enp1s0
   ```

2. Display the `tx_ipsec` and `rx_ipsec` counters of the active port:
3. Send traffic through the IPsec tunnel. For example, ping a remote IP address:

```
# ping -c 5 remote_ip_address
```

4. Display the tx_ipsec and rx_ipsec counters of the active port again:

```
# ethtool -S enp1s0 | egrep "_ipsec"
  tx_ipsec: 15
  rx_ipsec: 15
```

If the counter values have increased, ESP hardware offload works.

Additional resources

- Configuring network bonding
- The Configuring a VPN with IPsec section in the Securing networks documentation
- Configuring a VPN with IPsec chapter in the Securing networks document.
CHAPTER 14. CONFIGURING IP TUNNELS

Similar to a VPN, an IP tunnel directly connects two networks over a third network, such as the Internet. However, not all tunnel protocols support encryption.

The routers in both networks that establish the tunnel requires at least two interfaces:

- One interface that is connected to the local network
- One interface that is connected to the network through which the tunnel is established.

To establish the tunnel, you create a virtual interface on both routers with an IP address from the remote subnet.

NetworkManager supports the following IP tunnels:

- Generic Routing Encapsulation (GRE)
- Generic Routing Encapsulation over IPv6 (IP6GRE)
- Generic Routing Encapsulation Terminal Access Point (GRETAP)
- Generic Routing Encapsulation Terminal Access Point over IPv6 (IP6GRETAP)
- IPv4 over IPv4 (IPIP)
- IPv4 over IPv6 (IPIPv6)
- IPv6 over IPv6 (IP6IP6)
- Simple Internet Transition (SIT)

Depending on the type, these tunnels act either on layer 2 or 3 of the Open Systems Interconnection (OSI) model.

14.1. CONFIGURING AN IPIP TUNNEL USING NMCLI TO ENCAPSULATE IPV4 TRAFFIC IN IPV4 PACKETS

An IP over IP (IPIP) tunnel operates on OSI layer 3 and encapsulates IPv4 traffic in IPv4 packets as described in RFC 2003.

IMPORTANT

Data sent through an IPIP tunnel is not encrypted. For security reasons, use the tunnel only for data that is already encrypted, for example, by other protocols, such as HTTPS.

Note that IPIP tunnels support only unicast packets. If you require an IPv4 tunnel that supports multicast, see Configuring a GRE tunnel using nmcli to encapsulate layer-3 traffic in IPv4 packets.

This procedure describes how to create an IPIP tunnel between two RHEL routers to connect two internal subnets over the Internet as shown in the following diagram:
Prerequisites

- Each RHEL router has a network interface that is connected to its local subnet.
- Each RHEL router has a network interface that is connected to the Internet.
- The traffic you want to send through the tunnel is IPv4 unicast.

Procedure

1. On the RHEL router in network A:
   a. Create an IPIP tunnel interface named tun0:
      
      ```
      # nmcli connection add type ip-tunnel ip-tunnel.mode ipip con-name tun0 ifname tun0 remote 198.51.100.5 local 203.0.113.10
      ```
      
      The **remote** and **local** parameters set the public IP addresses of the remote and the local routers.

   b. Set the IPv4 address to the **tun0** device:
      
      ```
      # nmcli connection modify tun0 ipv4.addresses '10.0.1.1/30'
      ```
      
      Note that a /30 subnet with two usable IP addresses is sufficient for the tunnel.

   c. Configure the **tun0** connection to use a manual IPv4 configuration:
      
      ```
      # nmcli connection modify tun0 ipv4.method manual
      ```

   d. Add a static route that routes traffic to the **172.16.0.0/24** network to the tunnel IP on router B:
      
      ```
      # nmcli connection modify tun0 +ipv4.routes "172.16.0.0/24 10.0.1.2"
      ```

   e. Enable the **tun0** connection.
# nmcli connection up tun0

f. Enable packet forwarding:

```
  # echo "net.ipv4.ip_forward=1" > /etc/sysctl.d/95-IPv4-forwarding.conf
  # sysctl -p /etc/sysctl.d/95-IPv4-forwarding.conf
```

2. On the RHEL router in network B:
   a. Create an IPIP tunnel interface named **tun0**:

```
  # nmcli connection add type ip-tunnel ip-tunnel.mode ipip con-name tun0 ifname tun0 remote 203.0.113.10 local 198.51.100.5
```

The **remote** and **local** parameters set the public IP addresses of the remote and local routers.

b. Set the IPv4 address to the **tun0** device:

```
  # nmcli connection modify tun0 ipv4.addresses '10.0.1.2/30'
```

c. Configure the **tun0** connection to use a manual IPv4 configuration:

```
  # nmcli connection modify tun0 ipv4.method manual
```

d. Add a static route that routes traffic to the **192.0.2.0/24** network to the tunnel IP on router A:

```
  # nmcli connection modify tun0 +ipv4.routes "192.0.2.0/24 10.0.1.1"
```

e. Enable the **tun0** connection.

```
  # nmcli connection up tun0
```

f. Enable packet forwarding:

```
  # echo "net.ipv4.ip_forward=1" > /etc/sysctl.d/95-IPv4-forwarding.conf
  # sysctl -p /etc/sysctl.d/95-IPv4-forwarding.conf
```

**Verification steps**

- From each RHEL router, ping the IP address of the internal interface of the other router:
  a. On Router A, ping **172.16.0.1**:

```
  # ping 172.16.0.1
```

  b. On Router B, ping **192.0.2.1**:

```
  # ping 192.0.2.1
```

**Additional resources**
14.2. CONFIGURING A GRE TUNNEL USING NMCLI TO ENCAPSULATE LAYER-3 TRAFFIC IN IPV4 PACKETS

A Generic Routing Encapsulation (GRE) tunnel encapsulates layer-3 traffic in IPv4 packets as described in RFC 2784. A GRE tunnel can encapsulate any layer 3 protocol with a valid Ethernet type.

IMPORTANT

Data sent through a GRE tunnel is not encrypted. For security reasons, use the tunnel only for data that is already encrypted, for example, by other protocols, such as HTTPS.

This procedure describes how to create a GRE tunnel between two RHEL routers to connect two internal subnets over the Internet as shown in the following diagram:

NOTE

The gre0 device name is reserved. Use gre1 or a different name for the device.

Prerequisites

- Each RHEL router has a network interface that is connected to its local subnet.
- Each RHEL router has a network interface that is connected to the Internet.

Procedure

1. On the RHEL router in network A:
   a. Create a GRE tunnel interface named gre1:

```
# nmcli connection add type ip-tunnel ip-tunnel.mode gre con-name gre1 ifname
  gre1 remote 198.51.100.5 local 203.0.113.10
```
The **remote** and **local** parameters set the public IP addresses of the remote and the local routers.

b. Set the IPv4 address to the **gre1** device:

```bash
# nmcli connection modify gre1 ipv4.addresses '10.0.1.1/30'
```

Note that a /30 subnet with two usable IP addresses is sufficient for the tunnel.

c. Configure the **gre1** connection to use a manual IPv4 configuration:

```bash
# nmcli connection modify gre1 ipv4.method manual
```

d. Add a static route that routes traffic to the **172.16.0.0/24** network to the tunnel IP on router B:

```bash
# nmcli connection modify gre1 +ipv4.routes "172.16.0.0/24 10.0.1.2"
```

e. Enable the **gre1** connection.

```bash
# nmcli connection up gre1
```

f. Enable packet forwarding:

```bash
# echo "net.ipv4.ip_forward=1" > /etc/sysctl.d/95-IPv4-forwarding.conf
# sysctl -p /etc/sysctl.d/95-IPv4-forwarding.conf
```

2. On the RHEL router in network B:

a. Create a GRE tunnel interface named **gre1**:

```bash
# nmcli connection add type ip-tunnel ip-tunnel.mode gre con-name gre1 ifname
  gre1 remote 203.0.113.10 local 198.51.100.5
```

The **remote** and **local** parameters set the public IP addresses of the remote and the local routers.

b. Set the IPv4 address to the **gre1** device:

```bash
# nmcli connection modify gre1 ipv4.addresses '10.0.1.2/30'
```

c. Configure the **gre1** connection to use a manual IPv4 configuration:

```bash
# nmcli connection modify gre1 ipv4.method manual
```

d. Add a static route that routes traffic to the **192.0.2.0/24** network to the tunnel IP on router A:

```bash
# nmcli connection modify gre1 +ipv4.routes "192.0.2.0/24 10.0.1.1"
```

e. Enable the **gre1** connection.

```bash
# nmcli connection up gre1
```
f. Enable packet forwarding:

```
# echo "net.ipv4.ip_forward=1" > /etc/sysctl.d/95-IPv4-forwarding.conf
# sysctl -p /etc/sysctl.d/95-IPv4-forwarding.conf
```

Verification steps

1. From each RHEL router, ping the IP address of the internal interface of the other router:
   a. On Router A, ping 172.16.0.1:

```
# ping 172.16.0.1
```
   b. On Router B, ping 192.0.2.1:

```
# ping 192.0.2.1
```

Additional resources

- `nmcli` man page
- The `ip-tunnel settings` section in the `nm-settings(5)` man page

**14.3. CONFIGURING A GRETAP TUNNEL TO TRANSFER ETHERNET FRAMES OVER IPv4**

A Generic Routing Encapsulation Terminal Access Point (GRETAP) tunnel operates on OSI level 2 and encapsulates Ethernet traffic in IPv4 packets as described in RFC 2784.

**IMPORTANT**

Data sent through a GRETAP tunnel is not encrypted. For security reasons, establish the tunnel over a VPN or a different encrypted connection.

This procedure describes how to create a GRETAP tunnel between two RHEL routers to connect two networks using a bridge as shown in the following diagram:
NOTE

The `gretap0` device name is reserved. Use `gretap1` or a different name for the device.

Prerequisites

- Each RHEL router has a network interface that is connected to its local network, and the interface has no IP configuration assigned.
- Each RHEL router has a network interface that is connected to the Internet.

Procedure

1. On the RHEL router in network A:
   a. Create a bridge interface named `bridge0`:

      ```bash
      # nmcli connection add type bridge con-name bridge0 ifname bridge0
      ```
   b. Configure the IP settings of the bridge:

      ```bash
      # nmcli connection modify bridge0 ipv4.addresses '192.0.2.1/24'
      # nmcli connection modify bridge0 ipv4.method manual
      ```
   c. Add a new connection profile for the interface that is connected to local network to the bridge:

      ```bash
      # nmcli connection add type ethernet slave-type bridge con-name bridge0-port1
      ifname enp1s0 master bridge0
      ```
   d. Add a new connection profile for the GRETAP tunnel interface to the bridge:
# nmcli connection add type ip-tunnel ip-tunnel.mode gretap slave-type bridge con-name bridge0-port2 ifname gretap1 remote 198.51.100.5 local 203.0.113.10 master bridge0

The `remote` and `local` parameters set the public IP addresses of the remote and the local routers.

e. Optional: Disable the Spanning Tree Protocol (STP) if you do not need it:

    # nmcli connection modify bridge0 bridge.stp no

By default, STP is enabled and causes a delay before you can use the connection.

f. Configure that activating the `bridge0` connection automatically activates the ports of the bridge:

    # nmcli connection modify bridge0 connection.autoconnect-slaves 1

g. Active the `bridge0` connection:

    # nmcli connection up bridge0

2. On the RHEL router in network B:

a. Create a bridge interface named `bridge0`:

    # nmcli connection add type bridge con-name bridge0 ifname bridge0

b. Configure the IP settings of the bridge:

    # nmcli connection modify bridge0 ipv4.addresses '192.0.2.2/24'
    # nmcli connection modify bridge0 ipv4.method manual

c. Add a new connection profile for the interface that is connected to local network to the bridge:

    # nmcli connection add type ethernet slave-type bridge con-name bridge0-port1 ifname enp1s0 master bridge0

d. Add a new connection profile for the GRETAP tunnel interface to the bridge:

    # nmcli connection add type ip-tunnel ip-tunnel.mode gretap slave-type bridge con-name bridge0-port2 ifname gretap1 remote 203.0.113.10 local 198.51.100.5 master bridge0

The `remote` and `local` parameters set the public IP addresses of the remote and the local routers.

e. Optional: Disable the Spanning Tree Protocol (STP) if you do not need it:

    # nmcli connection modify bridge0 bridge.stp no
Configure that activating the bridge0 connection automatically activates the ports of the bridge:

```bash
# nmcli connection modify bridge0 connection.autoconnect-slaves 1
```

g. Active the bridge0 connection:

```bash
# nmcli connection up bridge0
```

**Verification steps**

1. On both routers, verify that the enp1s0 and gretap1 connections are connected and that the CONNECTION column displays the connection name of the port:

```bash
# nmcli device
nmcli device
DEVICE   TYPE      STATE      CONNECTION
...
bridge0  bridge    connected  bridge0
enp1s0   ethernet  connected  bridge0-port1
gretap1  iptunnel  connected  bridge0-port2
```

2. From each RHEL router, ping the IP address of the internal interface of the other router:
   
a. On Router A, ping 192.0.2.2:

```bash
# ping 192.0.2.2
```

b. On Router B, ping 192.0.2.1:

```bash
# ping 192.0.2.1
```

**Additional resources**

- nmcli man page
- The ip-tunnel settings section in the nm-settings(5) man page

14.4. ADDITIONAL RESOURCES

- ip-link(8) man page
CHAPTER 15. PORT MIRRORING

Network administrators can use port mirroring to replicate inbound and outbound network traffic being communicated from one network device to another. Administrators use port mirroring to monitor network traffic and collect network data to:

- Debug networking issues and tune the network flow
- Inspect and analyze the network traffic to troubleshoot networking problems
- Detect an intrusion

15.1. MIRRORING A NETWORK INTERFACE USING NMCLI

You can configure port mirroring using NetworkManager. The following procedure mirrors the network traffic from `enp1s0` to `enp7s0` by adding Traffic Control (`tc`) rules and filters to the `enp1s0` network interface.

**Prerequisites**

- A network interface to mirror the network traffic to.

**Procedure**

1. Add a network connection profile that you want to mirror the network traffic from:

   ```
   # nmcli connection add type ethernet ifname enp1s0 con-name enp1s0 autoconnect no
   ```

2. Attach a `prio qdisc` to `enp1s0` for the egress (outgoing) traffic with the `10:` handle:

   ```
   # nmcli connection modify enp1s0 +tc.qdisc "root prio handle 10:"
   ```

   The `prio qdisc` attached without children allows attaching filters.

3. Add a `qdisc` for the ingress traffic, with the `ffff:` handle:

   ```
   # nmcli connection modify enp1s0 +tc.qdisc "ingress handle ffff:"
   ```

4. Add the following filters to match packets on the ingress and egress `qdiscs`, and to mirror them to `enp7s0`:

   ```
   # nmcli connection modify enp1s0 +tc.tfilter "parent ffff: matchall action mirred egress mirror dev enp7s0"
   # nmcli connection modify enp1s0 +tc.tfilter "parent 10: matchall action mirred egress mirror dev enp7s0"
   ```

   The `matchall` filter matches all packets, and the `mirred` action redirects packets to destination.

5. Activate the connection:

   ```
   # nmcli connection up enp1s0
   ```
Verification steps

1. Install the `tcpdump` utility:

   ```
   # dnf install tcpdump
   ```

2. Display the traffic mirrored on the target device (`enp7s0`):

   ```
   # tcpdump -i enp7s0
   ```

Additional resources

- How to capture network packets using `tcpdump`
CHAPTER 16. CONFIGURING NETWORK DEVICES TO ACCEPT TRAFFIC FROM ALL MAC ADDRESSES

Network devices usually intercept and read packets that their controller is programmed to receive. You can configure the network devices to accept traffic from all MAC addresses in a virtual switch or at the port group level.

You can use this network mode to:

- diagnose network connectivity issues,
- monitor network activity for security reasons,
- intercept private data-in-transit or intrusion in the network.

This section describes how to configure a network device to accept traffic from all the MAC addresses using `iproute2`, `nmcli`, or `nmstatectl` utilities. You can enable this mode for any kind of network device except InfiniBand.

16.1. TEMPORARILY CONFIGURING A NETWORK DEVICE TO ACCEPT ALL TRAFFIC USING IPROUTE2

This procedure describes how to configure a network device to accept all traffic regardless of the MAC addresses. Any change made using the `iproute2` utility is temporary and lost after the machine reboots.

Procedure

1. Optional: Display the network interfaces to identify the one for which you want to receive all traffic:

   ```plaintext
   # ip a
   1: enp1s0: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc fq_codel state DOWN group default qlen 1000
      link/ether 98:fa:9b:a4:34:09 brd ff:ff:ff:ff:ff:ff
   2: bond0: <NO-CARRIER,BROADCAST,MULTICAST,MASTER,UP> mtu 1500 qdisc noqueue state DOWN group default qlen 1000
      link/ether 6a:fd:16:b0:83:5c brd ff:ff:ff:ff:ff:ff
   3: wlp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qlen 1000
      ... 
   ```

2. Modify the device to enable or disable this property.

   - To enable the `accept-all-mac-addresses` mode for `enp1s0`:
     ```plaintext
     # ip link set enp1s0 promisc on
     ```

   - To disable the `accept-all-mac-addresses` mode for `enp1s0`:
     ```plaintext
     # ip link set enp1s0 promisc off
     ```

Verification steps
To verify that the `accept-all-mac-addresses` mode is enabled:

```
# ip link show enp1s0
1: enp1s0: <NO-CARRIER,BROADCAST,MULTICAST,PROMISC,UP> mtu 1500 qdisc fq_codel
  state DOWN mode DEFAULT group default qlen 1000
  link/ether 98:fa:9b:a4:34:09 brd ff:ff:ff:ff:ff:ff
```

The `PROMISC` flag in the device description indicates that the mode is enabled.

### 16.2. PERMANENTLY CONFIGURING A NETWORK DEVICE TO ACCEPT ALL TRAFFIC USING NMCLI

This procedure describes how to configure a network device to accept traffic regardless of MAC addresses using the `nmcli` commands.

**Procedure**

1. Optional: Display the network interfaces to identify the one for which you want to receive all traffic:

   ```
   # ip a
   1: enp1s0: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc fq_codel state
   DOWN group default qlen 1000
   link/ether 98:fa:9b:a4:34:09 brd ff:ff:ff:ff:ff:ff
   2: bond0: <NO-CARRIER,BROADCAST,MULTICAST,MASTER,UP> mtu 1500 qdisc
   noqueue state DOWN group default qlen 1000
   link/ether 6a:fd:16:b0:83:5c brd ff:ff:ff:ff:ff:ff
   3: wlp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP
group default qlen 1000
   ...
   
   You can create a new connection, if you do not have any.
   
   2. Modify the network device to enable or disable this property.
      
      - To enable the `ethernet.accept-all-mac-addresses` mode for `enp1s0`:
        
        ```
        # nmcli connection modify enp1s0 ethernet.accept-all-mac-addresses yes
        
        - To disable the `accept-all-mac-addresses` mode for `enp1s0`:
          
          ```
          # nmcli connection modify enp1s0 ethernet.accept-all-mac-addresses no
          
      3. To apply the changes, reactivate the connection:
      
      ```
      # nmcli connection up enp1s0
      ```
      
**Verification steps**

- To verify that the `ethernet.accept-all-mac-addresses` mode is enabled:
The `802-3-ethernet.accept-all-mac-addresses: true` indicates that the mode is enabled.

16.3. PERMANENTLY CONFIGURING A NETWORK NETWORK DEVICE TO ACCEPT ALL TRAFFIC USING NMSTATECTL

This procedure describes how to configure a network device to accept all traffic regardless of MAC addresses using the `nmstatectl` utility.

Prerequisites

- The `nmstate` package is installed.
- The `.yml` file that you used to configure the device is available.

Procedure

1. Edit the existing `enp1s0.yml` file for the `enp1s0` connection and add the following content to it.

   ```yaml
   ---
   interfaces:
     - name: enp1s0
       type: ethernet
       state: up
       accept-all-mac-address: true
   ```

2. Apply the network settings.

   ```bash
   # nmstatectl apply ~/enp1s0.yml
   ```

Verification steps

- To verify that the `802-3-ethernet.accept-all-mac-addresses` mode is enabled:

   ```bash
   # nmstatectl show enp1s0
   interfaces:
     - name: enp1s0
       type: ethernet
       state: up
       accept-all-mac-addresses: true
   ```

The `802-3-ethernet.accept-all-mac-addresses: true` indicates that the mode is enabled.

Additional resources

- For further details about `nmstatectl`, see the `nmstatectl(8)` man page.
- For more configuration examples, see the `/usr/share/doc/nmstate/examples/` directory.
CHAPTER 17. SETTING UP AN 802.1X NETWORK AUTHENTICATION SERVICE FOR LAN CLIENTS USING HOSTAPD WITH FREERADIUS BACKEND

The IEEE 802.1X standard defines secure authentication and authorization methods to protect networks from unauthorized clients. Using the hostapd service and FreeRADIUS, you can provide network access control (NAC) in your network.

In this documentation, the RHEL host acts as a bridge to connect different clients with an existing network. However, the RHEL host grants only authenticated clients access to the network.

17.1. PREREQUISITES

- A clean installation of FreeRADIUS.
  If the freeradius package is already installed, remove the /etc/raddb/ directory, uninstall and then install the package again. Do not reinstall the package using the dnf reinstall command, because the permissions and symbolic links in the /etc/raddb/ directory are then different.

17.2. SETTING UP THE BRIDGE ON THE AUTHENTICATOR

A network bridge is a link-layer device which forwards traffic between hosts and networks based on a table of MAC addresses. If you set up RHEL as an 802.1X authenticator, add both the interfaces on which to perform authentication and the LAN interface to the bridge.

Prerequisites

- The server has multiple Ethernet interfaces.

Procedure

1. Create the bridge interface:

   # nmcli connection add type bridge con-name br0 ifname br0

2. Assign the Ethernet interfaces to the bridge:

   # nmcli connection add type ethernet slave-type bridge con-name br0-port1 ifname enp1s0 master br0
   # nmcli connection add type ethernet slave-type bridge con-name br0-port2 ifname enp9s0
### enp7s0 master br0

```
# nmcli connection add type ethernet slave-type bridge con-name br0-port3 ifname enp8s0 master br0
# nmcli connection add type ethernet slave-type bridge con-name br0-port4 ifname enp9s0 master br0
```

3. Enable the bridge to forward extensible authentication protocol over LAN (EAPOL) packets:

```
# nmcli connection modify br0 group-forward-mask 8
```

4. Configure the connection to automatically activate the ports:

```
# nmcli connection modify br0 connection.autoconnect-slaves 1
```

5. Activate the connection:

```
# nmcli connection up br0
```

### Verification

1. Display the link status of Ethernet devices that are ports of a specific bridge:

```
# ip link show master br0
3: enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel master
    br0 state UP mode DEFAULT group default qlen 1000
        link/ether 52:54:00:62:61:0e brd ff:ff:ff:ff:ff:ff
    ... 
```

2. Verify if forwarding of EAPOL packets is enabled on the **br0** device:

```
# cat /sys/class/net/br0/bridge/group_fwd_mask
0x8
```

If the command returns `0x8`, forwarding is enabled.

### Additional resources

- [nm-settings(5) man page](#)

### 17.3. CERTIFICATE REQUIREMENTS BY FREERADIUS

For a secure FreeRADIUS service, you require TLS certificates for different purposes:

- A TLS server certificate for encrypted connections to the server. Use a trusted certificate authority (CA) to issue the certificate. The server certificate requires the extended key usage (EPU) field set to **TLS Web Server Authentication**.

- Client certificates issued by the same CA for extended authentication protocol transport layer security (EAP-TLS). EAP-TLS provides certificate-based authentication and is enabled by default. The client certificates require their EPU field set to **TLS Web Client Authentication**.
WARNING
To secure connection, use your company’s CA or create your own CA to issue certificates for FreeRADIUS. If you use a public CA, you allow it to authenticate users and issue client certificates for EAP-TLS.

17.4. CREATING A SET OF CERTIFICATES ON A FREERADIUS SERVER FOR TESTING PURPOSES

For testing purposes, the freeradius package installs scripts and configuration files in the /etc/raddb/certs/ directory to create your own certificate authority (CA) and issue certificates.

IMPORTANT
If you use the default configuration, certificates generated by these scripts expire after 60 days and keys use an insecure password (“whatever”). However, you can customize the CA, server, and client configuration.

After you perform the procedure, the following files, which you require later in this documentation, are created:

- /etc/raddb/certs/ca.pem: CA certificate
- /etc/raddb/certs/server.key: Private key of the server certificate
- /etc/raddb/certs/server.pem: Server certificate
- /etc/raddb/certs/client.key: Private key of the client certificate
- /etc/raddb/certs/client.pem: Client certificate

Prerequisites

- You installed the freeradius package.

Procedure

1. Change into the /etc/raddb/certs/ directory:

   ```
   # cd /etc/raddb/certs/
   ```

2. Optional: Customize the CA configuration:

   ```ini
   [ req ]
   default_bits = 2048
   input_password = ca_password
   output_password = ca_password
   ...  ```
[certificate_authority]
countryName = US
stateOrProvinceName = North Carolina
localityName = Raleigh
organizationName = Example Inc.
emailAddress = admin@example.org
commonName = "Example Certificate Authority"
...

3. Optional: Customize the server configuration:

... 
[ CA_default ]
default_days = 730
...
[ req ]
distinguished_name = server
default_bits = 2048
input_password = key_password
output_password = key_password
...
[server]
countryName = US
stateOrProvinceName = North Carolina
localityName = Raleigh
organizationName = Example Inc.
emailAddress = admin@example.org
commonName = "Example Server Certificate"
...

4. Optional: Customize the client configuration:

... 
[ CA_default ]
default_days = 365
...
[ req ]
distinguished_name = client
default_bits = 2048
input_password = password_on_private_key
output_password = password_on_private_key
...
[client]
countryName = US
stateOrProvinceName = North Carolina
localityName = Raleigh
organizationName = Example Inc.
emailAddress = user@example.org
commonName = user@example.org
...

5. Create the certificates:

```bash
# make all
```
6. Change the group on the `/etc/raddb/certs/server.pem` file to `radiusd`:

```
# chgrp radiusd /etc/raddb/certs/server.pem
```

Additional resources

- `/etc/raddb/certs/README.md`

### 17.5. CONFIGURING FREERADIUS TO AUTHENTICATE NETWORK CLIENTS SECURELY USING EAP

FreeRADIUS supports different methods of the Extensible authentication protocol (EAP). However, for a secure network, this documentation describes how to configure FreeRADIUS to support only the following secure EAP authentication methods:

- **EAP-TLS** (transport layer security) uses a secure TLS connection to authenticate clients using certificates. To use EAP-TLS, you need TLS client certificates for each network client and a server certificate for the server. Note that the same certificate authority (CA) must have issued the certificates. Always use your own CA to create certificates, because all client certificates issued by the CA you use can authenticate to your FreeRADIUS server.

- **EAP-TTLS** (tunneled transport layer security) uses a secure TLS connection and authenticates clients using mechanisms, such as password authentication protocol (PAP) or challenge handshake authentication protocol (CHAP). To use EAP-TTLS, you need a TLS server certificate.

- **EAP-PEAP** (protected extensible authentication protocol) uses a secure TLS connection as the outer authentication protocol to set up the tunnel. The authenticator authenticates the certificate of the RADIUS server. Afterwards, the supplicant authenticates through the encrypted tunnel using Microsoft challenge handshake authentication protocol version 2 (MS-CHAPv2) or other methods.

**NOTE**

The default FreeRADIUS configuration files serve as documentation and describe all parameters and directives. If you want to disable certain features, comment them out instead of removing the corresponding parts in the configuration files. This enables you to preserve the structure of the configuration files and the included documentation.

**Prerequisites**

- You installed the `freeradius` package.
- The configuration files in the `/etc/raddb/` directory are unchanged and as provided by the `freeradius` package.
- The following files exist on the server:
  - TLS private key of the FreeRADIUS host: `/etc/raddb/certs/server.key`
  - TLS server certificate of the FreeRADIUS host: `/etc/raddb/certs/server.pem`
  - TLS CA certificate: `/etc/raddb/certs/ca.pem`
If you store the files in a different location or if they have different names, set the `private_key_file`, `certificate_file`, and `ca_file` parameters in the `/etc/raddb/mods-available/eap` file accordingly.

**Procedure**

1. If the `/etc/raddb/certs/dh` with Diffie–Hellman (DH) parameters does not exist, create one. For example, to create a DH file with a 2048 bits prime, enter:

   ```
   # openssl dhparam -out /etc/raddb/certs/dh 2048
   ```

   For security reasons, do not use a DH file with less than a 2048 bits prime. Depending on the number of bits, the creation of the file can take several minutes.

2. Set secure permissions on the TLS private key, server certificate, CA certificate, and the file with DH parameters:

   ```
   # chmod 640 /etc/raddb/certs/server.key /etc/raddb/certs/server.pem 
   /etc/raddb/certs/ca.pem /etc/raddb/certs/dh 
   # chown root:radiusd /etc/raddb/certs/server.key /etc/raddb/certs/server.pem 
   /etc/raddb/certs/ca.pem /etc/raddb/certs/dh
   ```

3. Edit the `/etc/raddb/mods-available/eap` file:
   a. Set the password of the private key in the `private_key_password` parameter:

      ```
      eap {
          ...
          tls-config tls-common {
              ...
              private_key_password = key_password
              ...
          }
      }
      ```

   b. Depending on your environment, set the `default_eap_type` parameter in the `eap` directive to your primary EAP type you use:

      ```
      eap {
          ...
          default_eap_type = ttls
          ...
      }
      ```

      For a secure environment, use only `ttls`, `tls`, or `peap`.

   c. Comment out the `md5` directives to disable the insecure EAP–MD5 authentication method:

      ```
      eap {
          ...
          # md5 { 
          # } 
          ...
      }
      ```
Note that, in the default configuration file, other insecure EAP authentication methods are commented out by default.

4. Edit the `/etc/raddb/sites-available/default` file, and comment out all authentication methods other than `eap`:

```plaintext
authenticate {
    ... 
    # Auth-Type PAP {
    #     pap
    # }
    
    # Auth-Type CHAP {
    #     chap
    # }
    
    # Auth-Type MS-CHAP {
    #     mschap
    # }
    
    # mschap
    # digest
    ... 
}
```

This leaves only EAP enabled and disables plain-text authentication methods.

5. Edit the `/etc/raddb/clients.conf` file:

   a. Set a secure password in the `localhost` and `localhost_ipv6` client directives:

   ```plaintext
   client localhost {
       ipaddr = 127.0.0.1
       ... 
       secret = client_password
       ... 
   }
   
   client localhost_ipv6 {
       ipv6addr = ::1
       secret = client_password
   }
   
   client hostapd.example.org {
       ipaddr = 192.0.2.2/32
       secret = client_password
   }
   
   The `ipaddr` parameter accepts IPv4 and IPv6 addresses, and you can use the optional classless inter-domain routing (CIDR) notation to specify ranges. However, you can set only one value in this parameter. For example, to grant access to an IPv4 and IPv6 address, add two client directives.
Use a descriptive name for the client directive, such as a hostname or a word that describes where the IP range is used.

6. If you want to use EAP-TTLS or EAP-PEAP, add the users to the `/etc/raddb/users` file:
   ```
   example_user Cleartext-Password := "user_password"
   ```
   For users who should use certificate-based authentication (EAP-TLS), do not add any entry.

7. Verify the configuration files:
   ```
   # radiusd -XC
   ...
   Configuration appears to be OK
   ```

8. Enable and start the `radiusd` service:
   ```
   # systemctl enable --now radiusd
   ```

**Verification**

- Testing EAP-TTLS authentication against a FreeRADIUS server or authenticator
- Testing EAP-TLS authentication against a FreeRADIUS server or authenticator

**Troubleshooting**

1. Stop the `radiusd` service:
   ```
   # systemctl stop radiusd
   ```

2. Start the service in debug mode:
   ```
   # radiusd -X
   ...
   Ready to process requests
   ```

3. Perform authentication tests on the FreeRADIUS host, as referenced in the **Verification** section.

**Next steps**

- Disable unrequired authentication methods and other features you do not use.

**17.6. CONFIGURING HOSTAPD AS AN AUTHENTICATOR IN A WIRED NETWORK**

The host access point daemon (`hostapd`) service can act as an authenticator in a wired network to provide 802.1X authentication. For this, the `hostapd` service requires a RADIUS server that authenticates the clients.
The **hostapd** service provides an integrated RADIUS server. However, use the integrated RADIUS server only for testing purposes. For production environments, use FreeRADIUS server, which supports additional features, such as different authentication methods and access control.

**IMPORTANT**

The **hostapd** service does not interact with the traffic plane. The service acts only as an authenticator. For example, use a script or service that uses the **hostapd** control interface to allow or deny traffic based on the result of authentication events.

**Prerequisites**

- You installed the **hostapd** package.
- The FreeRADIUS server has been configured, and it is ready to authenticate clients.

**Procedure**

1. Create the `/etc/hostapd/hostapd.conf` file with the following content:

```conf
# General settings of hostapd
# =================================

# Control interface settings
ctrl_interface=/var/run/hostapd
ctrl_interface_group=wheel

# Enable logging for all modules
logger_syslog=-1
logger_stdout=-1

# Log level
logger_syslog_level=2
logger_stdout_level=2

# Wired 802.1X authentication
# =================================

# Driver interface type
driver=wired

# Enable IEEE 802.1X authorization
ieee8021x=1

# Use port access entry (PAE) group address
# (01:80:c2:00:00:03) when sending EAPOL frames
use_pae_group_addr=1

# Network interface for authentication requests
interface=br0

# RADIUS client configuration
```
# # Local IP address used as NAS-IP-Address
# own_ip_addr=192.0.2.2
#
# Unique NAS-Identifier within scope of RADIUS server
# nas_identifier=hostapd.example.org
#
# RADIUS authentication server
# auth_server_addr=192.0.2.1
# auth_server_port=1812
# auth_server_shared_secret=client_password
#
# RADIUS accounting server
# acct_server_addr=192.0.2.1
# acct_server_port=1813
# acct_server_shared_secret=client_password

For further details about the parameters used in this configuration, see their descriptions in the /usr/share/doc/hostapd/hostapd.conf example configuration file.

2. Enable and start the hostapd service:

   # systemctl enable --now hostapd

Verification

- See:
  - Testing EAP-TTLS authentication against a FreeRADIUS server or authenticator
  - Testing EAP-TLS authentication against a FreeRADIUS server or authenticator

Troubleshooting

1. Stop the hostapd service:

   # systemctl stop hostapd

2. Start the service in debug mode:

   # hostapd -d /etc/hostapd/hostapd.conf

3. Perform authentication tests on the FreeRADIUS host, as referenced in the Verification section.

Additional resources

- hostapd.conf(5) man page
- /usr/share/doc/hostapd/hostapd.conf
### 17.7. TESTING EAP-TTLS AUTHENTICATION AGAINST A FREERADIUS SERVER OR AUTHENTICATOR

To test if authentication using extensible authentication protocol (EAP) over tunneled transport layer security (EAP-TTLS) works as expected, run this procedure:

- After you set up the FreeRADIUS server
- After you set up the **hostapd** service as an authenticator for 802.1X network authentication.

The output of the test utilities used in this procedure provide additional information about the EAP communication and help you to debug problems.

#### Prerequisites

- When you want to authenticate to:
  - A FreeRADIUS server:
    - The [eapol_test](https://www.freevos.org/~dave/eapolstrtotime) utility, provided by the **hostapd** package, is installed.
    - The client, on which you run this procedure, has been authorized in the FreeRADIUS server's client databases.
  - An authenticator, the **wpa_supplicant** utility, provided by the same-named package, is installed.
  - You stored the certificate authority (CA) certificate in the `/etc/pki/tls/certs/ca.pem` file.

#### Procedure

1. Create the `/etc/wpa_supplicant/wpa_supplicant-TTLS.conf` file with the following content:

   ```
   ap_scan=0
   
   network={
     eap=TTLS
     eapol_flags=0
     key_mgmt=IEEE8021X
     
     # Anonymous identity (sent in unencrypted phase 1)
     # Can be any string
     anonymous_identity="anonymous"
     
     # Inner authentication (sent in TLS-encrypted phase 2)
     phase2="auth=PAP"
     identity="example_user"
     password="user_password"
     
     # CA certificate to validate the RADIUS server's identity
     ca_cert="/etc/pki/tls/certs/ca.pem"
   }
   ```

2. To authenticate to:
   - A FreeRADIUS server, enter:
# eapol_test -c /etc/wpa_supplicant/wpa_supplicant-TTLS.conf -a 192.0.2.1 -s client_password
...
EAP: Status notification: remote certificate verification (param=success)
...
CTRL-EVENT-EAP-SUCCESS EAP authentication completed successfully
...
SUCCESS

The `a` option defines the IP address of the FreeRADIUS server, and the `s` option specifies the password for the host on which you run the command in the FreeRADIUS server’s client configuration.

- An authenticator, enter:

  # wpa_supplicant -c /etc/wpa_supplicant/wpa_supplicant-TTLS.conf -D wired -i enp0s31f6
...
enp0s31f6: CTRL-EVENT-EAP-SUCCESS EAP authentication completed successfully
...

The `i` option specifies the network interface name on which `wpa_supplicant` sends out extended authentication protocol over LAN (EAPOL) packets.

For more debugging information, pass the `-d` option to the command.

Additional resources

- `/usr/share/doc/wpa_supplicant/wpa_supplicant.conf`

### 17.8. TESTING EAP-TLS AUTHENTICATION AGAINST A FREERADIUS SERVER OR AUTHENTICATOR

To test if authentication using extensible authentication protocol (EAP) transport layer security (EAP-TLS) works as expected, run this procedure:

- After you set up the FreeRADIUS server

- After you set up the `hostapd` service as an authenticator for 802.1X network authentication.

The output of the test utilities used in this procedure provide additional information about the EAP communication and help you to debug problems.

**Prerequisites**

- When you want to authenticate to:
  - A FreeRADIUS server:
    - The `eapol_test` utility, provided by the `hostapd` package, is installed.
    - The client, on which you run this procedure, has been authorized in the FreeRADIUS server’s client databases.
An authenticator, the `wpa_supplicant` utility, provided by the same-named package, is installed.

- You stored the certificate authority (CA) certificate in the `/etc/pki/tls/certs/ca.pem` file.
- The CA that issued the client certificate is the same that issued the server certificate of the FreeRADIUS server.
- You stored the client certificate in the `/etc/pki/tls/certs/client.pem` file.
- You stored the private key of the client in the `/etc/pki/tls/private/client.key`

**Procedure**

1. Create the `/etc/wpa_supplicant/wpa_supplicant-TLS.conf` file with the following content:

   ```
   ap_scan=0

   network={
     eap=TLS
     eapol_flags=0
     key_mgmt=IEEE8021X

     identity="user@example.org"
     client_cert="/etc/pki/tls/certs/client.pem"
     private_key="/etc/pki/tls/private/client.key"
     private_key_passwd="password_on_private_key"

     ca_cert="/etc/pki/tls/certs/ca.pem"
   }
   ```

2. To authenticate to:
   - A FreeRADIUS server, enter:
     ```
     # eapol_test -c /etc/wpa_supplicant/wpa_supplicant-TLS.conf -a 192.0.2.1 -s client_password
     ...
     EAP: Status notification: remote certificate verification (param=success)
     ...
     CTRL-EVENT-EAP-SUCCESS EAP authentication completed successfully
     ...
     SUCCESS
     ```
     The `-a` option defines the IP address of the FreeRADIUS server, and the `-s` option specifies the password for the host on which you run the command in the FreeRADIUS server’s client configuration.
   - An authenticator, enter:
     ```
     # wpa_supplicant -c /etc/wpa_supplicant/wpa_supplicant-TLS.conf -D wired -i enp0s31f6
     ...
     enp0s31f6: CTRL-EVENT-EAP-SUCCESS EAP authentication completed successfully
     ```
The -l option specifies the network interface name on which wpa_supplicant sends out extended authentication protocol over LAN (EAPOL) packets.

For more debugging information, pass the -d option to the command.

Additional resources

- /usr/share/doc/wpa_supplicant/wpa_supplicant.conf

17.9. BLOCKING AND ALLOWING TRAFFIC BASED ON HOSTAPD AUTHENTICATION EVENTS

The hostapd service does not interact with the traffic plane. The service acts only as an authenticator. However, you can write a script to allow and deny traffic based on the result of authentication events.

**IMPORTANT**

This procedure is not supported and is no enterprise-ready solution. It only demonstrates how to block or allow traffic by evaluating events retrieved by hostapd_cli.

When the 802-1x-tr-mgmt systemd service starts, RHEL blocks all traffic on the listen port of hostapd except extensible authentication protocol over LAN (EAPOL) packets and uses the hostapd_cli utility to connect to the hostapd control interface. The /usr/local/bin/802-1x-tr-mgmt script then evaluates events. Depending on the different events received by hostapd_cli, the script allows or blocks traffic for MAC addresses. Note that, when the 802-1x-tr-mgmt service stops, all traffic is automatically allowed again.

Perform this procedure on the hostapd server.

**Prerequisites**

- The hostapd service has been configured, and the service is ready to authenticate clients.

**Procedure**

1. Create the /usr/local/bin/802-1x-tr-mgmt file with the following content:

```bash
#!/bin/sh
if [ "x$1" == "xblock_all" ]
then
    nft delete table bridge tr-mgmt-br0 2>/dev/null || true
    nft -f - << EOF
    table bridge tr-mgmt-br0 {
        set allowed_macs {
            type ether_addr
        }
    }
    chain accesscontrol {
        ether saddr @allowed_macs accept
        ether daddr @allowed_macs accept
        drop
    }
```
chain forward {
    type filter hook forward priority 0; policy accept;
    meta ibname "br0" jump accesscontrol
}
}
EOF

echo "802-1x-tr-mgmt Blocking all traffic through br0. Traffic for given host will be allowed after 802.1x authentication"

elif [ "x$1" == "xallow_all" ]
then
    nft delete table bridge tr-mgmt-br0
    echo "802-1x-tr-mgmt Allowed all forwarding again"
fi
case ${2:-NOTANEVENT} in
    AP-STA-CONNECTED | CTRL-EVENT-EAP-SUCCESS | CTRL-EVENT-EAP-SUCCESS2)
        nft add element bridge tr-mgmt-br0 allowed_macs { $3 }
        echo "$1: Allowed traffic from $3"
    ;;
    AP-STA-DISCONNECTED | CTRL-EVENT-EAP-FAILURE)
        nft delete element bridge tr-mgmt-br0 allowed_macs { $3 }
        echo "802-1x-tr-mgmt $1: Denied traffic from $3"
    ;;
esac

2. Create the `/etc/systemd/system/802-1x-tr-mgmt@.service` systemd service file with the following content:

```
[Unit]
Description=Example 802.1x traffic management for hostapd
After=hostapd.service
After=sys-devices-virtual-net-%i.device

[Service]
Type=simple
ExecStartPre=-/bin/sh -c '/usr/sbin/tc qdisc del dev %i ingress > /dev/null 2>&1'
ExecStartPre=-/bin/sh -c '/usr/sbin/tc qdisc del dev %i clsact > /dev/null 2>&1'
ExecStartPre=/usr/sbin/tc qdisc add dev %i clsact
ExecStartPre=/usr/sbin/tc filter add dev %i ingress pref 10000 protocol 0x888e matchall action ok index 100
ExecStartPre=/usr/sbin/tc filter add dev %i ingress pref 10001 protocol all matchall action drop index 101
ExecStart=/usr/sbin/hostapd_cli -i %i -a /usr/local/bin/802-1x-tr-mgmt
ExecStopPost=/usr/sbin/tc qdisc del dev %i clsact

[Install]
WantedBy=multi-user.target
```
3. Reload systemd:

```bash
# systemctl daemon-reload
```

4. Enable and start the `802-1x-tr-mgmt` service with the interface name `hostapd` is listening on:

```bash
# systemctl enable --now 802-1x-tr-mgmt@br0.service
```

**Verification**

- Authenticate with a client to the network. See:
  - Testing EAP-TTLS authentication against a FreeRADIUS server or authenticator
  - Testing EAP-TLS authentication against a FreeRADIUS server or authenticator

**Additional resources**

- `systemd.service(5)` man page
CHAPTER 18. AUTHENTICATING A RHEL CLIENT TO THE NETWORK USING THE 802.1X STANDARD WITH A CERTIFICATE STORED ON THE FILE SYSTEM

Administrators frequently use port-based Network Access Control (NAC) based on the IEEE 802.1X standard to protect a network from unauthorized LAN and Wi-Fi clients. The procedures in this section describe different options to configure network authentication.

18.1. CONFIGURING 802.1X NETWORK AUTHENTICATION ON AN EXISTING ETHERNET CONNECTION USING NMCLI

Using the `nmcli` utility, you can configure the client to authenticate itself to the network. This procedure describes how to configure TLS authentication in an existing NetworkManager Ethernet connection profile named `enp1s0` to authenticate to the network.

Prerequisites

- The network supports 802.1X network authentication.
- The Ethernet connection profile exists in NetworkManager and has a valid IP configuration.
- The following files required for TLS authentication exist on the client:
  - The client key stored is in the `/etc/pki/tls/private/client.key` file, and the file is owned and only readable by the `root` user.
  - The client certificate is stored in the `/etc/pki/tls/certs/client.crt` file.
  - The Certificate Authority (CA) certificate is stored in the `/etc/pki/tls/certs/ca.crt` file.
- The `wpa_supplicant` package is installed.

Procedure

1. Set the Extensible Authentication Protocol (EAP) to `tls` and the paths to the client certificate and key file:

   ```
   # nmcli connection modify enp1s0 802-1x.eap tls 802-1x.client-cert /etc/pki/tls/certs/client.crt 802-1x.private-key /etc/pki/tls/certs/certs/client.key
   ```

   Note that you must set the `802-1x.eap`, `802-1x.client-cert`, and `802-1x.private-key` parameters in a single command.

2. Set the path to the CA certificate:

   ```
   # nmcli connection modify enp1s0 802-1x.ca-cert /etc/pki/tls/certs/ca.crt
   ```

3. Set the identity of the user used in the certificate:

   ```
   # nmcli connection modify enp1s0 802-1x.identity user@example.com
   ```

4. Optionally, store the password in the configuration:
# nmcli connection modify enp1s0 802-1x.private-key-password password

## IMPORTANT

By default, NetworkManager stores the password in clear text in the `/etc/sysconfig/network-scripts/keys-connection_name` file, that is readable only by the `root` user. However, clear text passwords in a configuration file can be a security risk.

To increase the security, set the `802-1x.password-flags` parameter to `0x1`. With this setting, on servers with the GNOME desktop environment or the `nm-applet` running, NetworkManager retrieves the password from these services. In other cases, NetworkManager prompts for the password.

5. Activate the connection profile:

```bash
# nmcli connection up enp1s0
```

### Verification steps

- Access resources on the network that require network authentication.

### Additional resources

- Configuring an Ethernet connection
- The `802-1x settings` section in the `nm-settings(5)` man page
- `nmcli(1)` man page

## 18.2. CONFIGURING A STATIC ETHERNET CONNECTION WITH 802.1X NETWORK AUTHENTICATION USING NMSTATECTL

Using the `nmstate` utility, you can create an Ethernet connection that uses the 802.1X standard to authenticate the client. This procedure describes how to add an Ethernet connection for the `enp1s0` interface with the following settings:

- A static IPv4 address - `192.0.2.1` with a `/24` subnet mask
- A static IPv6 address - `2001:db8:1::1` with a `/64` subnet mask
- An IPv4 default gateway - `192.0.2.254`
- An IPv6 default gateway - `2001:db8:1::ffe`
- An IPv4 DNS server - `192.0.2.200`
- An IPv6 DNS server - `2001:db8:1::ffbb`
- A DNS search domain - `example.com`
- 802.1X network authentication using the TLS Extensible Authentication Protocol (EAP)
NOTE

The `nmstate` library only supports the **TLS** EAP method.

**Prerequisites**

- The network supports 802.1X network authentication.
- The managed node uses NetworkManager.
- The following files required for TLS authentication exist on the client:
  - The client key stored is in the `/etc/pki/tls/private/client.key` file, and the file is owned and only readable by the `root` user.
  - The client certificate is stored in the `/etc/pki/tls/certs/client.crt` file.
  - The Certificate Authority (CA) certificate is stored in the `/etc/pki/tls/certs/ca.crt` file.

**Procedure**

1. Create a YAML file, for example `~/create-ethernet-profile.yml`, with the following contents:

```yaml
---
interfaces:
  - name: enp1s0
type: ethernet
state: up
ipv4:
  enabled: true
  address:
    - ip: 192.0.2.1
      prefix-length: 24
dhcp: false
ipv6:
  enabled: true
  address:
    - ip: 2001:db8:1::1
      prefix-length: 64
      autoconf: false
dhcp: false
802.1x:
  ca-cert: /etc/pki/tls/certs/ca.crt
  client-cert: /etc/pki/tls/certs/client.crt
eap-methods:
  - tls
  identity: client.example.org
  private-key: /etc/pki/tls/private/client.key
  private-key-password: password
routes:
  config:
    - destination: 0.0.0.0/0
      next-hop-address: 192.0.2.254
      next-hop-interface: enp1s0
    - destination: ::/0
      next-hop-address: 2001:db8:1::ffe
```
next-hop-interface: enp1s0
dns-resolver:
  config:
  search:
  - example.com
  server:
  - 192.0.2.200
  - 2001:db8:1::ffbb

2. Apply the settings to the system:

    # nmstatectl apply ~/create-ethernet-profile.yml

Verification

- Access resources on the network that require network authentication.

18.3. CONFIGURING A STATIC ETHERNET CONNECTION WITH 802.1X NETWORK AUTHENTICATION USING RHEL SYSTEM ROLES

Using the network RHEL System Role, you can automate the creation of an Ethernet connection that uses the 802.1X standard to authenticate the client. This procedure describes how to remotely add an Ethernet connection for the enp1s0 interface with the following settings by running an Ansible playbook:

- A static IPv4 address - 192.0.2.1 with a /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with a /64 subnet mask
- An IPv4 default gateway - 192.0.2.254
- An IPv6 default gateway - 2001:db8:1::ffe
- An IPv4 DNS server - 192.0.2.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com
- 802.1X network authentication using the TLS Extensible Authentication Protocol (EAP)

Run this procedure on the Ansible control node.

Prerequisites

- The ansible-core and rhel-system-roles packages are installed on the control node.
- If you use a different remote user than root when you run the playbook, you must have appropriate sudo permissions on the managed node.
- The network supports 802.1X network authentication.
- The managed node uses NetworkManager.
- The following files required for TLS authentication exist on the control node:
- The client key is stored in the `/srv/data/client.key` file.
- The client certificate is stored in the `/srv/data/client.crt` file.
- The Certificate Authority (CA) certificate is stored in the `/srv/data/ca.crt` file.

**Procedure**

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

```
node.example.com
```

2. Create the `~/enable-802.1x.yml` playbook with the following content:

```yaml
---
- name: Configure an Ethernet connection with 802.1X authentication
  hosts: node.example.com
  become: true
  tasks:
  - name: Copy client key for 802.1X authentication
    copy:
      src: "/srv/data/client.key"
      dest: "/etc/pki/tls/private/client.key"
      mode: 0600

  - name: Copy client certificate for 802.1X authentication
    copy:
      src: "/srv/data/client.crt"
      dest: "/etc/pki/tls/certs/client.crt"

  - name: Copy CA certificate for 802.1X authentication
    copy:
      src: "/srv/data/ca.crt"
      dest: "/etc/pki/ca-trust/source/anchors/ca.crt"

  - include_role:
    name: rhel-system-roles.network

  vars:
    network_connections:
      - name: enp1s0
        type: ethernet
        autoconnect: yes
        ip:
          address:
            - 192.0.2.1/24
            - 2001:db8:1::1/64
        gateway4: 192.0.2.254
        gateway6: 2001:db8:1::ffe
        dns:
          - 192.0.2.200
          - 2001:db8:1::ffbe
        dns_search:
          - example.com
        ieee802_1x:
          identity: user_name
```
3. Run the playbook:

- To connect as root user to the managed host, enter:

  ```
  # ansible-playbook -u root ~/enable-802.1x.yml
  ```

- To connect as a user to the managed host, enter:

  ```
  # ansible-playbook -u user_name --ask-become-pass ~/ethernet-static-IP.yml
  ```

  The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

  If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

**Additional resources**

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file
- `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file
- `ansible-playbook(1)` man page

**18.4. CONFIGURING A WIFI CONNECTION WITH 802.1X NETWORK AUTHENTICATION USING THE RHEL SYSTEM ROLES**

Using RHEL System Roles, you can automate the creation of a wifi connection. This procedure describes how to remotely add a wireless connection profile for the `wlp1s0` interface using an Ansible playbook. The created profile uses the 802.1X standard to authenticate the client to a wifi network. The playbook configures the connection profile to use DHCP. To configure static IP settings, adapt the parameters in the `ip` dictionary accordingly.

**Prerequisites**

- You installed the ansible and rhel-system-roles packages on the control node.
- The network supports 802.1X network authentication.
- If you use a different remote user than root when you run the playbook, you must have appropriate sudo permissions on the managed node.
- You installed the `wpa_supplicant` package on the managed node.
- DHCP is available in the network of the managed node.
- The following files required for TLS authentication exist on the control node:
- The client key is stored in the /srv/data/client.key file.
- The client certificate is stored in the /srv/data/client.crt file.
- The CA certificate is stored in the /srv/data/ca.crt file.

Perform the following procedure on the Ansible control node.

Procedure

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the /etc/ansible/hosts Ansible inventory file:

```
node.example.com
```

2. Create the ~/enable-802.1x.yml playbook with the following content:

```yaml
---
- name: Configure a wifi connection with 802.1X authentication
  hosts: "node.example.com"
  become: true
  tasks:
    - name: Copy client key for 802.1X authentication
      copy:
        src: "/srv/data/client.key"
        dest: "/etc/pki/tls/private/client.key"
        mode: 0400
    - name: Copy client certificate for 802.1X authentication
      copy:
        src: "/srv/data/client.crt"
        dest: "/etc/pki/tls/certs/client.crt"
    - name: Copy CA certificate for 802.1X authentication
      copy:
        src: "/srv/data/ca.crt"
        dest: "/etc/pki/ca-trust/source/anchors/ca.crt"
    - block:
      - import_role:
        name: linux-system-roles.network
        vars:
          network_connections:
            - name: Configure the Example-wifi profile
              interface_name: wlp1s0
              state: up
              type: wireless
              autoconnect: yes
              ip:
                dhcp4: true
                auto6: true
              wireless:
                ssid: "Example-wifi"
                key_mgmt: "wpa-eap"
              ieee802_1x:
                identity: "user_name"
```

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3. Run the playbook:

- To connect as a root user to the managed host, enter:

  ```
  # ansible-playbook -u root ~/enable-802.1x.yml
  ```

- To connect as a user to the managed host, enter:

  ```
  # ansible-playbook -u user_name --ask-become-pass ~/ethernet-static-IP.yml
  ```

  The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

  If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

Additional resources

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md` file
- `ansible-playbook(1)` man page
CHAPTER 19. MANAGING THE DEFAULT GATEWAY SETTING

The default gateway is a router that forwards network packets when no other route matches the destination of a packet. In a local network, the default gateway is typically the host that is one hop closer to the internet.

19.1. SETTING THE DEFAULT GATEWAY ON AN EXISTING CONNECTION USING NMCLI

In most situations, administrators set the default gateway when they create a connection as explained in, for example, Configuring a static Ethernet connection using nmcli.

This section describes how to set or update the default gateway on a previously created connection using the nmcli utility.

Prerequisites

- At least one static IP address must be configured on the connection on which the default gateway will be set.
- If the user is logged in on a physical console, user permissions are sufficient. Otherwise, user must have root permissions.

Procedure

1. Set the IP address of the default gateway.
   For example, to set the IPv4 address of the default gateway on the example connection to 192.0.2.1:

   ```
   $ sudo nmcli connection modify example ipv4.gateway "192.0.2.1"
   ```

   For example, to set the IPv6 address of the default gateway on the example connection to 2001:db8:1::1:

   ```
   $ sudo nmcli connection modify example ipv6.gateway "2001:db8::1"
   ```

2. Restart the network connection for changes to take effect. For example, to restart the example connection using the command line:

   ```
   $ sudo nmcli connection up example
   ```

   **WARNING**
   All connections currently using this network connection are temporarily interrupted during the restart.

3. Optionally, verify that the route is active.
   To display the IPv4 default gateway:

   ```
   $ sudo nmcli connection show example
   ```
$ ip -4 route
default via 192.0.2.1 dev example proto static metric 100

To display the IPv6 default gateway:

$ ip -6 route
default via 2001:db8:1::1 dev example proto static metric 100 pref medium

Additional resources

- Configuring a static Ethernet connection using nmcli

19.2. SETTING THE DEFAULT GATEWAY ON AN EXISTING CONNECTION USING THE NMCLI INTERACTIVE MODE

In most situations, administrators set the default gateway when they create a connection as explained in, for example, Configuring a dynamic Ethernet connection using the nmcli interactive editor.

This section describes how to set or update the default gateway on a previously created connection using the interactive mode of the nmcli utility.

Prerequisites

- At least one static IP address must be configured on the connection on which the default gateway will be set.
- If the user is logged in on a physical console, user permissions are sufficient. Otherwise, the user must have root permissions.

Procedure

1. Open the nmcli interactive mode for the required connection. For example, to open the nmcli interactive mode for the example connection:

   $ sudo nmcli connection edit example

2. Set the default gateway.
   For example, to set the IPv4 address of the default gateway on the example connection to 192.0.2.1:

   nmcli> set ipv4.gateway 192.0.2.1

   For example, to set the IPv6 address of the default gateway on the example connection to 2001:db8:1::1:

   nmcli> set ipv6.gateway 2001:db8:1::1

3. Optionally, verify that the default gateway was set correctly:

   nmcli> print
   ...
   ipv4.gateway:               192.0.2.1
4. Save the configuration:

   nmcli> **save persistent**

5. Restart the network connection for changes to take effect:

   nmcli> **activate example**

   **WARNING**
   All connections currently using this network connection are temporarily interrupted during the restart.

6. Leave the **nmcli** interactive mode:

   nmcli> **quit**

7. Optionally, verify that the route is active.
   To display the IPv4 default gateway:

   `$ **ip -4 route**
   default via 192.0.2.1 dev example proto static metric 100`

   To display the IPv6 default gateway:

   `$ **ip -6 route**
   default via 2001:db8:1::1 dev example proto static metric 100 pref medium`

**Additional resources**

- Configuring a static Ethernet connection using the **nmcli** interactive editor

**19.3. SETTING THE DEFAULT GATEWAY ON AN EXISTING CONNECTION USING NM-CONNECTION-EDITOR**

In most situations, administrators set the default gateway when they create a connection. This section describes how to set or update the default gateway on a previously created connection using the **nm-connection-editor** application.

**Prerequisites**

- At least one static IP address must be configured on the connection on which the default gateway will be set.
Procedure

1. Open a terminal, and enter `nm-connection-editor`:

   ```
   $ nm-connection-editor
   ```

2. Select the connection to modify, and click the gear wheel icon to edit the existing connection.

3. Set the IPv4 default gateway. For example, to set the IPv4 address of the default gateway on the connection to **192.0.2.1**:
   a. Open the **IPv4 Settings** tab.
   b. Enter the address in the **gateway** field next to the IP range the gateway’s address is within:

<table>
<thead>
<tr>
<th>Addresses</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>Netmask</td>
<td>Gateway</td>
</tr>
<tr>
<td>192.0.2.123</td>
<td>24</td>
<td><strong>192.0.2.1</strong></td>
</tr>
</tbody>
</table>

4. Set the IPv6 default gateway. For example, to set the IPv6 address of the default gateway on the connection to **2001:db8:1::1**:
   a. Open the **IPv6** tab.
   b. Enter the address in the **gateway** field next to the IP range the gateway’s address is within:

<table>
<thead>
<tr>
<th>Addresses</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>Prefix</td>
<td>Gateway</td>
</tr>
<tr>
<td>2001:db8:1:5</td>
<td>64</td>
<td><strong>2001:db8:1:1</strong></td>
</tr>
</tbody>
</table>

5. Click **OK**.

6. Click **Save**.

7. Restart the network connection for changes to take effect. For example, to restart the **example** connection using the command line:

   ```
   $ sudo nmcli connection up example
   ```

   **WARNING**

   All connections currently using this network connection are temporarily interrupted during the restart.

8. Optionally, verify that the route is active.
   To display the IPv4 default gateway:
$ ip -4 route
default via 192.0.2.1 dev example proto static metric 100

To display the IPv6 default gateway:

$ ip -6 route
default via 2001:db8:1::1 dev example proto static metric 100 pref medium

Additional resources
- Configuring an Ethernet connection using nm-connection-editor

19.4. SETTING THE DEFAULT GATEWAY ON AN EXISTING CONNECTION USING CONTROL-CENTER

In most situations, administrators set the default gateway when they create a connection. This section describes how to set or update the default gateway on a previously created connection using the control-center application.

Prerequisites
- At least one static IP address must be configured on the connection on which the default gateway will be set.
- The network configuration of the connection is open in the control-center application.

Procedure

1. Set the IPv4 default gateway. For example, to set the IPv4 address of the default gateway on the connection to 192.0.2.1:
   a. Open the IPv4 tab.
   b. Enter the address in the gateway field next to the IP range the gateway’s address is within:

<table>
<thead>
<tr>
<th>Addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>192.0.2.123</td>
</tr>
</tbody>
</table>

2. Set the IPv6 default gateway. For example, to set the IPv6 address of the default gateway on the connection to 2001:db8:1::1:
   a. Open the IPv6 tab.
   b. Enter the address in the gateway field next to the IP range the gateway’s address is within:

<table>
<thead>
<tr>
<th>Addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>2001:db8:1::5</td>
</tr>
</tbody>
</table>

3. Click Apply.
4. Back in the **Network** window, disable and re-enable the connection by switching the button for the connection to **Off** and back to **On** for changes to take effect.

![WARNING]

**WARNING**

All connections currently using this network connection are temporarily interrupted during the restart.

5. Optionally, verify that the route is active.

To display the IPv4 default gateway:

```
$ ip -4 route
default via 192.0.2.1 dev example proto static metric 100
```

To display the IPv6 default gateway:

```
$ ip -6 route
default via 2001:db8:1::1 dev example proto static metric 100 pref medium
```

**Additional resources**

- Configuring an Ethernet connection using control-center

### 19.5. SETTING THE DEFAULT GATEWAY ON AN EXISTING CONNECTION USING NMSTATECTL

You can set the default gateway of a network connection using the `nmstatectl` utility. This procedure describes how to set the default gateway of the existing `enp1s0` connection to **192.0.2.1**.

**Prerequisites**

- At least one static IP address must be configured on the connection on which the default gateway will be set.
- The `enp1s0` interface is configured, and the IP address of the default gateway is within the subnet of the IP configuration of this interface.
- The `nmstate` package is installed.

**Procedure**

1. Create a YAML file, for example `~/set-default-gateway.yml`, with the following contents:

   ```yaml
   ---
   routes:
   config:
   ```
- destination: 0.0.0.0/0
  next-hop-address: 192.0.2.1
  next-hop-interface: enp1s0

2. Apply the settings to the system:

```
# nmstatectl apply ~/set-default-gateway.yml
```

Additional resources

- For further details about `nmstatectl`, see the `nmstatectl(8)` man page.
- For more configuration examples, see the `/usr/share/doc/nmstate/examples/` directory.

19.6. SETTING THE DEFAULT GATEWAY ON AN EXISTING CONNECTION USING SYSTEM ROLES

You can use the `network` RHEL System Role to set the default gateway.

**IMPORTANT**

When you run a play that uses the `network` RHEL System Role, the system role overrides an existing connection profile with the same name if the value of settings does not match the ones specified in the play. Therefore, always specify the whole configuration of the network connection profile in the play, even if, for example, the IP configuration already exists. Otherwise, the role resets these values to their defaults.

Depending on whether it already exists, the procedure creates or updates the `enp1s0` connection profile with the following settings:

- A static IPv4 address - `198.51.100.20` with a `/24` subnet mask
- A static IPv6 address - `2001:db8:1::1` with a `/64` subnet mask
- An IPv4 default gateway - `198.51.100.254`
- An IPv6 default gateway - `2001:db8:1::fffe`
- An IPv4 DNS server - `198.51.100.200`
- An IPv6 DNS server - `2001:db8:1::ffbb`
- A DNS search domain - `example.com`

**Prerequisites**

- The `ansible-core` and `rhel-system-roles` packages are installed on the control node.
- If you use a different remote user than `root` when you run the playbook, this user has appropriate `sudo` permissions on the managed node.

**Procedure**
1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:

   ```
   node.example.com
   ```

2. Create the `~/ethernet-connection.yml` playbook with the following content:

   ```yaml
   ---
   - name: Configure an Ethernet connection with static IP and default gateway
     hosts: node.example.com
     become: true
     tasks:
     - include_role:
       name: rhel-system-roles.network

     vars:
     network_connections:
       - name: enp1s0
         type: ethernet
         autoconnect: yes
         ip:
           address:
             - 198.51.100.20/24
             - 2001:db8:1::1/64
         gateway4: 198.51.100.254
         gateway6: 2001:db8:1::fffe
         dns:
           - 198.51.100.200
           - 2001:db8:1::ffbb
         dns_search:
           - example.com
       state: up
   ```

3. Run the playbook:

   - To connect as `root` user to the managed host, enter:
     ```
     # ansible-playbook -u root ~/ethernet-connection.yml
     ```

   - To connect as a user to the managed host, enter:
     ```
     # ansible-playbook -u user_name --ask-become-pass ~/ethernet-connection.yml
     ```

     The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

     If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

Additional resources

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md`
- `ansible-playbook(1)` man page
19.7. HOW NETWORKMANAGER MANAGES MULTIPLE DEFAULT GATEWAYS

In certain situations, for example for fallback reasons, you set multiple default gateways on a host. However, to avoid asynchronous routing issues, each default gateway of the same protocol requires a separate metric value. Note that RHEL only uses the connection to the default gateway that has the lowest metric set.

You can set the metric for both the IPv4 and IPv6 gateway of a connection using the following command:

```
# nmcli connection modify connection-name ipv4.route-metric value ipv6.route-metric value
```

**IMPORTANT**

Do not set the same metric value for the same protocol in multiple connection profiles to avoid routing issues.

If you set a default gateway without a metric value, NetworkManager automatically sets the metric value based on the interface type. For that, NetworkManager assigns the default value of this network type to the first connection that is activated, and sets an incremented value to each other connection of the same type in the order they are activated. For example, if two Ethernet connections with a default gateway exist, NetworkManager sets a metric of 100 on the route to the default gateway of the connection that you activate first. For the second connection, NetworkManager sets 101.

The following is an overview of frequently-used network types and their default metrics:

<table>
<thead>
<tr>
<th>Connection type</th>
<th>Default metric value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VPN</td>
<td>50</td>
</tr>
<tr>
<td>Ethernet</td>
<td>100</td>
</tr>
<tr>
<td>MACsec</td>
<td>125</td>
</tr>
<tr>
<td>InfiniBand</td>
<td>150</td>
</tr>
<tr>
<td>Bond</td>
<td>300</td>
</tr>
<tr>
<td>Team</td>
<td>350</td>
</tr>
<tr>
<td>VLAN</td>
<td>400</td>
</tr>
<tr>
<td>Bridge</td>
<td>425</td>
</tr>
<tr>
<td>TUN</td>
<td>450</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>600</td>
</tr>
</tbody>
</table>
### 19.8. CONFIGURING NETWORKMANAGER TO AVOID USING A SPECIFIC PROFILE TO PROVIDE A DEFAULT GATEWAY

You can configure that NetworkManager never uses a specific profile to provide the default gateway. Follow this procedure for connection profiles that are not connected to the default gateway.

**Prerequisites**
- The NetworkManager connection profile for the connection that is not connected to the default gateway exists.

**Procedure**

1. If the connection uses a dynamic IP configuration, configure that NetworkManager does not use the connection as the default route for IPv4 and IPv6 connections:

   ```bash
   # nmcli connection modify connection_name ipv4.never-default yes ipv6.never-default yes
   
   Note that setting `ipv4.never-default` and `ipv6.never-default` to `yes`, automatically removes the default gateway’s IP address for the corresponding protocol from the connection profile.
   
2. Activate the connection:

   ```bash
   # nmcli connection up connection_name
   
   Verification steps
   - Use the `ip -4 route` and `ip -6 route` commands to verify that RHEL does not use the network interface for the default route for the IPv4 and IPv6 protocol.

### 19.9. FIXING UNEXPECTED ROUTING BEHAVIOR DUE TO MULTIPLE DEFAULT GATEWAYS

There are only a few scenarios, such as when using multipath TCP, in which you require multiple default gateways on a host. In most cases, you configure only a single default gateway to avoid unexpected routing behavior or asynchronous routing issues.
NOTE

To route traffic to different internet providers, use policy-based routing instead of multiple default gateways.

Prerequisites

- The host uses NetworkManager to manage network connections, which is the default.
- The host has multiple network interfaces.
- The host has multiple default gateways configured.

Procedure

1. Display the routing table:
   - For IPv4, enter:
     ```
     # ip -4 route
default via 192.0.2.1 dev enp1s0 proto static metric 101
default via 198.51.100.1 dev enp7s0 proto static metric 102
     ...
     ```
   - For IPv6, enter:
     ```
     # ip -6 route
default via 2001:db8:1::1 dev enp1s0 proto static metric 101 pref medium
default via 2001:db8:2::1 dev enp7s0 proto static metric 102 pref medium
     ...
     ```

   Entries starting with `default` indicate a default route. Note the interface names of these entries displayed next to `dev`.

2. Use the following commands to display the NetworkManager connections that use the interfaces you identified in the previous step:
   ```
   # nmcli -f GENERAL.CONNECTION,IP4.GATEWAY,IP6.GATEWAY device show enp1s0
   GENERAL.CONNECTION: Corporate-LAN
   IP4.GATEWAY: 192.168.122.1
   IP6.GATEWAY: 2001:db8:1::1
   
   # nmcli -f GENERAL.CONNECTION,IP4.GATEWAY,IP6.GATEWAY device show enp7s0
   GENERAL.CONNECTION: Internet-Provider
   IP4.GATEWAY: 198.51.100.1
   IP6.GATEWAY: 2001:db8:2::1
   ```

   In these examples, the profiles named `Corporate-LAN` and `Internet-Provider` have the default gateways set. Because, in a local network, the default gateway is typically the host that is one hop closer to the internet, the rest of this procedure assumes that the default gateways in the `Corporate-LAN` are incorrect.

3. Configure that NetworkManager does not use the `Corporate-LAN` connection as the default route for IPv4 and IPv6 connections:
# nmcli connection modify Corporate-LAN ipv4.never-default yes ipv6.never-default yes

Note that setting `ipv4.never-default` and `ipv6.never-default` to `yes`, automatically removes the default gateway’s IP address for the corresponding protocol from the connection profile.

4. Activate the Corporate-LAN connection:

```bash
# nmcli connection up Corporate-LAN
```

### Verification steps

- Display the IPv4 and IPv6 routing tables and verify that only one default gateway is available for each protocol:
  - For IPv4, enter:
    ```bash
    # ip -4 route
default via 192.0.2.1 dev enp1s0 proto static metric 101
    ...
    ```
  - For IPv6, enter:
    ```bash
    # ip -6 route
default via 2001:db8:1::1 dev enp1s0 proto static metric 101 pref medium
    ...
    ```

### Additional resources

- Configuring policy-based routing to define alternative routes
- Getting started with Multipath TCP
CHAPTER 20. CONFIGURING STATIC ROUTES

Routing ensures that you can send and receive traffic between mutually-connected networks. In larger environments, administrators typically configure services so that routers can dynamically learn about other routers. In smaller environments, administrators often configure static routes to ensure that traffic can reach from one network to the next.

You need static routes to achieve a functioning communication among multiple networks if all of these conditions apply:

- The traffic has to pass multiple networks.
- The exclusive traffic flow through the default gateways is not sufficient.

Section 20.1, “Example of a network that requires static routes” describes scenarios and how the traffic flows between different networks when you do not configure static routes.

20.1. EXAMPLE OF A NETWORK THAT REQUIRES STATIC ROUTES

You require static routes in this example because not all IP networks are directly connected through one router. Without the static routes, some networks cannot communicate with each other. Additionally, traffic from some networks flows only in one direction.

NOTE

The network topology in this example is artificial and only used to explain the concept of static routing. It is not a recommended topology in production environments.

For a functioning communication among all networks in this example, configure a static route to Raleigh (198.51.100.0/24) with next the hop Router 2 (203.0.113.10). The IP address of the next hop is the one of Router 2 in the data center network (203.0.113.0/24).

You can configure the static route as follows:

- For a simplified configuration, set this static route only on Router 1. However, this increases the traffic on Router 1 because hosts from the data center (203.0.113.0/24) send traffic to Raleigh (198.51.100.0/24) always through Router 1 to Router 2.

- For a more complex configuration, configure this static route on all hosts in the data center (203.0.113.0/24). All hosts in this subnet then send traffic directly to Router 2 (203.0.113.10) that is closer to Raleigh (198.51.100.0/24).

For more details between which networks traffic flows or not, see the explanations below the diagram.
In case that the required static routes are not configured, the following describes in which situations the communication works and does not work:

- Hosts in the Berlin network (192.0.2.0/24):
  - Can communicate with other hosts in the same subnet because they are directly connected.
  - Can communicate with the Internet because Router 1 is in the Berlin network (192.0.2.0/24) and has a default gateway, which leads to the Internet.
  - Can communicate with the data center network (203.0.113.0/24) because Router 1 has interfaces in both the Berlin (192.0.2.0/24) and the data center (203.0.113.0/24) networks.
  - Cannot communicate with the Raleigh network (198.51.100.0/24) because Router 1 has no interface in this network. Therefore, Router 1 sends the traffic to its own default gateway (Internet).

- Hosts in the data center network (203.0.113.0/24):
  - Can communicate with other hosts in the same subnet because they are directly connected.
  - Can communicate with the Internet because they have their default gateway set to Router 1, and Router 1 has interfaces in both networks, the data center (203.0.113.0/24) and to the Internet.
Can communicate with the Berlin network (192.0.2.0/24) because they have their default gateway set to Router 1, and Router 1 has interfaces in both the data center (203.0.113.0/24) and the Berlin (192.0.2.0/24) networks.

Cannot communicate with the Raleigh network (198.51.100.0/24) because the data center network has no interface in this network. Therefore, hosts in the data center network (203.0.113.0/24) send traffic to their default gateway (Router 1). Router 1 also has no interface in the Raleigh network (198.51.100.0/24) and, as a result, Router 1 sends this traffic to its own default gateway (Internet).

- Hosts in the Raleigh network (198.51.100.0/24):
  - Can communicate with other hosts in the same subnet because they are directly connected.
  - Cannot communicate with hosts on the Internet. Router 2 sends the traffic to Router 1 because of the default gateway settings. The actual behavior of Router 1 depends on the reverse path filter (rp_filter) system control (sysctl) setting. By default on RHEL, Router 1 drops the outgoing traffic instead of routing it to the Internet. However, regardless of the configured behavior, communication is not possible without the static route.

- Cannot communicate with the data center network (203.0.113.0/24). The outgoing traffic reaches the destination through Router 2 because of the default gateway setting. However, replies to packets do not reach the sender because hosts in the data center network (203.0.113.0/24) send replies to their default gateway (Router 1). Router 1 then sends the traffic to the Internet.

- Cannot communicate with the Berlin network (192.0.2.0/24). Router 2 sends the traffic to Router 1 because of the default gateway settings. The actual behavior of Router 1 depends on the rp_filter sysctl setting. By default on RHEL, Router 1 drops the outgoing traffic instead of sending it to the Berlin network (192.0.2.0/24). However, regardless of the configured behavior, communication is not possible without the static route.

**NOTE**

In addition to configuring the static routes, you must enable IP forwarding on both routers.

**Additional resources**

- Why can’t a server be pinged if net.ipv4.conf.all_rp_filter is set on the server?
- Enabling IP forwarding

**20.2. HOW TO USE THE NMCLI COMMAND TO CONFIGURE A STATIC ROUTE**

To configure a static route, use the `nmcli` utility with the following syntax:

```bash
$ nmcli connection modify connection_name ipv4.routes "ip[/prefix] [next_hop] [metric] [attribute=value] [attribute=value] ...
```

The command supports the following route attributes:

- **cwnd=n**: Sets the congestion window (CWND) size, defined in number of packets.
- lock-cwnd=true|false: Defines whether or not the kernel can update the CWND value.
- lock-mtu=true|false: Defines whether or not the kernel can update the MTU to path MTU discovery.
- lock-window=true|false: Defines whether or not the kernel can update the maximum window size for TCP packets.
- mtu=n: Sets the maximum transfer unit (MTU) to use along the path to the destination.
- onlink=true|false: Defines whether the next hop is directly attached to this link even if it does not match any interface prefix.
- scope=n: For an IPv4 route, this attribute sets the scope of the destinations covered by the route prefix. Set the value as an integer (0-255).
- src=address: Sets the source address to prefer when sending traffic to the destinations covered by the route prefix.
- table=table_id: Sets the ID of the table the route should be added to. If you omit this parameter, NetworkManager uses the main table.
- tos=n: Sets the type of service (TOS) key. Set the value as an integer (0-255).
- type=value: Sets the route type. NetworkManager supports the unicast, local, blackhole, unreachable, prohibit, and throw route types. The default is unicast.
- window=n: Sets the maximal window size for TCP to advertise to these destinations, measured in bytes.

If you use the ipv4.routes sub-command, nmcli overrides all current settings of this parameter.

To add a route:

```
$ nmcli connection modify connection_name +ipv4.routes "..."
```

Similarly, to remove a specific route:

```
$ nmcli connection modify connection_name -ipv4.routes "..."
```

### 20.3. CONFIGURING A STATIC ROUTE USING AN NMCLI COMMAND

You can add a static route to an existing NetworkManager connection profile using the nmcli connection modify command.

This procedure configures the following routes:

- An IPv4 route to the remote 198.51.100.0/24 network. The corresponding gateway with the IP address 192.0.2.10 is reachable through the example connection.
- An IPv6 route to the remote 2001:db8:2::/64 network. The corresponding gateway with the IP address 2001:db8:1::10 is reachable through the example connection.

### Prerequisites
The `example` connection profile exists and it configures this host to be in the same IP subnet as the gateways.

Procedure

1. Add the static IPv4 route to the `example` connection profile:

   ```
   # nmcli connection modify example +ipv4.routes "198.51.100.0/24 192.0.2.10"
   ```

   To set multiple routes in one step, pass the individual routes comma-separated to the command. For example, to add a route to the 198.51.100.0/24 and 203.0.113.0/24 networks, both routed through the 192.0.2.10 gateway, enter:

   ```
   # nmcli connection modify example +ipv4.routes "198.51.100.0/24 192.0.2.10, 203.0.113.0/24 192.0.2.10"
   ```

2. Add the static IPv6 route to the `example` connection profile:

   ```
   # nmcli connection modify example +ipv6.routes "2001:db8:2::/64 2001:db8:1::10"
   ```

3. Re-activate the connection:

   ```
   # nmcli connection up example
   ```

Verification

1. Display the IPv4 routes:

   ```
   # ip -4 route
   ...
   198.51.100.0/24 via 192.0.2.10 dev enp1s0
   ```

2. Display the IPv6 routes:

   ```
   # ip -6 route
   ...
   2001:db8:2::/64 via 2001:db8:1::10 dev enp1s0 metric 1024 pref medium
   ```

Additional resources

- The `nmcli(1)` man page
- The `nm-settings-nmcli(5)` man page

### 20.4. CONFIGURING A STATIC ROUTE USING NMTUI

The `nmtui` application provides a text-based user interface for NetworkManager. You can use `nmtui` to configure static routes on a host without a graphical interface.

This procedure describes how to add a route to the 192.0.2.0/24 network that uses the gateway running on 198.51.100.1, which is reachable through an existing connection profile.
In nmtui:

- Navigate by using the cursor keys.
- Press a button by selecting it and hitting Enter.
- Select and deselect checkboxes by using Space.

Prerequisites

- The network is configured.
- The gateway for the static route must be directly reachable on the interface.
- If the user is logged in on a physical console, user permissions are sufficient. Otherwise, the command requires root permissions.

Procedure

1. Start nmtui:

   # nmtui

2. Select Edit a connection, and press Enter.

3. Select the connection profile through which you can reach the next hop to the destination network, and press Enter.

4. Depending on whether it is an IPv4 or IPv6 route, press the Show button next to the protocol’s configuration area.

5. Press the Edit button next to Routing. This opens a new window where you configure static routes:

   a. Press the Add button and fill in:

      - The destination network, including the prefix in Classless Inter-Domain Routing (CIDR) format
      - The IP address of the next hop
      - A metric value, if you add multiple routes to the same network and want to prioritize the routes by efficiency

   b. Repeat the previous step for every route you want to add and that is reachable through this connection profile.

   c. Press the OK button to return to the window with the connection settings.
6. Press the **OK** button to return to the **nmtui** main menu.

7. Select **Activate a connection** and press **Enter**.

8. Select the connection profile that you edited, and press **Enter** twice to deactivate and activate it again.

**IMPORTANT**

Skip this step if you run **nmtui** over a remote connection, such as SSH, that uses the connection profile you want to reactivate. In this case, if you would deactivate it in **nmtui**, the connection is terminated and, consequently, you cannot activate it again. To avoid this problem, use the **nmcli connection connection_profile_name up** command to reactivate the connection in the mentioned scenario.

9. Press the **Back** button to return to the main menu.

10. Select **Quit**, and press **Enter** to close the **nmtui** application.

**Verification**

- Verify that the route is active:

  ```
  $ ip route
  ...
  192.0.2.0/24 via 198.51.100.1 dev example proto static metric 100
  ```

**20.5. CONFIGURING A STATIC ROUTE USING CONTROL-CENTER**

You can use **control-center** in GNOME to add a static route to the configuration of a network connection.

This procedure configures the following routes:

- An IPv4 route to the remote **198.51.100.0/24** network. The corresponding gateway has the IP address **192.0.2.10**.

- An IPv6 route to the remote **2001:db8:2::/64** network. The corresponding gateway has the IP address **2001:db8:1::10**.

**Prerequisites**

- The network is configured.
• This host is in the same IP subnet as the gateways.

• The network configuration of the connection is opened in the control-center application. See Configuring an Ethernet connection using nm-connection-editor.

Procedure

1. On the IPv4 tab:

   a. Optional: Disable automatic routes by clicking the On button in the Routes section of the IPv4 tab to use only static routes. If automatic routes are enabled, Red Hat Enterprise Linux uses static routes and routes received from a DHCP server.

   b. Enter the address, netmask, gateway, and optionally a metric value of the IPv4 route:

   ![IPv4 Route Table]

2. On the IPv6 tab:

   a. Optional: Disable automatic routes by clicking the On button in the Routes section of the IPv4 tab to use only static routes.

   b. Enter the address, netmask, gateway, and optionally a metric value of the IPv6 route:

   ![IPv6 Route Table]

3. Click Apply.

4. Back in the Network window, disable and re-enable the connection by switching the button for the connection to Off and back to On for changes to take effect.

   ![WARNING]

   Restarting the connection briefly disrupts connectivity on that interface.

Verification

1. Display the IPv4 routes:

   ```
   # ip -4 route
   ... 
   198.51.100.0/24 via 192.0.2.10 dev enp1s0
   ```

2. Display the IPv6 routes:
20.6. CONFIGURING A STATIC ROUTE USING NM-CONNECTION-EDITOR

You can use the `nm-connection-editor` application to add a static route to the configuration of a network connection.

This procedure configures the following routes:

- An IPv4 route to the remote `198.51.100.0/24` network. The corresponding gateway with the IP address `192.0.2.10` is reachable through the `example` connection.
- An IPv6 route to the remote `2001:db8:2::/64` network. The corresponding gateway with the IP address `2001:db8:1::10` is reachable through the `example` connection.

Prerequisites

- The network is configured.
- This host is in the same IP subnet as the gateways.

Procedure

1. Open a terminal, and enter `nm-connection-editor`:

   $ `nm-connection-editor`

2. Select the `example` connection profile, and click the gear wheel icon to edit the existing connection.

3. On the IPv4 Settings tab:
   a. Click the Routes button.
   b. Click the Add button and enter the address, netmask, gateway, and optionally a metric value.
   c. Click OK.

4. On the IPv6 Settings tab:
   a. Click the Routes button.
b. Click the **Add** button and enter the address, netmask, gateway, and optionally a metric value.

![Editing IPv6 routes for example](image)

<table>
<thead>
<tr>
<th>Address</th>
<th>Prefix</th>
<th>Gateway</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001:db8:2::</td>
<td>64</td>
<td>2001:db8:1::10</td>
<td></td>
</tr>
</tbody>
</table>

C. Click **OK**.

5. Click **Save**.

6. Restart the network connection for changes to take effect. For example, to restart the **example** connection using the command line:

```
# nmcli connection up example
```

### Verification

1. Display the IPv4 routes:

```
# ip -4 route
...
198.51.100.0/24 via 192.0.2.10 dev enp1s0
```

2. Display the IPv6 routes:

```
# ip -6 route
...
2001:db8:2::/64 via 2001:db8:1::10 dev enp1s0 metric 1024 pref medium
```

### 20.7. Configuring a Static Route Using the **nmcli** Interactive Mode

You can use the interactive mode of the **nmcli** utility to add a static route to the configuration of a network connection.

This procedure configures the following routes:

- An IPv4 route to the remote **198.51.100.0/24** network. The corresponding gateway with the IP address **192.0.2.10** is reachable through the **example** connection.

- An IPv6 route to the remote **2001:db8:2::/64** network. The corresponding gateway with the IP address **2001:db8:1::10** is reachable through the **example** connection.

### Prerequisites

- The **example** connection profile exists and it configures this host to be in the same IP subnet as the gateways.
Procedure

1. Open the `nmcli` interactive mode for the example connection:

   ```
   # nmcli connection edit example
   ```

2. Add the static IPv4 route:

   ```
   nmcli> set ipv4.routes 198.51.100.0/24 192.0.2.10
   ```

3. Add the static IPv6 route:

   ```
   nmcli> set ipv6.routes 2001:db8:2::/64 2001:db8:1::10
   ```

4. Optionally, verify that the routes were added correctly to the configuration:

   ```
   nmcli> print
   ...
   ipv4.routes: { ip = 198.51.100.0/24, nh = 192.0.2.10 }
   ...
   ipv6.routes: { ip = 2001:db8:2::/64, nh = 2001:db8:1::10 }
   ...
   ```

   The `ip` attribute displays the network to route and the `nh` attribute the gateway (next hop).

5. Save the configuration:

   ```
   nmcli> save persistent
   ```

6. Restart the network connection:

   ```
   nmcli> activate example
   ```

7. Leave the `nmcli` interactive mode:

   ```
   nmcli> quit
   ```

Verification

1. Display the IPv4 routes:

   ```
   # ip -4 route
   ...
   198.51.100.0/24 via 192.0.2.10 dev enp1s0
   ```

2. Display the IPv6 routes:

   ```
   # ip -6 route
   ...
   2001:db8:2::/64 via 2001:db8:1::10 dev enp1s0 metric 1024 pref medium
   ```

Additional resources
20.8. CONFIGURING A STATIC ROUTE USING NMSTATECTL

You can add a static route to the configuration of a network connection using the `nmstatectl` utility.

This procedure configures the following routes:

- An IPv4 route to the remote `198.51.100.0/24` network. The corresponding gateway with the IP address `192.0.2.10` is reachable through the `enp1s0` interface.
- An IPv6 route to the remote `2001:db8:2::/64` network. The corresponding gateway with the IP address `2001:db8:1::10` is reachable through the `enp1s0` interface.

Prerequisites

- The `enp1s0` network interface is configured and is in the same IP subnet as the gateways.
- The `nmstate` package is installed.

Procedure

1. Create a YAML file, for example `~/add-static-route-to-enp1s0.yml`, with the following contents:

   ```yaml
   ---
   routes:
   config:
   - destination: 198.51.100.0/24
     next-hop-address: 192.0.2.10
     next-hop-interface: enp1s0
   - destination: 2001:db8:2::/64
     next-hop-address: 2001:db8:1::10
     next-hop-interface: enp1s0
   ```

2. Apply the settings to the system:

   ```
   # nmstatectl apply ~/add-static-route-to-enp1s0.yml
   ```

Verification

1. Display the IPv4 routes:

   ```
   # ip -4 route
   ...
   198.51.100.0/24 via 192.0.2.10 dev enp1s0
   ```

2. Display the IPv6 routes:

   ```
   # ip -6 route
   ...
   2001:db8:2::/64 via 2001:db8:1::10 dev enp1s0 metric 1024 pref medium
   ```
20.9. CONFIGURING A STATIC ROUTE USING RHEL SYSTEM ROLES

You can use the network RHEL System Role to configure static routes.

IMPORTANT

When you run a play that uses the network RHEL System Role, the system role overrides an existing connection profile with the same name if the value of settings does not match the ones specified in the play. Therefore, always specify the whole configuration of the network connection profile in the play, even if, for example, the IP configuration already exists. Otherwise, the role resets these values to their defaults.

Depending on whether it already exists, the procedure creates or updates the enp7s0 connection profile with the following settings:

- A static IPv4 address - 192.0.2.1 with a /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with a /64 subnet mask
- An IPv4 default gateway - 192.0.2.254
- An IPv6 default gateway - 2001:db8:1::fffe
- An IPv4 DNS server - 192.0.2.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com
- Static routes:
  - 198.51.100.0/24 with gateway 192.0.2.10
  - 2001:db8:2::/64 with gateway 2001:db8:1::10

Prerequisites

- The ansible-core and rhel-system-roles packages are installed on the control node.
- If you use a different remote user than root when you run the playbook, this user has appropriate sudo permissions on the managed node.

Procedure

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the /etc/ansible/hosts Ansible inventory file:

   node.example.com
2. Create the `~/add-static-routes.yml` playbook with the following content:

```yaml
- name: Configure an Ethernet connection with static IP and additional routes
  hosts: node.example.com
  become: true
  tasks:
    - include_role:
        name: rhel-system-roles.network
  vars:
    network_connections:
      - name: enp7s0
        type: ethernet
        autoconnect: yes
        ip:
          address:
            - 192.0.2.1/24
            - 2001:db8:1::1/64
        gateway4: 192.0.2.254
        gateway6: 2001:db8:1::fffe
        dns:
          - 192.0.2.200
          - 2001:db8:1::ffbb
        dns_search:
          - example.com
        route:
          - network: 198.51.100.0
            prefix: 24
            gateway: 192.0.2.10
          - network: 2001:db8:2::
            prefix: 64
            gateway: 2001:db8:1::10
          state: up
```

3. Run the playbook:

- To connect as root user to the managed host, enter:

  ```
  # ansible-playbook -u root ~/add-static-routes.yml
  ```

- To connect as a user to the managed host, enter:

  ```
  # ansible-playbook -u user_name --ask-become-pass ~/add-static-routes.yml
  ```

  The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

  If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

**Verification steps**

1. Display the IPv4 routes:
# ip -4 route
...
198.51.100.0/24 via 192.0.2.10 dev enp7s0

2. Display the IPv6 routes:

# ip -6 route
...
2001:db8:2::/64 via 2001:db8:1::10 dev enp7s0 metric 1024 pref medium

Additional resources

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md`
- `ansible-playbook(1)`
CHAPTER 21. CONFIGURING POLICY-BASED ROUTING TO DEFINE ALTERNATIVE ROUTES

By default, the kernel in RHEL decides where to forward network packets based on the destination address using a routing table. Policy-based routing enables you to configure complex routing scenarios. For example, you can route packets based on various criteria, such as the source address, packet metadata, or protocol.

This section describes how to configure policy-based routing using NetworkManager.

NOTE

On systems that use NetworkManager, only the nmcli utility supports setting routing rules and assigning routes to specific tables.

21.1. ROUTING TRAFFIC FROM A SPECIFIC SUBNET TO A DIFFERENT DEFAULT GATEWAY USING NETWORKMANAGER

You can use policy-based routing to configure a different default gateway for traffic from certain subnets. For example, you can configure RHEL as a router that, by default, routes all traffic to Internet provider A using the default route. However, traffic received from the internal workstations subnet is routed to provider B.

The procedure assumes the following network topology:

Prerequisites

- The system uses NetworkManager to configure the network, which is the default.
- The RHEL router you want to set up in the procedure has four network interfaces:
  - The enp7s0 interface is connected to the network of provider A. The gateway IP in the provider’s network is 198.51.100.2, and the network uses a /30 network mask.
  - The enp1s0 interface is connected to the network of provider B. The gateway IP in the provider’s network is 192.0.2.2, and the network uses a /30 network mask.
The `enp8s0` interface is connected to the `10.0.0.0/24` subnet with internal workstations. The `enp9s0` interface is connected to the `203.0.113.0/24` subnet with the company’s servers.

- Hosts in the internal workstations subnet use `10.0.0.1` as the default gateway. In the procedure, you assign this IP address to the `enp8s0` network interface of the router.
- Hosts in the server subnet use `203.0.113.1` as the default gateway. In the procedure, you assign this IP address to the `enp9s0` network interface of the router.
- The `firewalld` service is enabled and active.

### Procedure

1. Configure the network interface to provider A:

   ```
   # nmcli connection add type ethernet con-name Provider-A ifname enp7s0
   ipv4.method manual ipv4.addresses 198.51.100.1/30 ipv4.gateway 198.51.100.2
   ipv4.dns 198.51.100.200 connection.zone external
   ```

   The `nmcli connection add` command creates a NetworkManager connection profile. The following list describes the options of the command:

   - `type ethernet`: Defines that the connection type is Ethernet.
   - `con-name connection_name`: Sets the name of the profile. Use a meaningful name to avoid confusion.
   - `ifname network_device`: Sets the network interface.
   - `ipv4.method manual`: Enables to configure a static IP address.
   - `ipv4.addresses IP_address/subnet_mask`: Sets the IPv4 addresses and subnet mask.
   - `ipv4.gateway IP_address`: Sets the default gateway address.
   - `ipv4.dns IP_of_DNS_server`: Sets the IPv4 address of the DNS server.
   - `connection.zone firewalld_zone`: Assigns the network interface to the defined `firewalld` zone. Note that `firewalld` automatically enables masquerading for interfaces assigned to the `external` zone.

2. Configure the network interface to provider B:

   ```
   # nmcli connection add type ethernet con-name Provider-B ifname enp1s0
   ipv4.method manual ipv4.addresses 192.0.2.1/30 ipv4.routes "0.0.0.0/0 192.0.2.2 table=5000" connection.zone external
   ```

   This command uses the `ipv4.routes` parameter instead of `ipv4.gateway` to set the default gateway. This is required to assign the default gateway for this connection to a different routing table (5000) than the default. NetworkManager automatically creates this new routing table when the connection is activated.

3. Configure the network interface to the internal workstations subnet:
# nmcli connection add type ethernet con-name Internal-Workstations ifname enp8s0 ipv4.method manual ipv4.addresses 10.0.0.1/24 ipv4.routes "10.0.0.0/24 table=5000" ipv4.routing-rules "priority 5 from 10.0.0.0/24 table 5000" connection.zone trusted

This command uses the ipv4.routes parameter to add a static route to the routing table with ID 5000. This static route for the 10.0.0.0/24 subnet uses the IP of the local network interface to provider B (192.0.2.1) as next hop.

Additionally, the command uses the ipv4.routing-rules parameter to add a routing rule with priority 5 that routes traffic from the 10.0.0.0/24 subnet to table 5000. Low values have a high priority.

Note that the syntax in the ipv4.routing-rules parameter is the same as in an ip rule add command, except that ipv4.routing-rules always requires specifying a priority.

4. Configure the network interface to the server subnet:

# nmcli connection add type ethernet con-name Servers ifname enp9s0 ipv4.method manual ipv4.addresses 203.0.113.1/24 connection.zone trusted

Verification steps

1. On a RHEL host in the internal workstation subnet:
   a. Install the traceroute package:

      # dnf install traceroute

   b. Use the traceroute utility to display the route to a host on the Internet:

      # traceroute redhat.com
      traceroute to redhat.com (209.132.183.105), 30 hops max, 60 byte packets
      1 10.0.0.1 (10.0.0.1)   0.337 ms  0.260 ms  0.223 ms
      2 192.0.2.1 (192.0.2.1) 0.884 ms  1.066 ms  1.248 ms
      ...

      The output of the command displays that the router sends packets over 192.0.2.1, which is the network of provider B.

2. On a RHEL host in the server subnet:
   a. Install the traceroute package:

      # dnf install traceroute

   b. Use the traceroute utility to display the route to a host on the Internet:

      # traceroute redhat.com
      traceroute to redhat.com (209.132.183.105), 30 hops max, 60 byte packets
      1 203.0.113.1 (203.0.113.1) 2.179 ms  2.073 ms  1.944 ms
      2 198.51.100.2 (198.51.100.2) 1.868 ms  1.798 ms  1.549 ms
      ...


The output of the command displays that the router sends packets over 198.51.100.2, which is the network of provider A.

Troubleshooting steps

On the RHEL router:

1. Display the rule list:

   ```
   # ip rule list
   0: from all lookup local
   5: from 10.0.0.0/24 lookup 5000
       32766: from all lookup main
       32767: from all lookup default
   ```

   By default, RHEL contains rules for the tables **local**, **main**, and **default**.

2. Display the routes in table **5000**:

   ```
   # ip route list table 5000
   0.0.0.0/0 via 192.0.2.2 dev enp1s0 proto static metric 100
   10.0.0.0/24 dev enp8s0 proto static scope link src 192.0.2.1 metric 102
   ```

3. Display the interfaces and firewall zones:

   ```
   # firewall-cmd --get-active-zones
   external interfaces: enp1s0 enp7s0
   trusted interfaces: enp8s0 enp9s0
   ```

4. Verify that the **external** zone has masquerading enabled:

   ```
   # firewall-cmd --info-zone=external
   external (active)
   target: default
   icmp-block-inversion: no
   interfaces: enp1s0 enp7s0
   sources:
   services: ssh
   ports:
   protocols:
   masquerade: yes
   ... 
   ```

Additional resources

- The **IPv4 settings** section in the `nm-settings(5)` man page
- The **Connection settings** section in the `nm-settings(5)` man page
- The **Connection management commands** section in the `nmcli(1)` man page
- **Is it possible to set up Policy Based Routing with NetworkManager in RHEL?**
CHAPTER 22. CREATING A DUMMY INTERFACE

As a Red Hat Enterprise Linux user, you can create and use dummy network interfaces for debugging and testing purposes. A dummy interface provides a device to route packets without actually transmitting them. It enables you to create additional loopback-like devices managed by NetworkManager and makes an inactive SLIP (Serial Line Internet Protocol) address look like a real address for local programs.

22.1. CREATING A DUMMY INTERFACE WITH BOTH AN IPV4 AND IPV6 ADDRESS USING NMCLI

You can create a dummy interface with various settings. This procedure describes how to create a dummy interface with both an IPv4 and IPv6 address. After creating the dummy interface, NetworkManager automatically assigns it to the default `public` firewall zone.

NOTE

To configure a dummy interface without IPv4 or IPv6 address, set the `ipv4.method` and `ipv6.method` parameters to `disabled`. Otherwise, IP auto-configuration fails, and NetworkManager deactivates the connection and removes the dummy device.

Procedure

1. To create a dummy interface named `dummy0` with static IPv4 and IPv6 addresses, enter:
   
   ```
   # nmcli connection add type dummy ifname dummy0 ipv4.method manual ipv4.addresses 192.0.2.1/24 ipv6.method manual ipv6.addresses 2001:db8:2::1/64
   ```

2. Optional: To view the dummy interface, enter:
   
   ```
   # nmcli connection show
   NAME        UUID                                TYPE      DEVICE
   enp1s0      db1060e9-c164-476f-b2b5-caec62dc1b05  ethernet  ens3
   dummy-dummy0 aaf6eb56-73e5-4746-9037-eed42caa8a65  dummy    dummy0
   ```

Additional resources

- The `nm-settings(5)` man page
CHAPTER 23. USING NMSTATE-AUTOCONF TO AUTOMATICALLY CONFIGURE THE NETWORK STATE USING LLDP

Network devices can use the Link Layer Discovery Protocol (LLDP) to advertise their identity, capabilities, and neighbors in a LAN. The nmstate-autoconf utility can use this information to automatically configure local network interfaces.

IMPORTANT

The nmstate-autoconf utility is provided as a Technology Preview only. Technology Preview features are not supported with Red Hat production Service Level Agreements (SLAs), might not be functionally complete, and Red Hat does not recommend using them for production. These previews provide early access to upcoming product features, enabling customers to test functionality and provide feedback during the development process.

See Technology Preview Features Support Scope on the Red Hat Customer Portal for information about the support scope for Technology Preview features.

23.1. USING NMSTATE-AUTOCONF TO AUTOMATICALLY CONFIGURE NETWORK INTERFACES

The nmstate-autoconf utility uses LLDP to identify the VLAN settings of interfaces connected to a switch to configure local devices.

This procedure assumes the following scenario and that the switch broadcasts the VLAN settings using LLDP:

- The enp1s0 and enp2s0 interfaces of the RHEL server are connected to switch ports that are configured with VLAN ID 100 and VLAN name prod-net.
- The enp3s0 interface of the RHEL server is connected to a switch port that is configured with VLAN ID 200 and VLAN name mgmt-net.

The nmstate-autoconf utility then uses this information to create the following interfaces on the server:

- bond100 - A bond interface with enp1s0 and enp2s0 as ports.
- prod-net - A VLAN interface on top of bond100 with VLAN ID 100.
- mgmt-net - A VLAN interface on top of enp3s0 with VLAN ID 200

If you connect multiple network interfaces to different switch ports for which LLDP broadcasts the same VLAN ID, nmstate-autoconf creates a bond with these interfaces and, additionally, configures the common VLAN ID on top of it.

Prerequisites

- The nmstate package is installed.
- LLDP is enabled on the network switch.
- The Ethernet interfaces are up.
Procedure

1. Enable LLDP on the Ethernet interfaces:
   
   a. Create a YAML file, for example `~/enable-lldp.yml`, with the following contents:

   ```yaml
   interfaces:
   - name: enp1s0
     type: ethernet
     lldp:
       enabled: true
   - name: enp2s0
     type: ethernet
     lldp:
       enabled: true
   - name: enp3s0
     type: ethernet
     lldp:
       enabled: true
   
   b. Apply the settings to the system:

   ```
   # nmstatectl apply ~/enable-lldp.yml
   ```

2. Configure the network interfaces using LLDP:

   a. Optional, start a dry-run to display and verify the YAML configuration that `nmstate-autoconf` generates:

   ```
   # nmstate-autoconf -d enp1s0,enp2s0,enp3s0
   ---
   interfaces:
   - name: prod-net
     type: vlan
     state: up
     vlan:
       base-iface: bond100
       id: 100
   - name: mgmt-net
     type: vlan
     state: up
     vlan:
       base-iface: enp3s0
       id: 200
   - name: bond100
     type: bond
     state: up
     link-aggregation:
       mode: balance-rr
       port:
       - enp1s0
       - enp2s0
   ```

   b. Use `nmstate-autoconf` to generate the configuration based on information received from LLDP, and apply the settings to the system:
Next steps

- If there is no DHCP server in your network that provides the IP settings to the interfaces, configure them manually. For details, see:
  - Configuring an Ethernet connection
  - Configuring network bonding

Verification

1. Display the settings of the individual interfaces:

   ```
   # nmstatectl show <interface_name>
   ```

Additional resources

- The `nmstate-autoconf(8)` man page
CHAPTER 24. USING LLDP TO DEBUG NETWORK CONFIGURATION PROBLEMS

You can use the Link Layer Discovery Protocol (LLDP) to debug network configuration problems in the topology. This means that, LLDP can report configuration inconsistencies with other hosts or routers and switches.

24.1. DEBUGGING AN INCORRECT VLAN CONFIGURATION USING LLDP INFORMATION

If you configured a switch port to use a certain VLAN and a host does not receive these VLAN packets, you can use the Link Layer Discovery Protocol (LLDP) to debug the problem. Perform this procedure on the host that does not receive the packets.

Prerequisites

- The `nmstate` package is installed.
- The switch supports LLDP.
- LLDP is enabled on neighbor devices.

Procedure

1. Create the `~/enable-LLDP-enp1s0.yml` file with the following content:

   ```yaml
   interfaces:
     - name: enp1s0
       type: ethernet
       lldp:
         enabled: true
   ```

2. Use the `~/enable-LLDP-enp1s0.yml` file to enable LLDP on interface `enp1s0`:

   ```bash
   # nmstatectl apply ~/enable-LLDP-enp1s0.yml
   ```

3. Display the LLDP information:

   ```bash
   # nmstatectl show enp1s0
   - name: enp1s0
     type: ethernet
     state: up
     ipv4:
       enabled: false
dhcp: false
     ipv6:
       enabled: false
     autoconf: false
dhcp6: false
     lldp:
       enabled: true
     neighbors:
       - type: 5
   ```
system-name: Summit300-48
- type: 6
  system-description: Summit300-48 - Version 7.4e.1 (Build 5) 05/27/05 04:53:11
- type: 7
  system-capabilities:
    - MAC Bridge component
    - Router
  - type: 1
    _description: MAC address
    chassis-id: 00:01:30:F9:AD:A0
    chassis-id-type: 4
  - type: 2
    _description: Interface name
    port-id: 1/1
    port-id-type: 5
  - type: 127
    ieee-802-1-vlans:
    - name: v2-0488-03-0505
      vid: 488
      oui: 00:80:c2
      subtype: 3
  - type: 127
    ieee-802-3-mac-phy-conf:
      autoneg: true
      operational-mau-type: 16
      pmd-autoneg-cap: 27648
      oui: 00:12:0f
      subtype: 1
  - type: 127
    ieee-802-3-ppvids:
    - 0
      oui: 00:80:c2
      subtype: 2
  - type: 8
    management-addresses:
    - address: 00:01:30:F9:AD:A0
      address-subtype: MAC
      interface-number: 1001
      interface-number-subtype: 2
  - type: 127
    ieee-802-3-max-frame-size: 1522
    oui: 00:12:0f
    subtype: 4
    mac-address: 82:75:BE:6F:8C:7A
    mtu: 1500

4. Verify the output to ensure that the settings match your expected configuration. For example, the LLDP information of the interface connected to the switch shows that the switch port this host is connected to uses VLAN ID 448:

  - type: 127
    ieee-802-1-vlans:
    - name: v2-0488-03-0505
      vid: 488
If the network configuration of the `enp1s0` interface uses a different VLAN ID, change it accordingly.

Additional resources

Configuring VLAN tagging
CHAPTER 25. MANUALLY CREATING NETWORKMANAGER PROFILES IN KEYFILE FORMAT

By default, NetworkManager stores profiles in the keyfile format. For example, the `nmcli` utility, the `network` RHEL System Role, or the `nmstate` API to manage profiles use this format. However, NetworkManager still supports profiles in the deprecated `ifcfg` format.

25.1. THE KEYFILE FORMAT OF NETWORKMANAGER PROFILES

NetworkManager uses the INI-style keyfile format when it stores connection profiles on disk.

Example of an Ethernet connection profile in keyfile format

```
[connection]
id=example_connection
uuid=82c6272d-1ff7-4d56-9c7c-0eb27c300029
type=ethernet
autoconnect=true

[ipv4]
method=auto

[ipv6]
method=auto

[ethernet]
mac-address=00:53:00:8f:fa:66
```

Each section corresponds to a NetworkManager setting name as described in the `nm-settings(5)` and `nm-settings-keyfile(5)` man pages. Each key-value-pair in a section is one of the properties listed in the settings specification of the man page.

Most variables in NetworkManager keyfiles have a one-to-one mapping. This means that a NetworkManager property is stored in the keyfile as a variable of the same name and in the same format. However, there are exceptions, mainly to make the keyfile syntax easier to read. For a list of these exceptions, see the `nm-settings-keyfile(5)` man page.

**IMPORTANT**

For security reasons, because connection profiles can contain sensitive information, such as private keys and passphrases, NetworkManager uses only configuration files owned by the `root` and that are only readable and writable by `root`.

Depending on the purpose of the connection profile, save it in one of the following directories:

- `/etc/NetworkManager/system-connections/`: The general location for persistent profiles created by the user that can also be edited. NetworkManager copies them automatically to `/etc/NetworkManager/system-connections/`.
- `/run/NetworkManager/system-connections/`: For temporary profiles that are automatically removed when you reboot the system.
NetworkManager does not automatically reload profiles from disk. When you create or update a connection profile in keyfile format, use the `nmcli connection reload` command to inform NetworkManager about the changes.

### 25.2. CREATING A NETWORKMANAGER PROFILE IN KEYFILE FORMAT

This section explains a general procedure on how to manually create a NetworkManager connection profile in keyfile format.

**NOTE**

Manually creating or updating the configuration files can result in an unexpected or non-functional network configuration. Red Hat recommends that you use NetworkManager utilities, such as `nmcli`, the `network` RHEL System Role, or the `nmstate` API to manage NetworkManager connections.

**Procedure**

1. If you create a profile for a hardware interface, such as Ethernet, display the MAC address of this interface:

   ```bash
   # ip address show enp1s0
   2: enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP
       group default qlen 1000
       link/ether 00:53:00:8f:fa:66 brd ff:ff:ff:ff:ff:ff
   ```

2. Create a connection profile. For example, for a connection profile of an Ethernet device that uses DHCP, create the `/etc/NetworkManager/system-connections/example.nmconnection` file with the following content:

   ```yaml
   [connection]
   id=example_connection
   type=ethernet
   autoconnect=true

   [ipv4]
   method=auto

   [ipv6]
   method=auto

   [ethernet]
   mac-address=00:53:00:8f:fa:66
   ```
NOTE

You can use any file name with a .nmconnection suffix. However, when you later use nmcli commands to manage the connection, you must use the connection name set in the id variable when you refer to this connection. When you omit the id variable, use the file name without the .nmconnection to refer to this connection.

3. Set permissions on the configuration file so that only the root user can read and update it:

   # chown root:root /etc/NetworkManager/system-connections/example.nmconnection
   # chmod 600 /etc/NetworkManager/system-connections/example.nmconnection

4. Reload the connection profiles:

   # nmcli connection reload

5. Verify that NetworkManager read the profile from the configuration file:

   # nmcli -f NAME,UUID,FILENAME connection
   NAME                UUID                                  FILENAME
   example-connection  86da2486-068d-4d05-9ac7-957ec118afba
   /etc/NetworkManager/system-connections/example.nmconnection
   ...

   If the command does not show the newly added connection, verify that the file permissions and the syntax you used in the file are correct.

6. Optional: If you set the autoconnect variable in the profile to false, activate the connection:

   # nmcli connection up example_connection

Verification

1. Display the connection profile:

   # nmcli connection show example_connection

2. Display the IP settings of the interface:

   # ip address show enp1s0

Additional resources

- nm-settings-keyfile (5)
CHAPTER 26. USING NETCONSOLE TO LOG KERNEL MESSAGES OVER A NETWORK

Using the **netconsole** kernel module and the same-named service, you can log kernel messages over a network to debug the kernel when logging to disk fails or when using a serial console is not possible.

### 26.1. CONFIGURING THE NETCONSOLE SERVICE TO LOG KERNEL MESSAGES TO A REMOTE HOST

Using the **netconsole** kernel module, you can log kernel messages to a remote system log service.

**Prerequisites**

- A system log service, such as **rsyslog** is installed on the remote host.
- The remote system log service is configured to receive incoming log entries from this host.

**Procedure**

1. Install the **netconsole-service** package:

   ```bash
   # dnf install netconsole-service
   ```

2. Edit the `/etc/sysconfig/netconsole` file and set the **SYSLOGADDR** parameter to the IP address of the remote host:

   ```bash
   # SYSLOGADDR=192.0.2.1
   ```

3. Enable and start the **netconsole** service:

   ```bash
   # systemctl enable --now netconsole
   ```

**Verification steps**

- Display the `/var/log/messages` file on the remote system log server.

**Additional resources**

- [Configuring a remote logging solution](#)
CHAPTER 27. SYSTEMD NETWORK TARGETS AND SERVICES

NetworkManager configures the network during the system boot process. However, when booting with a remote root (/), such as if the root directory is stored on an iSCSI device, the network settings are applied in the initial RAM disk (initrd) before RHEL is started. For example, if the network configuration is specified on the kernel command line using rd.neednet=1 or a configuration is specified to mount remote file systems, then the network settings are applied on initrd.

This section describes different targets such as network, network-online, and NetworkManager-wait-online service that are used while applying network settings, and how to configure the systemd service to start after the network-online service is started.

27.1. DIFFERENCES BETWEEN THE NETWORK AND NETWORK-ONLINE SYSTEMD TARGET

Systemd maintains the network and network-online target units. The special units such as NetworkManager-wait-online.service, have WantedBy=network-online.target and Before=network-online.target parameters. If enabled, these units get started with network-online.target and delay the target to be reached until some form of network connectivity is established. They delay the network-online target until the network is connected.

The network-online target starts a service, which adds substantial delays to further execution. Systemd automatically adds dependencies with Wants and After parameters for this target unit to all the System V (SysV) init script service units with a Linux Standard Base (LSB) header referring to the $network facility. The LSB header is metadata for init scripts. You can use it to specify dependencies. This is similar to the systemd target.

The network target does not significantly delay the execution of the boot process. Reaching the network target means that the service that is responsible for setting up the network has started. However, it does not mean that a network device was configured. This target is important during the shutdown of the system. For example, if you have a service that was ordered after the network target during bootup, then this dependency is reversed during the shutdown. The network does not get disconnected until your service has been stopped. All mount units for remote network file systems automatically start the network-online target unit and order themselves after it.

NOTE

The network-online target unit is only useful during the system starts. After the system has completed booting up, this target does not track the online state of the network. Therefore, you cannot use network-online to monitor the network connection. This target provides a one-time system startup concept.

27.2. OVERVIEW OF NETWORKMANAGER-WAIT-ONLINE

The NetworkManager-wait-online service waits with a timeout for the network to be configured. This network configuration involves plugging-in an Ethernet device, scanning for a Wi-Fi device, and so forth. NetworkManager automatically activates suitable profiles that are configured to start automatically. The failure of the automatic activation process due to a DHCP timeout or similar event might keep NetworkManager busy for an extended period of time. Depending on the configuration, NetworkManager retries activating the same profile or a different profile.

When the startup completes, either all profiles are in a disconnected state or are successfully activated. You can configure profiles to auto-connect. The following are a few examples of parameters that set timeouts or define when the connection is considered active:
- `connection.wait-device-timeout` - sets the timeout for the driver to detect the device.
- `ipv4.may-fail` and `ipv6.may-fail` - sets activation with one IP address family ready, or whether a particular address family must have completed configuration.
- `ipv4.gateway-ping-timeout` - delays activation.

Additional resources
- The `nm-settings(5)` man page

### 27.3. CONFIGURING A SYSTEMD SERVICE TO START AFTER THE NETWORK HAS BEEN STARTED

Red Hat Enterprise Linux installs `systemd` service files in the `/usr/lib/systemd/system/` directory. This procedure creates a drop-in snippet for a service file in `/etc/systemd/system/service_name.service.d/` that is used together with the service file in `/usr/lib/systemd/system/` to start a particular service after the network is online. It has a higher priority if settings in the drop-in snippet overlap with the ones in the service file in `/usr/lib/systemd/system/`.

**Procedure**

1. To open the service file in the editor, enter:
   ```shell
   # systemctl edit service_name
   ```

2. Enter the following, and save the changes:
   ```ini
   [Unit]
   After=network-online.target
   ```

3. Reload the `systemd` service.
   ```shell
   # systemctl daemon-reload
   ```
CHAPTER 28. LINUX TRAFFIC CONTROL

Linux offers tools for managing and manipulating the transmission of packets. The Linux Traffic Control (TC) subsystem helps in policing, classifying, shaping, and scheduling network traffic. TC also mangles the packet content during classification by using filters and actions. The TC subsystem achieves this by using queuing disciplines (qdisc), a fundamental element of the TC architecture.

The scheduling mechanism arranges or rearranges the packets before they enter or exit different queues. The most common scheduler is the First-In-First-Out (FIFO) scheduler. You can do the qdiscs operations temporarily using the tc utility or permanently using NetworkManager.

This section explains queuing disciplines and describes how to update the default qdiscs in RHEL.

28.1. OVERVIEW OF QUEUING DISCIPLINES

Queuing disciplines (qdiscs) help with queuing up and, later, scheduling of traffic transmission by a network interface. A qdisc has two operations;

- enqueue requests so that a packet can be queued up for later transmission and
- dequeue requests so that one of the queued-up packets can be chosen for immediate transmission.

Every qdisc has a 16-bit hexadecimal identification number called a handle, with an attached colon, such as 1: or abcd:. This number is called the qdisc major number. If a qdisc has classes, then the identifiers are formed as a pair of two numbers with the major number before the minor, <major>:<minor>, for example abcd:1. The numbering scheme for the minor numbers depends on the qdisc type. Sometimes the numbering is systematic, where the first-class has the ID <major>:1, the second one <major>:2, and so on. Some qdiscs allow the user to set class minor numbers arbitrarily when creating the class.

Classful qdiscs

Different types of qdiscs exist and help in the transfer of packets to and from a networking interface. You can configure qdiscs with root, parent, or child classes. The point where children can be attached are called classes. Classes in qdisc are flexible and can always contain either multiple children classes or a single child, qdisc. There is no prohibition against a class containing a classful qdisc itself, this facilitates complex traffic control scenarios. Classful qdiscs do not store any packets themselves. Instead, they enqueue and dequeue requests down to one of their children according to criteria specific to the qdisc. Eventually, this recursive packet passing ends up where the packets are stored (or picked up from in the case of dequeuing).

Classless qdiscs

Some qdiscs contain no child classes and they are called classless qdiscs. Classless qdiscs require less customization compared to classful qdiscs. It is usually enough to attach them to an interface.

Additional resources

- tc(8) man page
- tc-actions.8 man page

28.2. AVAILABLE QDISCS IN RHEL
Each \textit{qdisc} addresses unique networking-related issues. The following is the list of \textit{qdiscs} available in RHEL. You can use any of the following \textit{qdisc} to shape network traffic based on your networking requirements.

### Table 28.1. Available schedulers in RHEL

<table>
<thead>
<tr>
<th>qdisc name</th>
<th>Included in</th>
<th>Offload support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asynchronous Transfer Mode (ATM)</td>
<td>\texttt{kernel-modules-extra}</td>
<td></td>
</tr>
<tr>
<td>Class-Based Queueing</td>
<td>\texttt{kernel-modules-extra}</td>
<td></td>
</tr>
<tr>
<td>Credit-Based Shaper</td>
<td>\texttt{kernel-modules-extra}</td>
<td></td>
</tr>
<tr>
<td>CHOose and Keep for responsive flows, CHOose and Kill for unresponsive flows (CHOKE)</td>
<td>\texttt{kernel-modules-extra}</td>
<td></td>
</tr>
<tr>
<td>Controlled Delay (CoDel)</td>
<td>\texttt{kernel-core}</td>
<td></td>
</tr>
<tr>
<td>Deficit Round Robin (DRR)</td>
<td>\texttt{kernel-modules-extra}</td>
<td></td>
</tr>
<tr>
<td>Differentiated Services marker (DSMARK)</td>
<td>\texttt{kernel-modules-extra}</td>
<td></td>
</tr>
<tr>
<td>Enhanced Transmission Selection (ETS)</td>
<td>\texttt{kernel-modules-extra}</td>
<td>Yes</td>
</tr>
<tr>
<td>Fair Queue (FQ)</td>
<td>\texttt{kernel-core}</td>
<td></td>
</tr>
<tr>
<td>Fair Queuing Controlled Delay (FQ_CODel)</td>
<td>\texttt{kernel-core}</td>
<td></td>
</tr>
<tr>
<td>Generalized Random Early Detection (GRED)</td>
<td>\texttt{kernel-modules-extra}</td>
<td></td>
</tr>
<tr>
<td>Hierarchical Fair Service Curve (HSFC)</td>
<td>\texttt{kernel-core}</td>
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<tr>
<td>Heavy-Hitter Filter (HHF)</td>
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<td>Hierarchy Token Bucket (HTB)</td>
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<td>INGRESS</td>
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<td>Yes</td>
</tr>
<tr>
<td>Multi Queue Priority (MQPRIO)</td>
<td>\texttt{kernel-modules-extra}</td>
<td>Yes</td>
</tr>
<tr>
<td>Multiqueue (MULTIQ)</td>
<td>\texttt{kernel-modules-extra}</td>
<td>Yes</td>
</tr>
</tbody>
</table>
### qdisc name | Included in | Offload support
--- | --- | ---
Network Emulator (NETEM) | kernel-modules-extra |  
Proportional Integral-controller Enhanced (PIE) | kernel-core |  
PLUG | kernel-core |  
Quick Fair Queueing (QFQ) | kernel-modules-extra |  
Random Early Detection (RED) | kernel-modules-extra | Yes  
Stochastic Fair Blue (SFB) | kernel-modules-extra |  
Stochastic Fairness Queueing (SFQ) | kernel-core |  
Token Bucket Filter (TBF) | kernel-core | Yes  
Trivial Link Equalizer (TEQL) | kernel-modules-extra |  

**IMPORTANT**

The qdisc offload requires hardware and driver support on NIC.

**Additional resources**

- The `tc(8)`, `cbq`, `cbs`, `choke`, `CoDel`, `drr`, `fq`, `htb`, `mqprio`, `netem`, `pie`, `sfb`, `pfifo`, `tc-red`, `sfq`, `tbf`, and `prio` man pages.

#### 28.3. INSPECTING QDISCS OF A NETWORK INTERFACE USING THE TC UTILITY

By default, Red Hat Enterprise Linux systems use `fq_codel qdisc`. This procedure describes how to inspect qdisc counters.

**Procedure**

1. Optional: View your current qdisc:
   ```bash
   # tc qdisc show dev enp0s1
   ```

2. Inspect the current qdisc counters:
   ```bash
   # tc -s qdisc show dev enp0s1
   qdisc fq_codel 0: root refcnt 2 limit 10240p flows 1024 quantum 1514 target 5.0ms interval 100.0ms memory_limit 32Mb ecn
   Sent 1008193 bytes 5559 pkt (dropped 233, overlimits 55 requeues 77) backlog 0b 0p requeues 0 
   ....
   ```
• **dropped** - the number of times a packet is dropped because all queues are full
• **overlimits** - the number of times the configured link capacity is filled
• **sent** - the number of dequeues

### 28.4. UPDATING THE DEFAULT QDISC

If you observe networking packet losses with the current qdisc, you can change the qdisc based on your network-requirements. You can select the qdisc, which meets your network requirements. This procedure describes how to change the default qdisc in Red Hat Enterprise Linux.

#### Procedure

1. View the current default qdisc:
   
   ```
   # sysctl -a | grep qdisc
   net.core.default_qdisc = fq_codel
   ```

2. View the qdisc of current Ethernet connection:
   
   ```
   # tc -s qdisc show dev enp0s1
   qdisc fq_codel 0: root refcnt 2 limit 10240p flows 1024 quantum 1514 target 5.0ms interval 100.0ms memory_limit 32Mb ecn
   Sent 0 bytes 0 pkt (dropped 0, overlimits 0 requeues 0)
   backlog 0b 0p requeues 0
   maxpacket 0 drop_overlimit 0 new_flow_count 0 ecn_mark 0
   new_flows_len 0 old_flows_len 0
   ```

3. Update the existing qdisc:
   
   ```
   # sysctl -w net.core.default_qdisc=pfifo_fast
   ```

4. To apply the changes, reload the network driver:
   
   ```
   # rmmod NETWORKDRIVERNAME
   # modprobe NETWORKDRIVERNAME
   ```

5. Start the network interface:
   
   ```
   # ip link set enp0s1 up
   ```

#### Verification steps

• View the qdisc of the Ethernet connection:
   
   ```
   # tc -s qdisc show dev enp0s1
   qdisc pfifo_fast 0: root refcnt 2 bands 3 priomap 1 2 2 1 2 0 0 1 1 1 1 1 1 1 1 1
   Sent 373186 bytes 5333 pkt (dropped 0, overlimits 0 requeues 0)
   backlog 0b 0p requeues 0
   ....
   ```

#### Additional resources

• How to set `sysctl` variables on Red Hat Enterprise Linux
28.5. TEMPORARILY SETTING THE CURRENT QDISK OF A NETWORK INTERFACE USING THE TC UTILITY

You can update the current qdisc without changing the default one. This procedure describes how to change the current qdisc in Red Hat Enterprise Linux.

Procedure

1. Optional: View the current qdisc:
   
   ```bash
   # tc -s qdisc show dev enp0s1
   ```

2. Update the current qdisc:
   
   ```bash
   # tc qdisc replace dev enp0s1 root htb
   ```

Verification step

- View the updated current qdisc:

```bash
# tc -s qdisc show dev enp0s1
qdisc htb 8001: root refcnt 2 r2q 10 default 0 direct_packets_stat 0 direct_qlen 1000
Sent 0 bytes 0 pkt (dropped 0, overlimits 0 requeues 0)
backlog 0b 0p requeues 0
```

28.6. PERMANENTLY SETTING THE CURRENT QDISK OF A NETWORK INTERFACE USING NETWORKMANAGER

You can update the current qdisc value of a NetworkManager connection.

Procedure

1. Optional: View the current qdisc:

   ```bash
   # tc qdisc show dev enp0s1
   qdisc fq_codel 0: root refcnt 2
   ```

2. Update the current qdisc:

   ```bash
   # nmcli connection modify enp0s1 tc.qdiscs 'root pfifo_fast'
   ```

3. Optional: To add another qdisc over the existing qdisc, use the +tc.qdisc option:

   ```bash
   # nmcli connection modify enp0s1 +tc.qdisc 'ingress handle ffff:'
   ```

4. Activate the changes:

   ```bash
   # nmcli connection up enp0s1
   ```

Verification steps

- View current qdisc the network interface:
# tc qdisc show dev enp0s1
qdisc pfifo_fast 8001: root refcnt 2 bands 3 priomap 1 2 2 2 1 2 0 0 1 1 1 1 1 1
qdisc ingress ffff: parent ffff:fff1 ----------------

Additional resources

- **nm-settings(5)** man page
CHAPTER 29. GETTING STARTED WITH MULTIPATH TCP

Multipath TCP (MPTCP) is an extension to the Transmission Control Protocol (TCP). Using Internet Protocol (IP), a host can send packets to a destination. TCP ensures reliable delivery of the data through the Internet and automatically adjusts its bandwidth in response to network load.

This section describes how to:

- Create a new MPTCP connection
- Enable the server to use MPTCP
- Disable MPTCP in the kernel

It also includes the advantages of using MPTCP.

29.1. MPTCP BENEFITS

The Multipath TCP (MPTCP) design improves connection stability. Note, that in MPTCP terminology, links are considered as paths.

The following are the advantages of MPTCP:

- It allows a connection to simultaneously use multiple network interfaces.

- In case a connection is bound to a link speed, the usage of multiple links can increase the connection throughput. Note, that in case of the connection is bound to a CPU, the usage of multiple links causes the connection slowdown.

- It increases the resilience to link failures.

29.2. PREPARING RHEL TO ENABLE MPTCP SUPPORT

By default the MPTCP support is disabled in RHEL. Enable MPTCP so that applications that support this feature can use it. Additionally, you have to configure user space applications to force use MPTCP sockets if those applications have TCP sockets by default.

Prerequisites

The following packages are installed:

- iperf3
- mptcpd

Procedure

1. Enable MPTCP sockets in the kernel:

   ```
   # echo "net.mptcp.enabled=1" > /etc/sysctl.d/90-enable-MPTCP.conf
   # sysctl -p /etc/sysctl.d/90-enable-MPTCP.conf
   ```

2. Start the iperf3 server, and force it to create MPTCP sockets instead of TCP sockets:
3. Connect the client to the server, and force it to create MPTCP sockets instead of TCP sockets:

```bash
# mptcpize iperf3 -c 127.0.0.1 -t 3
```

4. After the connection is established, verify the `ss` output to see the subflow-specific status:

```bash
# ss -nti \( \text{dport :5201 } \)
```

5. Verify MPTCP counters by using `nstat MPTcp*` command:

```bash
# nstat MPTcp*
```

```
#kernel
MPTcpExtMPCapableSYNRX 2 0.0
MPTcpExtMPCapableSYNTX 2 0.0
MPTcpExtMPCapableSYNACKRX 2 0.0
MPTcpExtMPCapableACKRX 2 0.0
```

Additional resources

- `tcp(7)` man page
- `mptcpize(8)` man page

### 29.3. USING IPROUTE2 TO CONFIGURE AND ENABLE MULTIPLE PATHS FOR MPTCP APPLICATIONS

Each MPTCP connection uses a single subflow similar to plain TCP. To leverage the MPTCP benefits specify a higher limit for maximum number of subflows for each MPTCP connection and configure additional endpoints to create those subflows.

Note that MPTCP does not yet support mixed IPv6 and IPv4 endpoints for the same socket. Use endpoints belonging to the same address family.

**Prerequisites**

- The `mptcpd` package is installed
- The `iperf3` package is installed
Server network interface settings:

- enp4s0: 192.0.2.1/24
- enp1s0: 198.51.100.1/24

Client network interface settings:

- enp4s0f0: 192.0.2.2/24
- enp4s0f1: 198.51.100.2/24

Procedure

1. Set the per connection additional subflow limits to 1 on the server:

   # ip mptcp limits set subflow 1

   Note, that sets a maximum number of additional subflows which each connection can have, excluding the initial one.

2. Set the per connection and additional subflow limits to 1 on the client:

   # ip mptcp limits set subflow 1 add_addr_accepted 1

3. Add IP address 198.51.100.1 as a new MPTCP endpoint on the server:

   # ip mptcp endpoint add 198.51.100.1 dev enp1s0 signal

   **IMPORTANT**

   You can set the following values for flags to subflow, backup, signal. Setting the flag to:
   - **signal**, sends an ADD_ADDR packet after the three-way-handshake is completed
   - **subflow**, sends an MP_JOIN SYN by the client
   - **backup**, sets the endpoint as a backup address

4. Start the iperf3 server, and force it to create MPTCP sockets instead of TCP sockets:

   # mptcpize run iperf3 -s

   Server listening on 5201

5. Connect the client to the server, and force it to create MPTCP sockets instead of TCP sockets:

   # mptcpize iperf3 -c 192.0.2.1 -t 3

Verification steps

1. Verify the connection is established:
2. Verify the connection and IP address limit:

```
# ip mptcp limit show
```

3. Verify the newly added endpoint:

```
# ip mptcp endpoint show
```

4. Verify MPTCP counters by using the `nstat MPTcp*` command on a server:

```
# nstat MPTcp*
```

```text
#kernel
MPTcpExtMPCapableSYNRX          2                  0.0
MPTcpExtMPCapableACKRX          2                  0.0
MPTcpExtMPJoinSynRx             2                  0.0
MPTcpExtMPJoinAckRx             2                  0.0
MPTcpExtEchoAdd                 2                  0.0
```

### Additional resources

- `ip-mptcp(8)` man page
- `mptcpize(8)` man page

## 29.4. MONITORING MPTCP SUB-FLOWS

The life cycle of a multipath TCP (MPTCP) socket can be complex: The main MPTCP socket is created, the MPTCP path is validated, one or more sub-flows are created and eventually removed. Finally, the MPTCP socket is terminated.

The MPTCP protocol allows monitoring MPTCP-specific events related to socket and sub-flow creation and deletion, using the `ip` utility provided by the `iproute` package. This utility uses the `netlink` interface to monitor MPTCP events.

This procedure demonstrates how to monitor MPTCP events. For that, it simulates a MPTCP server application, and a client connects to this service. The involved clients in this example use the following interfaces and IP addresses:

- **Server**: `192.0.2.1`
- **Client (Ethernet connection)**: `192.0.2.2`
- **Client (WiFi connection)**: `192.0.2.3`

To simplify this example, all interfaces are within the same subnet. This is not a requirement. However, it is important that routing has been configured correctly, and the client can reach the server via both interfaces.

### Prerequisites

- A RHEL client with two network interfaces, such as a laptop with Ethernet and WiFi
The client can connect to the server via both interfaces

A RHEL server

Both the client and the server run RHEL 9.0 or later

You installed the mptcpd package on both the client and the server

Procedure

1. Set the per connection additional subflow limits to 1 on both client and server:

   ```bash
   # ip mptcp limits set add_addr_accepted 0 subflows 1
   ```

2. On the server, to simulate a MPTCP server application, start `netcat (nc)` in listen mode with enforced MPTCP sockets instead of TCP sockets:

   ```bash
   # mptcpize run nc -l -k -p 12345
   ```

   The `-k` option causes that `nc` does not close the listener after the first accepted connection. This is required to demonstrate the monitoring of sub-flows.

3. On the client:
   a. Identify the interface with the lowest metric:

   ```bash
   # ip -4 route
   192.0.2.0/24 dev enp1s0 proto kernel scope link src 192.0.2.2 metric 100
   192.0.2.0/24 dev wlp1s0 proto kernel scope link src 192.0.2.3 metric 600
   ```

   The `enp1s0` interface has a lower metric than `wlp1s0`. Therefore, RHEL uses `enp1s0` by default.

   b. On the first terminal, start the monitoring:

   ```bash
   # ip mptcp monitor
   ```

   c. On the second terminal, start a MPTCP connection to the server:

   ```bash
   # mptcpize run nc 192.0.2.1 12345
   ```

   RHEL uses the `enp1s0` interface and its associated IP address as a source for this connection.

   On the monitoring terminal, the `ip mptcp monitor` command now logs:

   ```bash
   [       CREATED] token=63c070d2 remid=0 locid=0 saddr4=192.0.2.2 daddr4=192.0.2.1
   sport=36444 dport=12345
   ```

   The token identifies the MPTCP socket as an unique ID, and later it enables you to correlate MPTCP events on the same socket.
d. On the terminal with the running `nc` connection to the server, press Enter. This first data packet fully establishes the connection. Note that, as long as no data has been sent, the connection is not established. On the monitoring terminal, `ip mptcp monitor` now logs:

    | ESTABLISHED] token=63c070d2 remid=0 locid=0 saddr4=192.0.2.2
daddr4=192.0.2.1 sport=36444 dport=12345

e. Optional: Display the connections to port 12345 on the server:

    # ss -taunp | grep ":12345"
tcp ESTAB  0  0         192.0.2.2:36444 192.0.2.1:12345

At this point, only one connection to the server has been established.

f. On a third terminal, create another endpoint:

    # ip mptcp endpoint add dev wlp1s0 192.0.2.3 subflow

This command sets the name and IP address of the WiFi interface of the client in this command. On the monitoring terminal, `ip mptcp monitor` now logs:

    | SF_ESTABLISHED] token=63c070d2 remid=0 locid=2 saddr4=192.0.2.3
daddr4=192.0.2.1 sport=53345 dport=12345 backup=0 ifindex=3

The `locid` field displays the local address ID of the new sub-flow and identifies this sub-flow even if the connection uses network address translation (NAT). The `saddr4` field matches the endpoint’s IP address from the `ip mptcp endpoint add` command.

g. Optional: Display the connections to port 12345 on the server:

    # ss -taunp | grep ":12345"
tcp ESTAB  0  0         192.0.2.2:36444 192.0.2.1:12345
tcp ESTAB  0  0  192.0.2.3%wlp1s0:53345 192.0.2.1:12345

The command now displays two connections:

- The connection with source address 192.0.2.2 corresponds to the first MPTCP sub-flow that you established previously.

- The connection from the sub-flow over the `wlp1s0` interface with source address 192.0.2.3.

h. On the third terminal, delete the endpoint:

    # ip mptcp endpoint delete id 2

Use the ID from the `locid` field from the `ip mptcp monitor` output, or retrieve the endpoint ID using the `ip mptcp endpoint show` command.

On the monitoring terminal, `ip mptcp monitor` now logs:
On the first terminal with the nc client, press \texttt{Ctrl+C} to terminate the session. On the monitoring terminal, \texttt{ip mptcp monitor} now logs:

**Additional resources**

- \texttt{ip-mptcp(1)} man page
- How NetworkManager manages multiple default gateways

**29.5. DISABLING MULTIPATH TCP IN THE KERNEL**

This procedure describes how to disable the MPTCP option in the kernel.

**Procedure**

- Disable the \texttt{mptcp.enabled} option.

  ```
  # echo "net.mptcp.enabled=0" > /etc/sysctl.d/90-enable-MPTCP.conf
  # sysctl -p /etc/sysctl.d/90-enable-MPTCP.conf
  ```

**Verification steps**

- Verify whether the \texttt{mptcp.enabled} is disabled in the kernel.

  ```
  # sysctl -a | grep mptcp.enabled
  net.mptcp.enabled = 0
  ```
CHAPTER 30. MANAGING THE MPTCPD SERVICE

This section describes the basic management of the mptcpd service. The mptcpd package provides the mptcpize tool, which switches on the mptcp protocol in the TCP environment.

30.1. CONFIGURING MPTCPD

The mptcpd service is a component of the mptcp protocol which provides an instrument to configure mptcp endpoints. The mptcpd service creates a subflow endpoint for each address by default. The endpoint list is updated dynamically according to IP addresses modification on the running host. The mptcpd service creates the list of endpoints automatically. It enables multiple paths as an alternative to using the ip utility.

Prerequisites

- The mptcpd package installed

Procedure

1. Enable mptcp.enabled option in the kernel with the following command:

   # echo "net.mptcp.enabled=1" > /etc/sysctl.d/90-enable-MPTCP.conf
   # sysctl -p /etc/sysctl.d/90-enable-MPTCP.conf

2. Start the mptcpd service:

   # systemctl start mptcp.service

3. Verify endpoint creation:

   # ip mptcp endpoint

4. To stop the mptcpd service, use the following command:

   # systemctl stop mptcp.service

5. To configure mptcpd service manually, modify the /etc/mptcpd/mptcpd.conf configuration file.

Note, that the endpoint, which mptcpd service creates, lasts till the host shutdown.

Additional resources

- mptcpd(8) man page.

30.2. MANAGING APPLICATIONS WITH MPTCPIZE TOOL

Using the mptcpize tool manage applications and services.

The instruction below shows how to use the mptcpize tool to manage applications in the TCP environment.

Assuming, you need to run the iperf3 utility with the enabled MPTCP socket. You can achieve this goal by following the procedure below.

Prerequisites

- The mptcpd package is installed
The iperf3 package is installed

Procedure

- Start iperf3 utility with MPTCP sockets enabled:
  
  ```
  # mptcpize run iperf3 -s &
  ```

30.3. ENABLING MPTCP SOCKETS FOR A SERVICES USING THE MPTCPIZE UTILITY

The following set of commands instruct you how to manage services using the mptcpize tool. You can enable or disable the mptcp socket for a service.

Assuming, you need to manage mptcp socket for the nginx service. You can achieve this goal by following the procedure below.

Prerequisites

- The mptcpd package is installed
- The nginx package is installed

Procedure

1. Enable MPTCP sockets for a service:

   ```
   # mptcpize enable nginx
   ```

2. Disable the MPTCP sockets for a service:

   ```
   # mptcpize disable nginx
   ```

3. Restart the service to make the changes to take effect:

   ```
   # systemctl restart nginx
   ```
CHAPTER 31. CONFIGURING THE ORDER OF DNS SERVERS

Most applications use the `getaddrinfo()` function of the `glibc` library to resolve DNS requests. By default, `glibc` sends all DNS requests to the first DNS server specified in the `/etc/resolv.conf` file. If this server does not reply, Red Hat Enterprise Linux uses the next server in this file.

This section describes how to customize the order of DNS servers.

31.1. HOW NETWORKMANAGER ORDERS DNS SERVERS IN /ETC/RESOLV.CONF

NetworkManager orders DNS servers in the `/etc/resolv.conf` file based on the following rules:

- If only one connection profile exists, NetworkManager uses the order of IPv4 and IPv6 DNS server specified in that connection.

- If multiple connection profiles are activated, NetworkManager orders DNS servers based on a DNS priority value. If you set DNS priorities, the behavior of NetworkManager depends on the value set in the `dns` parameter. You can set this parameter in the `[main]` section in the `/etc/NetworkManager/NetworkManager.conf` file:
  - `dns=default` or if the `dns` parameter is not set:
    NetworkManager orders the DNS servers from different connections based on the `ipv4.dns-priority` and `ipv6.dns-priority` parameter in each connection.
    
    If you set no value or you set `ipv4.dns-priority` and `ipv6.dns-priority` to 0, NetworkManager uses the global default value. See Default values of DNS priority parameters.

  - `dns=dnsmasq` or `dns=systemd-resolved`:
    When you use one of these settings, NetworkManager sets either `127.0.0.1` for `dnsmasq` or `127.0.0.53` as `nameserver` entry in the `/etc/resolv.conf` file.

    Both the `dnsmasq` and `systemd-resolved` services forward queries for the search domain set in a NetworkManager connection to the DNS server specified in that connection, and forwards queries to other domains to the connection with the default route. When multiple connections have the same search domain set, `dnsmasq` and `systemd-resolved` forward queries for this domain to the DNS server set in the connection with the lowest priority value.

Default values of DNS priority parameters

NetworkManager uses the following default values for connections:

- **50** for VPN connections
- **100** for other connections

Valid DNS priority values:

You can set both the global default and connection-specific `ipv4.dns-priority` and `ipv6.dns-priority` parameters to a value between `-2147483647` and `2147483647`.

- A lower value has a higher priority.
- Negative values have the special effect of excluding other configurations with a greater value. For example, if at least one connection with a negative priority value exists, NetworkManager uses only the DNS servers specified in the connection profile with the lowest priority.
If multiple connections have the same DNS priority, NetworkManager prioritizes the DNS in the following order:

a. VPN connections
b. Connection with an active default route. The active default route is the default route with the lowest metric.

Additional resources
- The `dns-priority` parameter description in the `ipv4` and `ipv6` sections in the `nm-settings(5)` man page
- Using different DNS servers for different domains

31.2. SETTING A NETWORKMANAGER-WIDE DEFAULT DNS SERVER PRIORITY VALUE

NetworkManager uses the following DNS priority default values for connections:

- **50** for VPN connections
- **100** for other connections

This section describes how to override these system-wide defaults with a custom default value for IPv4 and IPv6 connections.

Procedure

1. Edit the `/etc/NetworkManager/NetworkManager.conf` file:
   a. Add the `[connection]` section, if it does not exist:

```
[connection]
```

   b. Add the custom default values to the `[connection]` section. For example, to set the new default for both IPv4 and IPv6 to **200**, add:

```
ipv4.dns-priority=200
ipv6.dns-priority=200
```

   You can set the parameters to a value between **-2147483647** and **2147483647**. Note that setting the parameters to **0** enables the built-in defaults (**50** for VPN connections and **100** for other connections).

2. Reload the **NetworkManager** service:

```
# systemctl reload NetworkManager
```

Additional resources
- **Connection Section** in the **NetworkManager.conf(5)** man page
31.3. SETTING THE DNS PRIORITY OF A NETWORKMANAGER CONNECTION

This section describes how to define the order of DNS servers when NetworkManager creates or updates the `/etc/resolv.conf` file.

Note that setting DNS priorities makes only sense if you have multiple connections with different DNS servers configured. If you have only one connection with multiple DNS servers configured, manually set the DNS servers in the preferred order in the connection profile.

Prerequisites

- The system has multiple NetworkManager connections configured.
- The system either has no `dns` parameter set in the `/etc/NetworkManager/NetworkManager.conf` file or the parameter is set to `default`.

Procedure

1. Optionally, display the available connections:

   ```
   # nmcli connection show
   NAME           UUID                                  TYPE      DEVICE
   Example_con_1  d17ee488-4665-4de2-b28a-48befab0cd43  ethernet  enp1s0
   Example_con_2  916e4f67-7145-3ffa-9f7b-e7cada8f6bf7  ethernet  enp7s0
   ...
   ```

2. Set the `ipv4.dns-priority` and `ipv6.dns-priority` parameters. For example, to set both parameters to 10 for the `Example_con_1` connection:

   ```
   # nmcli connection modify Example_con_1 ipv4.dns-priority 10 ipv6.dns-priority 10
   ```

3. Optionally, repeat the previous step for other connections.

4. Re-activate the connection you updated:

   ```
   # nmcli connection up Example_con_1
   ```

Verification steps

- Display the contents of the `/etc/resolv.conf` file to verify that the DNS server order is correct:

   ```
   # cat /etc/resolv.conf
   ```
CHAPTER 32. USING NETWORKMANAGER TO DISABLE IPV6 FOR A SPECIFIC CONNECTION

This section describes how to disable the IPv6 protocol on a system that uses NetworkManager to manage network interfaces. If you disable IPv6, NetworkManager automatically sets the corresponding sysctl values in the Kernel.

NOTE

If disabling IPv6 using kernel tunables or kernel boot parameters, additional consideration must be given to system configuration. For more information, see the How do I disable or enable the IPv6 protocol in RHEL? article.

Prerequisites

- The system uses NetworkManager to manage network interfaces, which is the default on Red Hat Enterprise Linux.

32.1. DISABLING IPV6 ON A CONNECTION USING NMCLI

This procedure describes how to disable the IPv6 protocol using the nmcli utility.

Procedure

1. Optionally, display the list of network connections:

   ```
   # nmcli connection show
   NAME    UUID                                  TYPE      DEVICE
   Example 7a7e0151-9c18-4e6f-89ee-65bb2d64d365  ethernet  enp1s0
   ...
   ```

2. Set the ipv6.method parameter of the connection to disabled:

   ```
   # nmcli connection modify Example ipv6.method "disabled"
   ```

3. Restart the network connection:

   ```
   # nmcli connection up Example
   ```

Verification steps

1. Enter the ip address show command to display the IP settings of the device:

   ```
   # ip address show enp1s0
   2: enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP
   group default qlen 1000
   link/ether 52:54:00:6b:74:be brd ff:ff:ff:ff:ff:ff
   inet 192.0.2.1/24 brd 192.10.2.255 scope global noprefixroute enp1s0
   valid_lft forever preferred_lft forever
   ```

   If no inet6 entry is displayed, IPv6 is disabled on the device.
2. Verify that the `/proc/sys/net/ipv6/conf/enp1s0/disable_ipv6` file now contains the value `1`:

```
# cat /proc/sys/net/ipv6/conf/enp1s0/disable_ipv6
1
```

The value `1` means that IPv6 is disabled for the device.
CHAPTER 33. MONITORING AND TUNING NIC RING BUFFERS

Receive ring buffers are shared between the device driver and network interface controller (NIC). The card assigns a transmit (TX) and receive (RX) ring buffer. As the name implies, the ring buffer is a circular buffer where an overflow overwrites existing data. There are two ways to move data from the NIC to the kernel, hardware interrupts and software interrupts, also called SoftIRQs.

The kernel uses the RX ring buffer to store incoming packets until they can be processed by the device driver. The device driver drains the RX ring, typically using SoftIRQs, which puts the incoming packets into a kernel data structure called an `sk_buff` or `skb` to begin its journey through the kernel and up to the application which owns the relevant socket.

The kernel uses the TX ring buffer to hold outgoing packets which are destined for the wire.

These ring buffers reside at the bottom of the stack and are a crucial point at which packet drop can occur, which in turn will adversely affect network performance.

33.1. DISPLAYING THE NUMBER OF DROPPED PACKETS

The `ethtool` utility enables administrators to query, configure, or control network driver settings.

The exhaustion of the ring buffers causes an increment in the counters, such as “discard” or “drop” in the output of `ethtool -S interface_name`. The discarded packets indicate that the available buffer is filling up faster than the kernel can process the packets.

Procedure

- Display the drop counters for the `enp1s0` interface:

  ```
  $ ethtool -S enp1s0
  ```

33.2. INCREASING THE RING BUFFERS TO REDUCE A HIGH PACKET DROP RATE

You can increase the size of an Ethernet device’s ring buffers if the packet drop rate causes applications to report:

- a loss of data
- cluster fence
- slow performance
- timeouts
- failed large data transfers, such as backups

Identify the number of dropped packets, and increase the TX and RX ring buffer to reduce a high packet drop rate.

Procedure

1. Display the maximum ring buffer sizes:
# ethtool -g enp1s0
Ring parameters for enp1s0:
Pre-set maximums:
RX: 4096
RX Mini: 0
RX Jumbo: 16320
TX: 4096
Current hardware settings:
RX: 255
RX Mini: 0
RX Jumbo: 0
TX: 255

2. If the values in the **Pre-set maximums** section are higher than in the **Current hardware settings** section increase the ring buffers:

   - To increase the RX ring buffer, enter:

     ```
     # nmcli connection modify Example-Connection ethtool.ring-rx 4096
     ```

   - To increase the TX ring buffer, enter:

     ```
     # nmcli connection modify Example-Connection ethtool.ring-tx 4096
     ```

3. Reload the NetworkManager connection:

   ```
   # nmcli connection up Example-Connection
   ```

**IMPORTANT**

Depending on the driver your network interface card uses, changing in the ring buffer can shortly interrupt the network connection.

Additional resources

- ifconfig and ip commands report packet drops
- Should I be concerned about a 0.05% packet drop rate?
- ethtool(8) man page
CHAPTER 34. CONFIGURING 802.3 LINK SETTINGS

34.1. UNDERSTANDING AUTO-NEGOCIATION

Auto-negotiation is a feature of the IEEE 802.3u Fast Ethernet protocol. It targets the device ports to provide an optimal performance of speed, duplex mode, and flow control for information exchange over a link. Using the auto-negotiation protocol, you have optimal performance of data transfer over the Ethernet.

NOTE

To utilize maximum performance of auto-negotiation, use the same configuration on both sides of a link.

34.2. CONFIGURING 802.3 LINK SETTINGS USING THE NMCLI UTILITY

To configure the 802.3 link settings of an Ethernet connection, modify the following configuration parameters:

- 802-3-ethernet.auto-negotiate
- 802-3-ethernet.speed
- 802-3-ethernet.duplex

Procedure

1. Display the current settings of the connection:

```bash
# nmcli connection show Example-connection
...
802-3-ethernet.speed: 0
802-3-ethernet.duplex: --
802-3-ethernet.auto-negotiate: no
...
```

You can use these values if you need to reset the parameters in case of any problems.

2. Set the speed and duplex link settings:

```bash
# nmcli connection modify Example-connection 802-3-ethernet.auto-negotiate no 802-3-ethernet.speed 10000 802-3-ethernet.duplex full
```

This command disables auto-negotiation and sets the speed of the connection to 10000 Mbit full duplex.

3. Reactivate the connection:

```bash
# nmcli connection up Example-connection
```

Verification

- Use the `ethtool` utility to verify the values of Ethernet interface `enp1s0`:
# ethtool enp1s0

Settings for enp1s0:
...
Advertised auto-negotiation: No
...
Speed: 10000Mb/s
Duplex: Full
Auto-negotiation: off
...
Link detected: yes

Additional resources

- Network interface speed is 100Mbps and should be 1Gbps
- **nm-settings(5)** man page
CHAPTER 35. CONFIGURING ETHTOOL OFFLOAD FEATURES

Network interface cards can use the TCP offload engine (TOE) to offload processing certain operations to the network controller to improve the network throughput.

This section describes how to set offload features.

35.1. OFFLOAD FEATURES SUPPORTED BY NETWORKMANAGER

You can set the following *ethtool* offload features using NetworkManager:

- `ethtool.feature-esp-hw-offload`
- `ethtool.feature-esp-tx-csum-hw-offload`
- `ethtool.feature-fcoe-mtu`
- `ethtool.feature-gro`
- `ethtool.feature-gso`
- `ethtool.feature-highdma`
- `ethtool.feature-hw-tc-offload`
- `ethtool.feature-l2-fwd-offload`
- `ethtool.feature-loopback`
- `ethtool.feature-lro`
- `ethtool.feature-macsec-hw-offload`
- `ethtool.feature-ntuple`
- `ethtool.feature-rx`
- `ethtool.feature-rx-all`
- `ethtool.feature-rx-fcs`
- `ethtool.feature-rx-gro-hw`
- `ethtool.feature-rx-gro-list`
- `ethtool.feature-rx-udp_tunnel-port-offload`
- `ethtool.feature-rx-udp-gro-forwarding`
- `ethtool.feature-rx-vlan-filter`
- `ethtool.feature-rx-vlan-stag-filter`
- `ethtool.feature-rx-vlan-stag-hw-parse`
- `ethtool.feature-rxhash`
- ethtool.feature-rxvlan
- ethtool.feature-sg
- ethtool.feature-tls-hw-record
- ethtool.feature-tls-hw-rx-offload
- ethtool.feature-tls-hw-tx-offload
- ethtool.feature-tso
- ethtool.feature-tx
- ethtool.feature-tx-checksum-fcoe-crc
- ethtool.feature-tx-checksum-ip-generic
- ethtool.feature-tx-checksum-ipv4
- ethtool.feature-tx-checksum-ipv6
- ethtool.feature-tx-checksum-sctp
- ethtool.feature-tx-esp-segmentation
- ethtool.feature-tx-fcoe-segmentation
- ethtool.feature-tx-gre-csum-segmentation
- ethtool.feature-tx-gre-segmentation
- ethtool.feature-tx-gso-list
- ethtool.feature-tx-gso-partial
- ethtool.feature-tx-gso-robust
- ethtool.feature-tx-ipxip4-segmentation
- ethtool.feature-tx-ipxip6-segmentation
- ethtool.feature-tx-nocache-copy
- ethtool.feature-tx-scatter-gather
- ethtool.feature-tx-scatter-gather-fraglist
- ethtool.feature-tx-sctp-segmentation
- ethtool.feature-tx-tcp-ecn-segmentation
- ethtool.feature-tx-tcp-mangleid-segmentation
- ethtool.feature-tx-tcp-segmentation
- ethtool.feature-tx-tcp6-segmentation
ethtool.feature-tx-tunnel-remcsum-segmentation
ethtool.feature-tx-udp-segmentation
ethtool.feature-tx-udp_tnl-csum-segmentation
ethtool.feature-tx-udp_tnl-segmentation
ethtool.feature-tx-vlan-stag-hw-insert
ethtool.feature-txvlan

For details about the individual offload features, see the documentation of the `ethtool` utility and the kernel documentation.

### 35.2. CONFIGURING AN ETHTOOL OFFLOAD FEATURE USING NETWORKMANAGER

This section describes how to enable and disable `ethtool` offload features using NetworkManager, as well as how to remove the setting for a feature from a NetworkManager connection profile.

#### Procedure

1. For example, to enable the RX offload feature and disable TX offload in the `enp1s0` connection profile, enter:

   ```bash
   # nmcli con modify enp1s0 ethtool.feature-rx on ethtool.feature-tx off
   ```

   This command explicitly enables RX offload and disables TX offload.

2. To remove the setting of an offload feature that you previously enabled or disabled, set the feature’s parameter to `ignore`. For example, to remove the configuration for TX offload, enter:

   ```bash
   # nmcli con modify enp1s0 ethtool.feature-tx ignore
   ```

3. Reactivate the network profile:

   ```bash
   # nmcli connection up enp1s0
   ```

#### Verification steps

- Use the `ethtool -k` command to display the current offload features of a network device:

  ```bash
  # ethtool -k network_device
  ```

#### Additional resources

- Offload features supported by NetworkManager

### 35.3. USING RHEL SYSTEM ROLES TO SET ETHTOOL FEATURES

You can use the `network` RHEL System Role to configure `ethtool` features of a NetworkManager connection.
IMPORTANT

When you run a play that uses the network RHEL System Role, the system role overrides an existing connection profile with the same name if the value of settings does not match the ones specified in the play. Therefore, always specify the whole configuration of the network connection profile in the play, even if, for example the IP configuration, already exists. Otherwise the role resets these values to their defaults.

Depending on whether it already exists, the procedure creates or updates the enp1s0 connection profile with the following settings:

- A static IPv4 address - 198.51.100.20 with a /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with a /64 subnet mask
- An IPv4 default gateway - 198.51.100.254
- An IPv6 default gateway - 2001:db8:1::ffe
- An IPv4 DNS server - 198.51.100.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com
- ethtool features:
  - Generic receive offload (GRO): disabled
  - Generic segmentation offload (GSO): enabled
  - TX stream control transmission protocol (SCTP) segmentation: disabled

Prerequisites

- The ansible-core package and rhel-system-roles packages are installed on the control node.
- If you use a different remote user than root when you run the playbook, this user has appropriate sudo permissions on the managed node.

Procedure

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the /etc/ansible/hosts Ansible inventory file:

   ```
   node.example.com
   ```

2. Create the ~/configure-ethernet-device-with-ethtool-features.yml playbook with the following content:

   ```
   ---
   - name: Configure an Ethernet connection with ethtool features
     hosts: node.example.com
     become: true
     tasks:
     - include_role:
   ```
name: rhel-system-roles.network

vars:
  network_connections:
    - name: enp1s0
      type: ethernet
      autoconnect: yes
      ip:
        address:
          - 198.51.100.20/24
          - 2001:db8:1::1/64
        gateway4: 198.51.100.254
        gateway6: 2001:db8:1::fffe
        dns:
          - 198.51.100.200
          - 2001:db8:1::ffbb
        dns_search:
          - example.com
    ethtool:
      features:
        gro: "no"
        gso: "yes"
        tx_sctp_segmentation: "no"
        state: up

3. Run the playbook:

- To connect as root user to the managed host, enter:

  # ansible-playbook -u root ~/configure-ethernet-device-with-ethtool-features.yml

- To connect as a user to the managed host, enter:

  # ansible-playbook -u user_name --ask-become-pass ~/configure-ethernet-device-with-ethtool-features.yml

  The --ask-become-pass option makes sure that the ansible-playbook command prompts for the sudo password of the user defined in the -u user_name option.

  If you do not specify the -u user_name option, ansible-playbook connects to the managed host as the user that is currently logged in to the control node.

Additional resources

- /usr/share/ansible/roles/rhel-system-roles.network/README.md file
- ansible-playbook(1) man page
CHAPTER 36. CONFIGURING ETHTOOL COALESCE SETTINGS

Using interrupt coalescing, the system collects network packets and generates a single interrupt for multiple packets. This increases the amount of data sent to the kernel with one hardware interrupt, which reduces the interrupt load, and maximizes the throughput.

This section provides different options to set the `ethtool` coalesce settings.

36.1. COALESCE SETTINGS SUPPORTED BY NETWORKMANAGER

You can set the following `ethtool` coalesce settings using NetworkManager:

- `coalesce-adaptive-rx`
- `coalesce-adaptive-tx`
- `coalesce-pkt-rate-high`
- `coalesce-pkt-rate-low`
- `coalesce-rx-frames`
- `coalesce-rx-frames-high`
- `coalesce-rx-frames-irq`
- `coalesce-rx-frames-low`
- `coalesce-rx-usecs`
- `coalesce-rx-usecs-high`
- `coalesce-rx-usecs-irq`
- `coalesce-rx-usecs-low`
- `coalesce-sample-interval`
- `coalesce-stats-block-usecs`
- `coalesce-tx-frames`
- `coalesce-tx-frames-high`
- `coalesce-tx-frames-irq`
- `coalesce-tx-frames-low`
- `coalesce-tx-usecs`
- `coalesce-tx-usecs-high`
- `coalesce-tx-usecs-irq`
- `coalesce-tx-usecs-low`
36.2. CONFIGURING ETHTOOL COALESCE SETTINGS USING NETWORKMANAGER

This section describes how to set ethtool coalesce settings using NetworkManager, as well as how you remove the setting from a NetworkManager connection profile.

Procedure

1. For example, to set the maximum number of received packets to delay to 128 in the enp1s0 connection profile, enter:

```bash
# nmcli connection modify enp1s0 ethtool.coalesce-rx-frames 128
```

2. To remove a coalesce setting, set the setting to ignore. For example, to remove the ethtool.coalesce-rx-frames setting, enter:

```bash
# nmcli connection modify enp1s0 ethtool.coalesce-rx-frames ignore
```

3. To reactivate the network profile:

```bash
# nmcli connection up enp1s0
```

Verification steps

1. Use the ethtool -c command to display the current offload features of a network device:

```bash
# ethtool -c network_device
```

Additional resources

- Coalesce settings supported by NetworkManager

36.3. USING RHEL SYSTEM ROLES TO CONFIGURE ETHTOOL COALESCE SETTINGS

You can use the network RHEL System Role to configure ethtool coalesce settings of a NetworkManager connection.

**IMPORTANT**

When you run a play that uses the network RHEL System Role, the system role overrides an existing connection profile with the same name if the value of settings does not match the ones specified in the play. Therefore, always specify the whole configuration of the network connection profile in the play, even if, for example the IP configuration, already exists. Otherwise the role resets these values to their defaults.

Depending on whether it already exists, the procedure creates or updates the enp1s0 connection profile with the following settings:

- A static IPv4 address - 198.51.100.20 with a /24 subnet mask
- A static IPv6 address - 2001:db8:1::1 with a /64 subnet mask
- An IPv4 default gateway - 198.51.100.254
- An IPv6 default gateway - 2001:db8:1::ffe
- An IPv4 DNS server - 198.51.100.200
- An IPv6 DNS server - 2001:db8:1::ffbb
- A DNS search domain - example.com
- `ethtool` coalesce settings:
  - RX frames: 128
  - TX frames: 128

**Prerequisites**

- The `ansible-core` and `rhel-system-roles` packages are installed on the control node.
- If you use a different remote user than root when you run the playbook, this user has appropriate `sudo` permissions on the managed node.

**Procedure**

1. If the host on which you want to execute the instructions in the playbook is not yet inventoried, add the IP or name of this host to the `/etc/ansible/hosts` Ansible inventory file:
   ```
   node.example.com
   ```
2. Create the `~/configure-ethernet-device-with-ethtoolcoalesce-settings.yml` playbook with the following content:
   ```yaml
   ---
   - name: Configure an Ethernet connection with ethtool coalesce settings
     hosts: node.example.com
     become: true
     tasks:
     - include_role:
       name: rhel-system-roles.network
     vars:
       network_connections:
         - name: enp1s0
           type: ethernet
           autoconnect: yes
           ip:
             address:
             - 198.51.100.20/24
             - 2001:db8:1::1/64
           gateway4: 198.51.100.254
           gateway6: 2001:db8:1::ffe
           dns:
             - 198.51.100.200
             - 2001:db8:1::ffbb
           dns_search:
   ```
3. Run the playbook:

- To connect as **root** user to the managed host, enter:

```bash
# ansible-playbook -u root ~/configure-ethernet-device-with-ethtoolcoalesce-settings.yml
```

- To connect as a user to the managed host, enter:

```bash
# ansible-playbook -u user_name --ask-become-pass ~/configure-ethernet-device-with-ethtoolcoalesce-settings.yml
```

The `--ask-become-pass` option makes sure that the `ansible-playbook` command prompts for the `sudo` password of the user defined in the `-u user_name` option.

If you do not specify the `-u user_name` option, `ansible-playbook` connects to the managed host as the user that is currently logged in to the control node.

**Additional resources**

- `/usr/share/ansible/roles/rhel-system-roles.network/README.md`

- `ansible-playbook(1)` man page
CHAPTER 37. USING MACSEC TO ENCRYPT LAYER-2 TRAFFIC IN THE SAME PHYSICAL NETWORK

You can use MACsec to secure the communication between two devices (point-to-point). For example, your branch office is connected over a Metro-Ethernet connection with the central office, you can configure MACsec on the two hosts that connect the offices to increase the security.

Media Access Control security (MACsec) is a layer 2 protocol that secures different traffic types over the Ethernet links including:

- dynamic host configuration protocol (DHCP)
- address resolution protocol (ARP)
- Internet Protocol version 4 / 6 (IPv4 / IPv6) and
- any traffic over IP such as TCP or UDP

MACsec encrypts and authenticates all traffic in LANs, by default with the GCM-AES-128 algorithm, and uses a pre-shared key to establish the connection between the participant hosts. If you want to change the pre-shared key, you need to update the NM configuration on all hosts in the network that uses MACsec.

A MACsec connection uses an Ethernet device, such as an Ethernet network card, VLAN, or tunnel device, as parent. You can either set an IP configuration only on the MACsec device to communicate with other hosts only using the encrypted connection, or you can also set an IP configuration on the parent device. In the latter case, you can use the parent device to communicate with other hosts using an unencrypted connection and the MACsec device for encrypted connections.

MACsec does not require any special hardware. For example, you can use any switch, except if you want to encrypt traffic only between a host and a switch. In this scenario, the switch must also support MACsec.

In other words, there are 2 common methods to configure MACsec;

- host to host and
- host to switch then switch to other host(s)

**IMPORTANT**

You can use MACsec only between hosts that are in the same (physical or virtual) LAN.

### 37.1. CONFIGURING A MACSEC CONNECTION USING NMCLI

You can configure Ethernet interfaces to use MACsec using the `nmcli` utility. This procedure describes how to create a MACsec connection between two hosts that are connected over Ethernet.

**Procedure**

1. On the first host on which you configure MACsec:
   - Create the connectivity association key (CAK) and connectivity-association key name (CKN) for the pre-shared key:
a. Create a 16-byte hexadecimal CAK:

```bash
# dd if=/dev/urandom count=16 bs=1 2> /dev/null | hexdump -e '1/2 "%04x"'
50b71a8ef0bd5751ea76de6d6c98c03a
```

b. Create a 32-byte hexadecimal CKN:

```bash
# dd if=/dev/urandom count=32 bs=1 2> /dev/null | hexdump -e '1/2 "%04x"'
f2b4297d39da7330910a74abc0449feb45b5c0b9fc23df1430e1898fcf1c4550
```

2. On both hosts you want to connect over a MACsec connection:

3. Create the MACsec connection:

```bash
# nmcli connection add type macsec con-name macsec0 ifname macsec0
collection.autoconnect yes macsec.parent enp1s0 macsec.mode psk macsec.mka-cak 50b71a8ef0bd5751ea76de6d6c98c03a macsec.mka-ckn f2b4297d39da7330910a74abc0449feb45b5c0b9fc23df1430e1898fcf1c4550
```

Use the CAK and CKN generated in the previous step in the `macsec.mka-cak` and `macsec.mka-ckn` parameters. The values must be the same on every host in the MACsec-protected network.

4. Configure the IP settings on the MACsec connection.

   a. Configure the IPv4 settings. For example, to set a static IPv4 address, network mask, default gateway, and DNS server to the `macsec0` connection, enter:

   ```bash
   # nmcli connection modify macsec0 ipv4.method manual ipv4.addresses '192.0.2.1/24' ipv4.gateway '192.0.2.254' ipv4.dns '192.0.2.253'
   ```

   b. Configure the IPv6 settings. For example, to set a static IPv6 address, network mask, default gateway, and DNS server to the `macsec0` connection, enter:

   ```bash
   ```

5. Activate the connection:

   ```bash
   # nmcli connection up macsec0
   ```

Verification steps

1. Verify that the traffic is encrypted:

   ```bash
   # tcpdump -nn -i enp1s0
   ```

2. Optional: Display the unencrypted traffic:

   ```bash
   # tcpdump -nn -i macsec0
   ```

3. Display MACsec statistics:
# ip macsec show

4. Display individual counters for each type of protection: integrity-only (encrypt off) and encryption (encrypt on)

# ip -s macsec show

37.2. ADDITIONAL RESOURCES

- MACsec: a different solution to encrypt network traffic blog.
CHAPTER 38. USING DIFFERENT DNS SERVERS FOR DIFFERENT DOMAINS

By default, Red Hat Enterprise Linux (RHEL) sends all DNS requests to the first DNS server specified in the /etc/resolv.conf file. If this server does not reply, RHEL uses the next server in this file.

In environments where one DNS server cannot resolve all domains, administrators can configure RHEL to send DNS requests for a specific domain to a selected DNS server. For example, you can configure one DNS server to resolve queries for example.com and another DNS server to resolve queries for example.net. For all other DNS requests, RHEL uses the DNS server configured in the connection with the default gateway.

IMPORTANT

The systemd-resolved service is provided as a Technology Preview only. Technology Preview features are not supported with Red Hat production Service Level Agreements (SLAs), might not be functionally complete, and Red Hat does not recommend using them for production. These previews provide early access to upcoming product features, enabling customers to test functionality and provide feedback during the development process.

See Technology Preview Features Support Scope on the Red Hat Customer Portal for information about the support scope for Technology Preview features.

38.1. SENDING DNS REQUESTS FOR A SPECIFIC DOMAIN TO A SELECTED DNS SERVER

This section configures systemd-resolved service and NetworkManager to send DNS queries for a specific domain to a selected DNS server.

If you complete the procedure in this section, RHEL uses the DNS service provided by systemd-resolved in the /etc/resolv.conf file. The systemd-resolved service starts a DNS service that listens on port 53 IP address 127.0.0.53. The service dynamically routes DNS requests to the corresponding DNS servers specified in NetworkManager.

NOTE

The 127.0.0.53 address is only reachable from the local system and not from the network.

Prerequisites

- The system has multiple NetworkManager connections configured.

- A DNS server and search domain are configured in the NetworkManager connections that are responsible for resolving a specific domain

  For example, if the DNS server specified in a VPN connection should resolve queries for the example.com domain, the VPN connection profile must have:

  - Configured a DNS server that can resolve example.com

  - Configured the search domain to example.com in the ipv4.dns-search and ipv6.dns-search parameters

Procedure
1. Start and enable the `systemd-resolved` service:

   ```
   # systemctl --now enable systemd-resolved
   ```

2. Edit the `/etc/NetworkManager/NetworkManager.conf` file, and set the following entry in the `[main]` section:

   ```
   dns=systemd-resolved
   ```

3. Reload the `NetworkManager` service:

   ```
   # systemctl reload NetworkManager
   ```

Verification steps

1. Verify that the `nameserver` entry in the `/etc/resolv.conf` file refers to `127.0.0.53`:

   ```
   # cat /etc/resolv.conf
   nameserver 127.0.0.53
   ```

2. Verify that the `systemd-resolved` service listens on port `53` on the local IP address `127.0.0.53`:

   ```
   # ss -tulpn | grep "127.0.0.53"
   udp  UNCONN 0  0      127.0.0.53%lo:53   0.0.0.0:*    users:(("systemd-resolve",pid=1050,fid=12))
   tcp  LISTEN 0  4096   127.0.0.53%lo:53   0.0.0.0:*    users:(("systemd-resolve",pid=1050,fid=13))
   ```

Additional resources

- The `dns` parameter description in the `NetworkManager.conf(5)` man page
CHAPTER 39. GETTING STARTED WITH IPVLAN

This document describes the IPVLAN driver.

39.1. IPVLAN OVERVIEW

IPVLAN is a driver for a virtual network device that can be used in container environment to access the host network. IPVLAN exposes a single MAC address to the external network regardless the number of IPVLAN device created inside the host network. This means that a user can have multiple IPVLAN devices in multiple containers and the corresponding switch reads a single MAC address. IPVLAN driver is useful when the local switch imposes constraints on the total number of MAC addresses that it can manage.

39.2. IPVLAN MODES

The following modes are available for IPVLAN:

- **L2 mode**
  In **L2 mode**, virtual devices receive and respond to address resolution protocol (ARP) requests. The `netfilter` framework runs only inside the container that owns the virtual device. No `netfilter` chains are executed in the default namespace on the containerized traffic. Using **L2 mode** provides good performance, but less control on the network traffic.

- **L3 mode**
  In **L3 mode**, virtual devices process only **L3** traffic and above. Virtual devices do not respond to ARP request and users must configure the neighbour entries for the IPVLAN IP addresses on the relevant peers manually. The egress traffic of a relevant container is landed on the `netfilter` POSTROUTING and OUTPUT chains in the default namespace while the ingress traffic is threaded in the same way as **L2 mode**. Using **L3 mode** provides good control but decreases the network traffic performance.

- **L3S mode**
  In **L3S mode**, virtual devices process the same way as in **L3 mode**, except that both egress and ingress traffics of a relevant container are landed on `netfilter` chain in the default namespace. **L3S mode** behaves in a similar way to **L3 mode** but provides greater control of the network.

**NOTE**

The IPVLAN virtual device does not receive broadcast and multicast traffic in case of L3 and L3S modes.

39.3. OVERVIEW OF MACVLAN

The MACVLAN driver allows to create multiple virtual network devices on top of a single NIC, each of them identified by its own unique MAC address. Packets which land on the physical NIC are demultiplexed towards the relevant MACVLAN device via MAC address of the destination. MACVLAN devices do not add any level of encapsulation.

39.4. COMPARISON OF IPVLAN AND MACVLAN

The following table shows the major differences between MACVLAN and IPVLAN.
### MACVLAN vs. IPVLAN

<table>
<thead>
<tr>
<th>MACVLAN</th>
<th>IPVLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uses MAC address for each MACVLAN device. The overlimit of MAC addresses of MAC table in switch might cause loosing the connectivity.</td>
<td>Uses single MAC address which does not limit the number of IPVLAN devices.</td>
</tr>
<tr>
<td>Netfilter rules for global namespace cannot affect traffic to or from MACVLAN device in a child namespace.</td>
<td>It is possible to control traffic to or from IPVLAN device in <strong>L3 mode</strong> and <strong>L3S mode</strong>.</td>
</tr>
</tbody>
</table>

Note that both IPVLAN and MACVLAN do not require any level of encapsulation.

### 39.5. CREATING AND CONFIGURING THE IPVLAN DEVICE USING `iproute2`

This procedure shows how to set up the IPVLAN device using `iproute2`.

#### Procedure

1. To create an IPVLAN device, enter the following command:

   ```
   # ip link add link real_NIC_device name IPVLAN_device type ipvlan mode l2
   ```

   Note that network interface controller (NIC) is a hardware component which connects a computer to a network.

   **Example 39.1. Creating an IPVLAN device**

   ```
   # ip link add link enp0s31f6 name my_ipvlan type ipvlan mode l2
   # ip link
   47: my_ipvlan@enp0s31f6: <BROADCAST,MULTICAST> mtu 1500 qdisc noop state DOWN mode DEFAULT group default qlen 1000 link/ether e8:6a:6e:8a:a2:44 brd ff:ff:ff:ff:ff:ff
   ```

2. To assign an **IPv4** or **IPv6** address to the interface, enter the following command:

   ```
   # ip addr add dev IPVLAN_device IP_address/subnet_mask_prefix
   ```

3. In case of configuring an IPVLAN device in **L3 mode** or **L3S mode**, make the following setups:

   a. Configure the neighbor setup for the remote peer on the remote host:

   ```
   # ip neigh add dev peer_device IPVLAN_device_IP_address lladdr MAC_address
   ```

      where `MAC_address` is the MAC address of the real NIC on which an IPVLAN device is based on.

   b. Configure an IPVLAN device for **L3 mode** with the following command:

   ```
   # ip route add dev <real_NIC_device> <peer_IP_address/32>
   ```
For **L3S mode:**

```
# ip route add dev real_NIC_device peer_IP_address/32
```

where IP-address represents the address of the remote peer.

4. To set an IPVLAN device active, enter the following command:

```
# ip link set dev IPVLAN_device up
```

5. To check if the IPVLAN device is active, execute the following command on the remote host:

```
# ping IP_address
```

where the `IP_address` uses the IP address of the IPVLAN device.
CHAPTER 40. REUSING THE SAME IP ADDRESS ON DIFFERENT INTERFACES

With Virtual routing and forwarding (VRF), administrators can use multiple routing tables simultaneously on the same host. For that, VRF partitions a network at layer 3. This enables the administrator to isolate traffic using separate and independent route tables per VRF domain. This technique is similar to virtual LANs (VLAN), which partitions a network at layer 2, where the operating system uses different VLAN tags to isolate traffic sharing the same physical medium.

One benefit of VRF over partitioning on layer 2 is that routing scales better considering the number of peers involved.

Red Hat Enterprise Linux uses a virtual \texttt{vrf} device for each VRF domain and adds routes to a VRF domain by adding existing network devices to a VRF device. Addresses and routes previously attached to the original device will be moved inside the VRF domain.

Note that each VRF domain is isolated from each other.

40.1. PERMANENTLY REUSING THE SAME IP ADDRESS ON DIFFERENT INTERFACES

This procedure describes how to permanently use the same IP address on different interfaces in one server by using the VRF feature.

**IMPORTANT**

To enable remote peers to contact both VRF interfaces while reusing the same IP address, the network interfaces must belong to different broadcasting domains. A broadcast domain in a network is a set of nodes, which receive broadcast traffic sent by any of them. In most configurations, all nodes connected to the same switch belong to the same broadcasting domain.

**Prerequisites**

- You are logged in as the \texttt{root} user.
- The network interfaces are not configured.

**Procedure**

1. Create and configure the first VRF device:
   a. Create a connection for the VRF device and assign it to a routing table. For example, to create a VRF device named \texttt{vrf0} that is assigned to the \texttt{1001} routing table:

   ```
   # nmcli connection add type vrf ifname vrf0 con-name vrf0 table 1001 ipv4.method disabled ipv6.method disabled
   ```

   b. Enable the \texttt{vrf0} device:

   ```
   # nmcli connection up vrf0
   ```
c. Assign a network device to the VRF just created. For example, to add the `enp1s0` Ethernet device to the `vrf0` VRF device and assign an IP address and the subnet mask to `enp1s0`, enter:

```
# nmcli connection add type ethernet con-name vrf.enp1s0 ifname enp1s0 master vrf0 ipv4.method manual ipv4.address 192.0.2.1/24
```

d. Activate the `vrf.enp1s0` connection:

```
# nmcli connection up vrf.enp1s0
```

2. Create and configure the next VRF device:

a. Create the VRF device and assign it to a routing table. For example, to create a VRF device named `vrf1` that is assigned to the `1002` routing table, enter:

```
# nmcli connection add type vrf ifname vrf1 con-name vrf1 table 1002 ipv4.method disabled ipv6.method disabled
```

b. Activate the `vrf1` device:

```
# nmcli connection up vrf1
```

c. Assign a network device to the VRF just created. For example, to add the `enp7s0` Ethernet device to the `vrf1` VRF device and assign an IP address and the subnet mask to `enp7s0`, enter:

```
# nmcli connection add type ethernet con-name vrf.enp7s0 ifname enp7s0 master vrf1 ipv4.method manual ipv4.address 192.0.2.1/24
```

d. Activate the `vrf.enp7s0` device:

```
# nmcli connection up vrf.enp7s0
```

### 40.2. TEMPORARILY REUSING THE SAME IP ADDRESS ON DIFFERENT INTERFACES

The procedure in this section describes how to temporarily use the same IP address on different interfaces in one server by using the virtual routing and forwarding (VRF) feature. Use this procedure only for testing purposes, because the configuration is temporary and lost after you reboot the system.

**IMPORTANT**

To enable remote peers to contact both VRF interfaces while reusing the same IP address, the network interfaces must belong to different broadcasting domains. A broadcast domain in a network is a set of nodes which receive broadcast traffic sent by any of them. In most configurations, all nodes connected to the same switch belong to the same broadcasting domain.

**Prerequisites**

- You are logged in as the root user.
Procedure

1. Create and configure the first VRF device:
   a. Create the VRF device and assign it to a routing table. For example, to create a VRF device named blue that is assigned to the 1001 routing table:
      
      ```
      # ip link add dev blue type vrf table 1001
      ```
   b. Enable the blue device:
      
      ```
      # ip link set dev blue up
      ```
   c. Assign a network device to the VRF device. For example, to add the enp1s0 Ethernet device to the blue VRF device:
      
      ```
      # ip link set dev enp1s0 master blue
      ```
   d. Enable the enp1s0 device:
      
      ```
      # ip link set dev enp1s0 up
      ```
   e. Assign an IP address and subnet mask to the enp1s0 device. For example, to set it to 192.0.2.1/24:
      
      ```
      # ip addr add dev enp1s0 192.0.2.1/24
      ```

2. Create and configure the next VRF device:
   a. Create the VRF device and assign it to a routing table. For example, to create a VRF device named red that is assigned to the 1002 routing table:
      
      ```
      # ip link add dev red type vrf table 1002
      ```
   b. Enable the red device:
      
      ```
      # ip link set dev red up
      ```
   c. Assign a network device to the VRF device. For example, to add the enp7s0 Ethernet device to the red VRF device:
      
      ```
      # ip link set dev enp7s0 master red
      ```
   d. Enable the enp7s0 device:
      
      ```
      # ip link set dev enp7s0 up
      ```
   e. Assign the same IP address and subnet mask to the enp7s0 device as you used for enp1s0 in the blue VRF domain:
3. Optionally, create further VRF devices as described above.

40.3. ADDITIONAL RESOURCES

- `/usr/share/doc/kernel-doc-<kernel_version>/Documentation/networking/vrf.txt` from the `kernel-doc` package
CHAPTER 41. STARTING A SERVICE WITHIN AN ISOLATED VRF NETWORK

With virtual routing and forwarding (VRF), you can create isolated networks with a routing table that is different to the main routing table of the operating system. You can then start services and applications so that they have only access to the network defined in that routing table.

41.1. CONFIGURING A VRF DEVICE

To use virtual routing and forwarding (VRF), you create a VRF device and attach a physical or virtual network interface and routing information to it.

WARNING

To prevent that you lock out yourself out remotely, perform this procedure on the local console or remotely over a network interface that you do not want to assign to the VRF device.

Prerequisites

- You are logged in locally or using a network interface that is different to the one you want to assign to the VRF device.

Procedure

1. Create the `vrf0` connection with a same-named virtual device, and attach it to routing table 1000:

   ```
   # nmcli connection add type vrf ifname vrf0 con-name vrf0 table 1000 ipv4.method disabled ipv6.method disabled
   ```

2. Add the `enp1s0` device to the `vrf0` connection, and configure the IP settings:

   ```
   # nmcli connection add type ethernet con-name enp1s0 ifname enp1s0 master vrf0 ipv4.method manual ipv4.address 192.0.2.1/24 ipv4.gateway 192.0.2.254
   ```

   This command creates the `enp1s0` connection as a port of the `vrf0` connection. Due to this configuration, the routing information are automatically assigned to the routing table 1000 that is associated with the `vrf0` device.

3. If you require static routes in the isolated network:

   a. Add the static routes:

      ```
      # nmcli connection modify enp1s0 +ipv4.routes "198.51.100.0/24 192.0.2.2"
      ```

      This adds a route to the 198.51.100.0/24 network that uses 192.0.2.2 as the router.

   b. Activate the connection:
# nmcli connection up enp1s0

**Verification**

1. Display the IP settings of the device that is associated with `vrf0`:
   ```
   # ip -br addr show vrf vrf0
   enp1s0  UP  192.0.2.15/24
   ```

2. Display the VRF devices and their associated routing table:
   ```
   # ip vrf show
   Name     Table
   -----------------------
   vrf0     1000
   ```

3. Display the main routing table:
   ```
   # ip route show
   default via 192.168.0.1 dev enp1s0 proto static metric 100
   ```

4. Display the routing table `1000`:
   ```
   # ip route show table 1000
   default via 192.0.2.254 dev enp1s0 proto static metric 101
   broadcast 192.0.2.0 dev enp1s0 proto kernel scope link src 192.0.2.1
   192.0.2.0/24 dev enp1s0 proto kernel scope link src 192.0.2.1 metric 101
   local 192.0.2.1 dev enp1s0 proto kernel scope host src 192.0.2.1
   broadcast 192.0.2.255 dev enp1s0 proto kernel scope link src 192.0.2.1
   198.51.100.0/24 via 192.0.2.2 dev enp1s0 proto static metric 101
   ```

   The default entry indicates that services that use this routing table, use `192.0.2.254` as their default gateway and not the default gateway in the main routing table.

5. Execute the `traceroute` utility in the network associated with `vrf0` to verify that the utility uses the route from table `1000`:
   ```
   # ip vrf exec vrf0 traceroute 203.0.113.1
   traceroute to 203.0.113.1 (203.0.113.1), 30 hops max, 60 byte packets
   1  192.0.2.254 (192.0.2.254) 0.516 ms 0.459 ms 0.430 ms
   ...
   ```

   The first hop is the default gateway that is assigned to the routing table `1000` and not the default gateway from the system's main routing table.

**Additional resources**

- `ip-vrf(8)`

**41.2. STARTING A SERVICE WITHIN AN ISOLATED VRF NETWORK**

You can configure a service, such as the Apache HTTP Server, to start within an isolated virtual routing and forwarding (VRF) network.
IMPORTANT

Services can only bind to local IP addresses that are in the same VRF network.

Prerequisites

- You configured the vrf0 device.
- You configured Apache HTTP Server to listen only on the IP address that is assigned to the interface associated with the vrf0 device.

Procedure

1. Display the content of the httpd systemd service:

```
# systemctl cat httpd
...
[Service]
ExecStart=/usr/sbin/httpd $OPTIONS -DFOREGROUND
...
```

You require the content of the ExecStart parameter in a later step to run the same command within the isolated VRF network.

2. Create the /etc/systemd/system/httpd.service.d/ directory:

```
# mkdir /etc/systemd/system/httpd.service.d/
```

3. Create the /etc/systemd/system/httpd.service.d/override.conf file with the following content:

```
[Service]
ExecStart=
ExecStart=/usr/sbin/ip vrf exec vrf0 /usr/sbin/httpd $OPTIONS -DFOREGROUND

To override the ExecStart parameter, you first need to unset it and then set it to the new value as shown.
```

4. Reload systemd.

```
# systemctl daemon-reload
```

5. Restart the httpd service.

```
# systemctl restart httpd
```

Verification

1. Display the process IDs (PID) of httpd processes:

```
# pidof -c httpd
1904 ...
```

2. Display the VRF association for the PIDs, for example:
# ip vrf identify 1904
vrf0

3. Display all PIDs associated with the vrf0 device:

```bash
# ip vrf pids vrf0
1904 httpd
...
```

Additional resources

- ip-vrf(8)
CHAPTER 42. SETTING THE ROUTING PROTOCOLS FOR YOUR SYSTEM

This section describes how to use the Free Range Routing (FRRouting, or FRR) feature to enable and set the required routing protocols for your system.

42.1. INTRODUCTION TO FRROUTING

Free Range Routing (FRRouting, or FRR) is a routing protocol stack, which is provided by the frr package available in the AppStream repository.

FRR replaces Quagga that was used on previous RHEL versions. As such, FRR provides TCP/IP-based routing services with support for multiple IPv4 and IPv6 routing protocols.

The supported protocols are:

- Border Gateway Protocol (BGP)
- Intermediate System to Intermediate System (IS-IS)
- Open Shortest Path First (OSPF)
- Protocol-Independent Multicast (PIM)
- Routing Information Protocol (RIP)
- Routing Information Protocol next generation (RIPng)
- Enhanced Interior Gateway Routing Protocol (EIGRP)
- Next Hop Resolution Protocol (NHRP)
- Bidirectional Forwarding Detection (BFD)
- Policy-based Routing (PBR)

FRR is a collection of the following services:

- zebra
- bgpd
- isisd
- ospfd
- ospf6d
- pimd
- ripd
- ripngd
- eigrpd
If **frr** is installed, the system can act as a dedicated router, which exchanges routing information with other routers in either internal or external network using the routing protocols.

### 42.2. SETTING UP FRROUTING

This section explains how you set up Free Range Routing (FRRouting, or FRR).

**Prerequisites**

- Make sure that the **frr** package is installed on your system:

```sh
dnf install frr
```

**Procedure**

1. Edit the `/etc/frr/daemons` configuration file, and enable the required daemons for your system. For example, to enable the **ripd** daemon, include the following line:

```sh
ripd=yes
```

**WARNING**

The **zebra** daemon must always be enabled, so that you must set `zebra=yes` to be able to use **FRR**.

**IMPORTANT**

By default, `/etc/frr/daemons` contains `[daemon_name]=no` entries for all daemons. Therefore, all daemons are disabled, and starting **FRR** after a new installation of the system has no effect.

2. Start the **frr** service:

```sh
systemctl start frr
```

3. Optionally, you can also set **FRR** to start automatically on boot:

```sh
systemctl enable frr
```
42.3. MODIFYING THE CONFIGURATION OF FRR

This section describes:

- How to enable an additional daemon after you set up FRR
- How to disable a daemon after you set up FRR

Prerequisites

- FRR is set up as described in Setting up FRRouting.

Procedure

1. Edit the /etc/frr/daemons configuration file, and modify the line for the required daemons to state yes instead of no. For example, to enable the ripd daemon:

   ```
   ripd=yes
   ```

2. Reload the frr service:

   ```
   # systemctl reload frr
   ```

42.4. MODIFYING A CONFIGURATION OF A PARTICULAR DAEMON

With the default configuration, every routing daemon in FRR can only act as a plain router.

For any additional configuration of a daemon, use the following procedure.

Procedure

1. Within the /etc/frr/ directory, create a configuration file for the required daemon, and name the file as follows:

   ```
   [daemon_name].conf
   ```

   For example, to further configure the eigrpd daemon, create the eigrpd.conf file in the mentioned directory.

2. Populate the new file with the required content. For configuration examples of particular FRR daemons, see the /usr/share/doc/frr/ directory.

3. Reload the frr service:

   ```
   # systemctl reload frr
   ```
CHAPTER 43. TESTING BASIC NETWORK SETTINGS

This section describes how to perform basic network testing.

43.1. USING THE PING UTILITY TO VERIFY THE IP CONNECTION TO OTHER HOSTS

The ping utility sends ICMP packets to a remote host. You can use this functionality to test if the IP connection to a different host works.

Procedure

- Ping the IP address of a host in the same subnet, such as your default gateway:

  ```bash
  # ping 192.0.2.3
  ```

  If the command fails, verify the default gateway settings.

- Ping an IP address of a host in a remote subnet:

  ```bash
  # ping 198.162.3.1
  ```

  If the command fails, verify the default gateway settings, and ensure that the gateway forwards packets between the connected networks.

43.2. USING THE HOST UTILITY TO VERIFY NAME RESOLUTION

This procedure describes how to verify name resolution in Red Hat Enterprise Linux.

Procedure

- Use the host utility to verify that name resolution works. For example, to resolve the client.example.com hostname to an IP address, enter:

  ```bash
  # host client.example.com
  ```

  If the command returns an error, such as connection timed out or no servers could be reached, verify your DNS settings.
CHAPTER 44. RUNNING DHCLIENT EXIT HOOKS USING NETWORKMANAGER A DISPATCHER SCRIPT

You can use a NetworkManager dispatcher script to execute dhclient exit hooks.

44.1. THE CONCEPT OF NETWORKMANAGER DISPATCHER SCRIPTS

The NetworkManager-dispatcher service executes user-provided scripts in alphabetical order when network events happen. These scripts are typically shell scripts, but can be any executable script or application. You can use dispatcher scripts, for example, to adjust network-related settings that you cannot manage with NetworkManager.

You can store dispatcher scripts in the following directories:

- /etc/NetworkManager/dispatcher.d/: The general location for dispatcher scripts the root user can edit.
- /usr/lib/NetworkManager/dispatcher.d/: For pre-deployed immutable dispatcher scripts.

For security reasons, the NetworkManager-dispatcher service executes scripts only if the following conditions met:

- The script is owned by the root user.
- The script is only readable and writable by root.
- The setuid bit is not set on the script.

The NetworkManager-dispatcher service runs each script with two arguments:

1. The interface name of the device the operation happened on.
2. The action, such as up, when the interface has been activated.

The Dispatcher scripts section in the NetworkManager(8) man page provides an overview of actions and environment variables you can use in scripts.

The NetworkManager-dispatcher service runs one script at a time, but asynchronously from the main NetworkManager process. Note that, if a script is queued, the service will always run it, even if a later event makes it obsolete. However, the NetworkManager-dispatcher service runs scripts that are symbolic links referring to files in /etc/NetworkManager/dispatcher.d/no-wait.d/ immediately, without waiting for the termination of previous scripts, and in parallel.

Additional resources

- The Dispatcher scripts section in the NetworkManager(8) man page

44.2. CREATING A NETWORKMANAGER DISPATCHER SCRIPT THAT RUNS DHCLIENT EXIT HOOKS

This section explains how to write a NetworkManager dispatcher script that runs dhclient exit hooks stored in the /etc/dhcp/dhclient-exit-hooks.d/ directory when an IPv4 address is assigned or updated from a DHCP server.
Prerequisites

- The **dhclient** exit hooks are stored in the `/etc/dhcp/dhclient-exit-hooks.d/` directory.

Procedure

1. Create the `/etc/NetworkManager/dispatcher.d/12-dhclient-down` file with the following content:

```bash
#!/bin/bash
# Run dhclient.exit-hooks.d scripts
if [ -n "$DHCP4_DHCP_LEASE_TIME" ] ; then
  if [ "$2" = "dhcp4-change" ] || [ "$2" = "up" ] ; then
    if [ -d /etc/dhcp/dhclient-exit-hooks.d ] ; then
      for f in /etc/dhcp/dhclient-exit-hooks.d/*.sh ; do
        if [ -x "${f}" ]; then
          "${f}"
        fi
      done
    fi
  fi
fi

2. Set the **root** user as owner of the file:

```
# chown root:root /etc/NetworkManager/dispatcher.d/12-dhclient-down
```

3. Set the permissions so that only the root user can execute it:

```
# chmod 0700 /etc/NetworkManager/dispatcher.d/12-dhclient-down
```

4. Restore the SELinux context:

```
# restorecon /etc/NetworkManager/dispatcher.d/12-dhclient-down
```

Additional resources

- The **Dispatcher scripts** section in the **NetworkManager(8)** man page.
CHAPTER 45. INTRODUCTION TO NETWORKMANAGER DEBUGGING

Increasing the log levels for all or certain domains helps to log more details of the operations NetworkManager performs. Administrators can use this information to troubleshoot problems. NetworkManager provides different levels and domains to produce logging information. The /etc/NetworkManager/NetworkManager.conf file is the main configuration file for NetworkManager. The logs are stored in the journal.

This section provides information on enabling debug logging for NetworkManager and using different logging levels and domains to configure the amount of logging details.

45.1. DEBUGGING LEVELS AND DOMAINS

You can use the levels and domains parameters to manage the debugging for NetworkManager. The level defines the verbosity level, whereas the domains define the category of the messages to record the logs with given severity (level).

<table>
<thead>
<tr>
<th>Log levels</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>Does not log any messages about NetworkManager</td>
</tr>
<tr>
<td>ERR</td>
<td>Logs only critical errors</td>
</tr>
<tr>
<td>WARN</td>
<td>Logs warnings that can reflect the operation</td>
</tr>
<tr>
<td>INFO</td>
<td>Logs various informational messages that are useful for tracking state and operations</td>
</tr>
<tr>
<td>DEBUG</td>
<td>Enables verbose logging for debugging purposes</td>
</tr>
<tr>
<td>TRACE</td>
<td>Enables more verbose logging than the DEBUG level</td>
</tr>
</tbody>
</table>

Note that subsequent levels log all messages from earlier levels. For example, setting the log level to INFO also logs messages contained in the ERR and WARN log level.

Additional resources

- NetworkManager.conf(5) man page

45.2. SETTING THE NETWORKMANAGER LOG LEVEL

By default, all the log domains are set to record the INFO log level. Disable rate-limiting before collecting debug logs. With rate-limiting, systemd-journald drops messages if there are too many of them in a short time. This can occur when the log level is TRACE.

This procedure disables rate-limiting and enables recording debug logs for the all (ALL) domains.

Procedure
1. To disable rate-limiting, edit the /etc/systemd/journald.conf file, uncomment the RateLimitBurst parameter in the [Journal] section, and set its value as 0:

   RateLimitBurst=0

2. Restart the systemd-journald service.

   # systemctl restart systemd-journald

3. Create the /etc/NetworkManager/conf.d/95-nm-debug.conf file with the following content:

   [logging]
domains=ALL:TRACE

   The domains parameter can contain multiple comma-separated domain:level pairs.

4. Restart the NetworkManager service.

   # systemctl restart NetworkManager

Verification

- Query the systemd journal to display the journal entries of the NetworkManager unit:

   # journalctl -u NetworkManager

   ... 
   Jun 30 15:24:32 server NetworkManager[164187]: <debug> [1656595472.4939] active-connection[0x5565143c80a0]: update activation type from assume to managed
   Jun 30 15:24:32 server NetworkManager[164187]: <trace> [1656595472.4939] device[55b33c3b1db7b00c]: sys-iface-state: assume -> managed
   Jun 30 15:24:32 server NetworkManager[164187]: <trace> [1656595472.4939] l3cfg[4281f43e356454,ifindex=3]: commit type register (type "update", source "device", existing a369f23014b9ede3) -> a369f23014b9ede3
   Jun 30 15:24:32 server NetworkManager[164187]: <info> [1656595472.4940] manager: NetworkManager state is now CONNECTED_SITE
   ...

45.3. TEMPORARILY SETTING LOG LEVELS AT RUN TIME USING NMCLI

You can change the log level at run time using nmcli. However, Red Hat recommends to enable debugging using configuration files and restart NetworkManager. Updating debugging levels and domains using the .conf file helps to debug boot issues and captures all the logs from the initial state.

Procedure

1. Optional: Display the current logging settings:

   # nmcli general logging

   LEVEL	DOMAINS
   INFO
   PLATFORM,RFKILL,ETHER,WIFI,BT,MB,DHCP4,DHCP6,PPP,WIFI_SCAN,IP4,IP6,AUTOIP4,DNS,VPN,SHARING,SUPPLICANT,AGENTS,SETTINGS,SUSPEND,CORE,DEVIC
2. To modify the logging level and domains, use the following options:

- To set the log level for all domains to the same `LEVEL`, enter:

  ```
  # nmcli general logging level LEVEL domains ALL
  ```

- To change the level for specific domains, enter:

  ```
  # nmcli general logging level LEVEL domains DOMAINS
  ```

  Note that updating the logging level using this command disables logging for all the other domains.

- To change the level of specific domains and preserve the level of all other domains, enter:

  ```
  # nmcli general logging level KEEP domains DOMAIN:LEVEL,DOMAIN:LEVEL
  ```

### 45.4. VIEWING NETWORKMANAGER LOGS

You can view the NetworkManager logs for troubleshooting.

**Procedure**

- To view the logs, enter:

  ```
  # journalctl -u NetworkManager -b
  ```

**Additional resources**

- The `NetworkManager.conf(5)` man page.
- The `journalctl` man page.
CHAPTER 46. CAPTURING NETWORK PACKETS

To debug network issues and communications, you can capture network packets. The following sections provide instructions and additional information about capturing network packets.

46.1. USING XDPDUMP TO CAPTURE NETWORK PACKETS INCLUDING PACKETS DROPPED BY XDP PROGRAMS

The `xdpdump` utility captures network packets. Unlike the `tcpdump` utility, `xdpdump` uses an extended Berkeley Packet Filter (eBPF) program for this task. This enables `xdpdump` to also capture packets dropped by Express Data Path (XDP) programs. User-space utilities, such as `tcpdump`, are not able to capture these dropped packages, as well as original packets modified by an XDP program.

You can use `xdpdump` to debug XDP programs that are already attached to an interface. Therefore, the utility can capture packets before an XDP program is started and after it has finished. In the latter case, `xdpdump` also captures the XDP action. By default, `xdpdump` captures incoming packets at the entry of the XDP program.

**IMPORTANT**

On other architectures than AMD and Intel 64-bit, the `xdpdump` utility is provided as a Technology Preview only. Technology Preview features are not supported with Red Hat production Service Level Agreements (SLAs), might not be functionally complete, and Red Hat does not recommend using them for production. These previews provide early access to upcoming product features, enabling customers to test functionality and provide feedback during the development process.

See Technology Preview Features Support Scope on the Red Hat Customer Portal for information about the support scope for Technology Preview features.

Note that `xdpdump` has no packet filter or decode capabilities. However, you can use it in combination with `tcpdump` for packet decoding.

The procedure describes how to capture all packets on the `enp1s0` interface and write them to the `/root/capture.pcap` file.

**Prerequisites**

- A network driver that supports XDP programs.
- An XDP program is loaded to the `enp1s0` interface. If no program is loaded, `xdpdump` captures packets in a similar way `tcpdump` does, for backward compatibility.

**Procedure**

1. To capture packets on the `enp1s0` interface and write them to the `/root/capture.pcap` file, enter:

   ```
   # xdpdump -i enp1s0 -w /root/capture.pcap
   ```

2. To stop capturing packets, press `Ctrl+C`.

**Additional resources**
● `xdpdump(8)` man page

● If you are a developer and you are interested in the source code of `xdpdump`, download and install the corresponding source RPM (SRPM) from the Red Hat Customer Portal.

### 46.2. ADDITIONAL RESOURCES

● **How to capture network packets with tcpdump?**
CHAPTER 47. GETTING STARTED WITH DPDK

The data plane development kit (DPDK) provides libraries and network drivers to accelerate package processing in user space.

Administrators use DPDK, for example, in virtual machines to use Single Root I/O Virtualization (SR-IOV) to reduce latencies and increase I/O throughput.

**NOTE**

Red Hat does not support experimental DPDK APIs.

47.1. INSTALLING THE DPDK PACKAGE

This section describes how to install the dpdk package.

**Prerequisites**

- Red Hat Enterprise Linux is installed.
- A valid subscription is assigned to the host.

**Procedure**

- Use the dnf utility to install the dpdk package:

  ```
  # dnf install dpdk
  ```

47.2. ADDITIONAL RESOURCES

- [Network Adapter Fast Datapath Feature Support Matrix](#)
CHAPTER 48. UNDERSTANDING THE EBPF NETWORKING FEATURES IN RHEL

The extended Berkeley Packet Filter (eBPF) is an in-kernel virtual machine that allows code execution in the kernel space. This code runs in a restricted sandbox environment with access only to a limited set of functions.

In networking, you can use eBPF to complement or replace kernel packet processing. Depending on the hook you use, eBPF programs have, for example:

- Read and write access to packet data and metadata
- Can look up sockets and routes
- Can set socket options
- Can redirect packets

48.1. OVERVIEW OF NETWORKING EBPF FEATURES IN RHEL

You can attach extended Berkeley Packet Filter (eBPF) networking programs to the following hooks in RHEL:

- eXpress Data Path (XDP): Provides early access to received packets before the kernel networking stack processes them.
- tc eBPF classifier with direct-action flag: Provides powerful packet processing on ingress and egress.
- Control Groups version 2 (cgroup v2): Enables filtering and overriding socket-based operations performed by programs in a control group.
- Socket filtering: Enables filtering of packets received from sockets. This feature was also available in the classic Berkeley Packet Filter (cBPF), but has been extended to support eBPF programs.
- Stream parser: Enables splitting up streams to individual messages, filtering, and redirecting them to sockets.
- SO_REUSEPORT socket selection: Provides a programmable selection of a receiving socket from a reuseport socket group.
- Flow dissector: Enables overriding the way the kernel parses packet headers in certain situations.
- TCP congestion control callbacks: Enables implementing a custom TCP congestion control algorithm.
- Routes with encapsulation: Enables creating custom tunnel encapsulation.

XDP

You can attach programs of the BPF_PROG_TYPE_XDP type to a network interface. The kernel then executes the program on received packets before the kernel network stack starts processing them. This allows fast packet forwarding in certain situations, such as fast packet dropping to prevent distributed denial of service (DDoS) attacks and fast packet redirects for load balancing scenarios.
You can also use XDP for different forms of packet monitoring and sampling. The kernel allows XDP programs to modify packets and to pass them for further processing to the kernel network stack.

The following XDP modes are available:

- **Native (driver) XDP**: The kernel executes the program from the earliest possible point during packet reception. At this moment, the kernel did not parse the packet and, therefore, no metadata provided by the kernel is available. This mode requires that the network interface driver supports XDP but not all drivers support this native mode.

- **Generic XDP**: The kernel network stack executes the XDP program early in the processing. At that time, kernel data structures have been allocated, and the packet has been pre-processed. If a packet should be dropped or redirected, it requires a significant overhead compared to the native mode. However, the generic mode does not require network interface driver support and works with all network interfaces.

- **Offloaded XDP**: The kernel executes the XDP program on the network interface instead of on the host CPU. Note that this requires specific hardware, and only certain eBPF features are available in this mode.

On RHEL, load all XDP programs using the `libxdp` library. This library enables system-controlled usage of XDP.

**NOTE**

Currently, there are some system configuration limitations for XDP programs. For example, you must disable certain hardware offload features on the receiving interface. Additionally, not all features are available with all drivers that support the native mode.

**AF_XDP**

Using an XDP program that filters and redirects packets to a given AF_XDP socket, you can use one or more sockets from the AF_XDP protocol family to fast copy packets from the kernel to the user space.

**Traffic Control**

The Traffic Control (tc) subsystem offers the following types of eBPF programs:

- **BPF_PROG_TYPE_SCHED_CLS**

- **BPF_PROG_TYPE_SCHED_ACT**

These types enable you to write custom tc classifiers and tc actions in eBPF. Together with the parts of the tc ecosystem, this provides the ability for powerful packet processing and is the core part of several container networking orchestration solutions.

In most cases, only the classifier is used, as with the direct-action flag, the eBPF classifier can execute actions directly from the same eBPF program. The clsact Queueing Discipline (qdisc) has been designed to enable this on the ingress side.

Note that using a flow dissector eBPF program can influence operation of some other qdiscs and tc classifiers, such as flower.

**Socket filter**

Several utilities use or have used the classic Berkeley Packet Filter (cBPF) for filtering packets received on a socket. For example, the tcpdump utility enables the user to specify expressions, which tcpdump then translates into cBPF code.
As an alternative to cBPF, the kernel allows eBPF programs of the
**BPF_PROG_TYPE_SOCKET_FILTER** type for the same purpose.

**Control Groups**
In RHEL, you can use multiple types of eBPF programs that you can attach to a cgroup. The kernel
executes these programs when a program in the given cgroup performs an operation. Note that you can
use only cgroups version 2.

The following networking-related cgroup eBPF programs are available in RHEL:

- **BPF_PROG_TYPE_SOCK_OPS**: The kernel calls this program on various TCP events. The
  program can adjust the behavior of the kernel TCP stack, including custom TCP header options,
  and so on.

- **BPF_PROG_TYPE_CGROUP_SOCK_ADDR**: The kernel calls this program during **connect**, **bind**, **sendto**, **recvmsg**, **getpeername**, and **getsockname** operations. This program allows
  changing IP addresses and ports. This is useful when you implement socket-based network
  address translation (NAT) in eBPF.

- **BPF_PROG_TYPE_CGROUP_SOCKOPT**: The kernel calls this program during **setsockopt**
  and **getsockopt** operations and allows changing the options.

- **BPF_PROG_TYPE_CGROUP_SOCK**: The kernel calls this program during socket creation,
  socket releasing, and binding to addresses. You can use these programs to allow or deny the
  operation, or only to inspect socket creation for statistics.

- **BPF_PROG_TYPE_CGROUP_SKB**: This program filters individual packets on ingress and
  egress, and can accept or reject packets.

- **BPF_PROG_TYPE_CGROUP_SYSCTL**: This program allows filtering of access to system
  controls (**sysctl**).

**Stream Parser**
A stream parser operates on a group of sockets that are added to a special eBPF map. The eBPF
program then processes packets that the kernel receives or sends on those sockets.

The following stream parser eBPF programs are available in RHEL:

- **BPF_PROG_TYPE_SK_SKB**: An eBPF program parses packets received from the socket into
  individual messages, and instructs the kernel to drop those messages or send them to another
  socket in the group.

- **BPF_PROG_TYPE_SK_MSG**: This program filters egress messages. An eBPF program parses
  the packets into individual messages and either approves or rejects them.

**SO_REUSEPORT** socket selection
Using this socket option, you can bind multiple sockets to the same IP address and port. Without eBPF,
the kernel selects the receiving socket based on a connection hash. With the
**BPF_PROG_TYPE_SK_REUSEPORT** program, the selection of the receiving socket is fully
programmable.

**Flow dissector**
When the kernel needs to process packet headers without going through the full protocol decode, they
are dissected. For example, this happens in the **tc** subsystem, in multipath routing, in bonding, or when
calculating a packet hash. In this situation the kernel parses the packet headers and fills internal
structures with the information from the packet headers. You can replace this internal parsing using the **BPF_PROG_TYPE_FLOW_DISSECTOR** program. Note that you can only dissect TCP and UDP over IPv4 and IPv6 in eBPF in RHEL.

**TCP Congestion Control**

You can write a custom TCP congestion control algorithm using a group of **BPF_PROG_TYPE_STRUCT_OPS** programs that implement **struct tcp_congestion_oops** callbacks. An algorithm that is implemented this way is available to the system alongside the built-in kernel algorithms.

**Routes with encapsulation**

You can attach one of the following eBPF program types to routes in the routing table as a tunnel encapsulation attribute:

- **BPF_PROG_TYPE_LWT_IN**
- **BPF_PROG_TYPE_LWT_OUT**
- **BPF_PROG_TYPE_LWT_XMIT**

The functionality of such an eBPF program is limited to specific tunnel configurations and does not allow creating a generic encapsulation or decapsulation solution.

**Socket lookup**

To bypass limitations of the **bind** system call, use an eBPF program of the **BPF_PROG_TYPE_SK_LOOKUP** type. Such programs can select a listening socket for new incoming TCP connections or an unconnected socket for UDP packets.

48.2. OVERVIEW OF XDP FEATURES BY NETWORK CARDS

The following is an overview of XDP-enabled network cards and the XDP features you can use with them:

<table>
<thead>
<tr>
<th>Network card</th>
<th>Driver</th>
<th>Basic</th>
<th>Redirect</th>
<th>Target</th>
<th>HW offload</th>
<th>Zero-copy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amazon Elastic Network Adapter</td>
<td>ena</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Broadcom NetXtreme-C/E 10/25/40/50 gigabit Ethernet</td>
<td>bnxt_en</td>
<td>yes</td>
<td>yes</td>
<td>yes[a]</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Cavium Thunder Virtual function</td>
<td>nicvf</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Intel® Ethernet Controller XL710 Family</td>
<td>i40e</td>
<td>yes</td>
<td>yes</td>
<td>yes[a]</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Intel® Ethernet Connection E800 Series</td>
<td>ice</td>
<td>yes</td>
<td>yes</td>
<td>yes[a]</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Intel® PCI Express Gigabit adapters</td>
<td>igb</td>
<td>yes</td>
<td>yes</td>
<td>yes[a]</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>
### Network card

<table>
<thead>
<tr>
<th>Network card</th>
<th>Driver</th>
<th>Basic</th>
<th>Redirect</th>
<th>Target</th>
<th>HW offload</th>
<th>Zero-copy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel® Ethernet Controller I225 Family</td>
<td>igc</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Intel® 10GbE PCI Express adapters</td>
<td>ixgbe</td>
<td>yes</td>
<td>yes</td>
<td>yes[b]</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Intel® 10GbE PCI Express Virtual Function Ethernet</td>
<td>ixgbevf</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Mellanox Technologies 1/10/40Gbit Ethernet</td>
<td>mlx4_en</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Mellanox 5th generation network adapters (ConnectX series)</td>
<td>mlx5_core</td>
<td>yes</td>
<td>yes</td>
<td>yes[b]</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Microsoft Azure Network Adapter</td>
<td>mana</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Microsoft Hyper-V virtual network</td>
<td>hv_netvsc</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Netronome® NFP4000/NFP6000 NIC</td>
<td>nfp</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>QEMU Virtio network</td>
<td>virtio_net</td>
<td>yes</td>
<td>yes</td>
<td>yes[a]</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>QLogic QED 25/40/100Gb Ethernet NIC</td>
<td>qede</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Solarflare SFC9000/SFC9100/EF100-family</td>
<td>sfc</td>
<td>yes</td>
<td>yes</td>
<td>yes[b]</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>STMicroelectronics Multi-Gigabit Ethernet</td>
<td>stmmac</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Universal TUN/TAP device</td>
<td>tun</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Virtual ethernet pair device</td>
<td>veth</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Xen paravirtual network device</td>
<td>xen-netfront</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

[a] Only if an XDP program is loaded on the interface.

[b] Requires a number of XDP TX queues allocated that is larger or equal to the largest CPU index.

**Legend:**
- Basic: Supports basic return codes: **DROP**, **PASS**, **ABORTED**, and **TX**.
- Redirect: Supports the **REDIRECT** return code.
- Target: Can be a target of a **REDIRECT** return code.
- HW offload: Supports XDP hardware offload.
- Zero-copy: Supports the zero-copy mode for the **AF_XDP** protocol family.
CHAPTER 49. NETWORK TRACING USING THE BPF COMPILER COLLECTION

This section explains what the BPF Compiler Collection (BCC) is, how you install the BCC, as well as how to perform different network tracing operations using the pre-created scripts provided by the `bcc-tools` package. All of these scripts support the `--ebpf` parameter to display the eBPF code the utility uploads to the kernel. You can use the code to learn more about writing eBPF scripts.

49.1. AN INTRODUCTION TO BCC

BPF Compiler Collection (BCC) is a library, which facilitates the creation of the extended Berkeley Packet Filter (eBPF) programs. The main utility of eBPF programs is analyzing OS performance and network performance without experiencing overhead or security issues.

BCC removes the need for users to know deep technical details of eBPF, and provides many out-of-the-box starting points, such as the `bcc-tools` package with pre-created eBPF programs.

NOTE

The eBPF programs are triggered on events, such as disk I/O, TCP connections, and process creations. It is unlikely that the programs should cause the kernel to crash, loop or become unresponsive because they run in a safe virtual machine in the kernel.

49.2. INSTALLING THE BCC-TOOLS PACKAGE

This section describes how to install the `bcc-tools` package, which also installs the BPF Compiler Collection (BCC) library as a dependency.

Procedure

1. Install `bcc-tools`:

   ```
   # dnf install bcc-tools
   ```

   The BCC tools are installed in the `/usr/share/bcc/tools/` directory.

2. Optionally, inspect the tools:

   ```
   # ll /usr/share/bcc/tools/
   ...
   -rwxr-xr-x. 1 root root 4198 Dec 14 17:53 dcsnoop
   -rwxr-xr-x. 1 root root 3931 Dec 14 17:53 dcstat
   -rwxr-xr-x. 1 root root 20040 Dec 14 17:53 deadlock_detector
   -rw-r--r--. 1 root root 7105 Dec 14 17:53 deadlock_detector.c
   drwxr-xr-x. 3 root root 8192 Mar 11 10:28 doc
   -rwxr-xr-x. 1 root root 7588 Dec 14 17:53 execsnoop
   -rwxr-xr-x. 1 root root 6373 Dec 14 17:53 ext4dist
   -rwxr-xr-x. 1 root root 10401 Dec 14 17:53 ext4slower
   ...
   ```

   The `doc` directory in the listing above contains documentation for each tool.
49.3. DISPLAYING TCP CONNECTIONS ADDED TO THE KERNEL’S ACCEPT QUEUE

After the kernel receives the ACK packet in a TCP 3-way handshake, the kernel moves the connection from the SYN queue to the accept queue after the connection’s state changes to ESTABLISHED. Therefore, only successful TCP connections are visible in this queue.

The tcpaccept utility uses eBPF features to display all connections the kernel adds to the accept queue. The utility is lightweight because it traces the accept() function of the kernel instead of capturing packets and filtering them. For example, use tcpaccept for general troubleshooting to display new connections the server has accepted.

Procedure

1. Enter the following command to start the tracing the kernel accept queue:

```
# /usr/share/bcc/tools/tcpaccept
PID   COMM      IP RADDR         RPORT  LADDR    LPORT
843   sshd      4  192.0.2.17    50598  192.0.2.1  22
1107  ns-slapd  4  198.51.100.6  38772  192.0.2.1  389
1107  ns-slapd  4  203.0.113.85  38774  192.0.2.1  389
...  
```

Each time the kernel accepts a connection, tcpaccept displays the details of the connections.

2. Press Ctrl+C to stop the tracing process.

Additional resources

- tcpaccept(8) man page
- /usr/share/bcc/tools/doc/tcpaccept_example.txt

49.4. TRACING OUTGOING TCP CONNECTION ATTEMPTS

The tcpconnect utility uses eBPF features to trace outgoing TCP connection attempts. The output of the utility also includes connections that failed.

The tcpconnect utility is lightweight because it traces, for example, the connect() function of the kernel instead of capturing packets and filtering them.

Procedure

1. Enter the following command to start the tracing process that displays all outgoing connections:

```
# /usr/share/bcc/tools/tcpconnect
PID    COMM         IP SADDR      DADDR          DPORT
31346  curl         4  192.0.2.1  198.51.100.16  80
31348  telnet       4  192.0.2.1  203.0.113.231  23
31361  isc-worker00 4  192.0.2.1  192.0.2.154   53
...  
```

Each time the kernel processes an outgoing connection, tcpconnect displays the details of the connections.
2. Press \textbf{Ctrl}+\textbf{C} to stop the tracing process.

Additional resources

- \texttt{tcpconnect(8)} man page
- \texttt{/usr/share/bcc/tools/doc/tcpconnect_example.txt}

\section*{49.5. MEASURING THE LATENCY OF OUTGOING TCP CONNECTIONS}

The TCP connection latency is the time taken to establish a connection. This typically involves the kernel TCP/IP processing and network round trip time, and not the application runtime.

The \texttt{tcpconnlat} utility uses eBPF features to measure the time between a sent \texttt{SYN} packet and the received response packet.

\textbf{Procedure}

1. Start measuring the latency of outgoing connections:

   \begin{verbatim}
   # /usr/share/bcc/tools/tcpconnlat
   PID  COMM    IP  SADDR      DADDR          DPORT  LAT(ms)
   32151 isc-worker00 4  192.0.2.1  192.0.2.254    53    0.60
   32155 ssh       4  192.0.2.1  203.0.113.190  22    26.34
   32319 curl      4  192.0.2.1  198.51.100.59  443   188.96
   ...
   \end{verbatim}

   Each time the kernel processes an outgoing connection, \texttt{tcpconnlat} displays the details of the connection after the kernel receives the response packet.

2. Press \textbf{Ctrl}+\textbf{C} to stop the tracing process.

Additional resources

- \texttt{tcpconnlat(8)} man page
- \texttt{/usr/share/bcc/tools/doc/tcpconnlat_example.txt}

\section*{49.6. DISPLAYING DETAILS ABOUT TCP PACKETS AND SEGMENTS THAT WERE DROPPED BY THE KERNEL}

The \texttt{tcpdrop} utility enables administrators to display details about TCP packets and segments that were dropped by the kernel. Use this utility to debug high rates of dropped packets that can cause the remote system to send timer-based retransmits. High rates of dropped packets and segments can impact the performance of a server.

Instead of capturing and filtering packets, which is resource-intensive, the \texttt{tcpdrop} utility uses eBPF features to retrieve the information directly from the kernel.

\textbf{Procedure}

1. Enter the following command to start displaying details about dropped TCP packets and segments:
Each time the kernel drops TCP packets and segments, `tcpdrop` displays the details of the connection, including the kernel stack trace that led to the dropped package.

2. Press Ctrl+C to stop the tracing process.

Additional resources

- `tcpdrop(8)` man page
- `/usr/share/bcc/tools/doc/tcpdrop_example.txt`

49.7. TRACING TCP SESSIONS

The `tcplife` utility uses eBPF to trace TCP sessions that open and close, and prints a line of output to summarize each one. Administrators can use `tcplife` to identify connections and the amount of transferred traffic.

The example in this section describes how to display connections to port 22 (SSH) to retrieve the following information:

- The local process ID (PID)
- The local process name
- The local IP address and port number
- The remote IP address and port number
- The amount of received and transmitted traffic in KB.
- The time in milliseconds the connection was active

Procedure

1. Enter the following command to start the tracing of connections to the local port 22:

```
/usr/share/bcc/tools/tcplife -L 22
```

PID COMM    LADDR      LPORT RADDR       RPORT TX_KB RX_KB      MS
19392 sshd  192.0.2.1  22    192.0.2.17  43892 53  52 6681.95
19431 sshd  192.0.2.1  22    192.0.2.245 43902 81 249381 7585.09
19487 sshd  192.0.2.1  22    192.0.2.121 43970 6998 7 16740.35
...
Each time a connection is closed, **tcplife** displays the details of the connections.

2. Press **Ctrl+C** to stop the tracing process.

**Additional resources**

- **tcplife(8)** man page
- **/usr/share/bcc/tools/doc/tcplife_example.txt**

### 49.8. TRACING TCP RETRANSMISSIONS

The **tcpretrans** utility displays details about TCP retransmissions, such as the local and remote IP address and port number, as well as the TCP state at the time of the retransmissions.

The utility uses eBPF features and, therefore, has a very low overhead.

**Procedure**

1. Use the following command to start displaying TCP retransmission details:

   ```
   # /usr/share/bcc/tools/tcpretrans
   TIME     PID  IP LADDR:LPORT   T> RADDR:RPORT         STATE
   00:23:02 0    4  192.0.2.1:22  R> 198.51.100.0:26788  ESTABLISHED
   00:23:02 0    4  192.0.2.1:22  R> 198.51.100.0:26788  ESTABLISHED
   00:45:43 0    4  192.0.2.1:22  R> 198.51.100.0:17634  ESTABLISHED
   ...
   ```

   Each time the kernel calls the TCP retransmit function, **tcpretrans** displays the details of the connection.

2. Press **Ctrl+C** to stop the tracing process.

**Additional resources**

- **tcpretrans(8)** man page
- **/usr/share/bcc/tools/doc/tcpretrans_example.txt**

### 49.9. DISPLAYING TCP STATE CHANGE INFORMATION

During a TCP session, the TCP state changes. The **tcpstates** utility uses eBPF functions to trace these state changes, and prints details including the duration in each state. For example, use **tcpstates** to identify if connections spend too much time in the initialization state.

**Procedure**

1. Use the following command to start tracing TCP state changes:

   ```
   # /usr/share/bcc/tools/tcpstates
   SKADDR           C-PID C-COMM     LADDR     LPORT RADDR       RPORT OLDSTATE    ->
   NEWSTATE    MS
   ffff9cd377b3af80 0     swapper/1  0.0.0.0   22    0.0.0.0     0     LISTEN      -> SYN_RECV
   0.000
   ```
Each time a connection changes its state, `tcpstates` displays a new line with updated connection details.

If multiple connections change their state at the same time, use the socket address in the first column (`SKADDR`) to determine which entries belong to the same connection.

2. Press `Ctrl+C` to stop the tracing process.

Additional resources

- `tcpstates(8)` man page
- `/usr/share/bcc/tools/doc/tcpstates_example.txt`

### 49.10. SUMMARIZING AND AGGREGATING TCP TRAFFIC SENT TO SPECIFIC SUBNETS

The `tcpsubnet` utility summarizes and aggregates IPv4 TCP traffic that the local host sends to subnets and displays the output on a fixed interval. The utility uses eBPF features to collect and summarize the data to reduce the overhead.

By default, `tcpsubnet` summarizes traffic for the following subnets:

- `127.0.0.1/32`
- `10.0.0.0/8`
- `172.16.0.0/12`
- `192.0.2.0/24/16`
- `0.0.0.0/0`

Note that the last subnet (`0.0.0.0/0`) is a catch-all option. The `tcpsubnet` utility counts all traffic for subnets different than the first four in this catch-all entry.

Follow the procedure to count the traffic for the `192.0.2.0/24` and `198.51.100.0/24` subnets. Traffic to other subnets will be tracked in the `0.0.0.0/0` catch-all subnet entry.

**Procedure**

1. Start monitoring the amount of traffic send to the `192.0.2.0/24, 198.51.100.0/24`, and other subnets:

   ```bash
   # /usr/share/bcc/tools/tcpsubnet 192.0.2.0/24,198.51.100.0/24,0.0.0.0/0
   ```
Tracing... Output every 1 secs. Hit Ctrl-C to end
[02/21/20 10:04:50]
192.0.2.0/24          856
198.51.100.0/24       7467
[02/21/20 10:04:51]
192.0.2.0/24          1200
198.51.100.0/24       8763
0.0.0.0/0              673
...

This command displays the traffic in bytes for the specified subnets once per second.

2. Press **Ctrl+C** to stop the tracing process.

**Additional resources**
- [tcpsubnet(8)](man page)
- `/usr/share/bcc/tools/doc/tcpsubnet.txt`

### 49.11. Displaying the Network Throughput by IP Address and Port

The **tcp** utility displays TCP traffic the host sends and receives in kilobytes. The report automatically refreshes and contains only active TCP connections. The utility uses eBPF features and, therefore, has only a very low overhead.

**Procedure**

1. To monitor the sent and received traffic, enter:

```bash
# /usr/share/bcc/tools/tcp
13:46:29 loadavg: 0.10 0.03 0.01 1/215 3875

   PID COMM     LADDR           RADDR              RX_KB   TX_KB
   3853 3853     192.0.2.1:22    192.0.2.165:41838 32     102626
   1285   sshd     192.0.2.1:22    192.0.2.45:39240   0           0
   ...```

The output of the command includes only active TCP connections. If the local or remote system closes a connection, the connection is no longer visible in the output.

2. Press **Ctrl+C** to stop the tracing process.

**Additional resources**
- [tcp](man page)
- `/usr/share/bcc/tools/doc/tcp.txt`

### 49.12. Tracing Established TCP Connections

The **tcp** utility traces the kernel functions that connect, accept, and close TCP connections. The utility uses eBPF features and, therefore, has a very low overhead.
Procedure

1. Use the following command to start the tracing process:

```
# /usr/share/bcc/tools/tcptracer
Tracing TCP established connections. Ctrl-C to end.
 T PID COMM IP SADDR DADDR SPORT DPORT
A 1088 ns-slapd 4 192.0.2.153 192.0.2.1 0 65535
A 845 sshd 4 192.0.2.1 192.0.2.67 22 42302
X 4502 sshd 4 192.0.2.1 192.0.2.67 22 42302
```

Each time the kernel connects, accepts, or closes a connection, `tcptracer` displays the details of the connections.

2. Press `Ctrl+C` to stop the tracing process.

Additional resources

- `tcptracer(8)` man page
- `/usr/share/bcc/tools/doc/tcptracer_example.txt` file

49.13. TRACING IPV4 AND IPV6 LISTEN ATTEMPTS

The `solisten` utility traces all IPv4 and IPv6 listen attempts. It traces the listen attempts including that ultimately fail or the listening program that does not accept the connection. The utility traces function that the kernel calls when a program wants to listen for TCP connections.

Procedure

1. Enter the following command to start the tracing process that displays all listen TCP attempts:

```
# /usr/share/bcc/tools/solisten
PID COMM PROTO BACKLOG PORT ADDR
3643 nc TCPv4 1 4242 0.0.0.0
3659 nc TCPv6 1 4242 2001:db8:1::1
4221 redis-server TCPv6 128 6379 ::
4221 redis-server TCPv4 128 6379 0.0.0.0
```

2. Press `Ctrl+C` to stop the tracing process.

Additional resources

- `solisten` man page

49.14. SUMMARIZING THE SERVICE TIME OF SOFT INTERRUPTS

The `softirqs` utility summarizes the time spent servicing soft interrupts (soft IRQs) and shows this time as either totals or histogram distributions. This utility uses the `irq:softirq_enter` and `irq:softirq_exit` kernel tracepoints, which is a stable tracing mechanism.
Procedure

1. Enter the following command to start the tracing soft irq event time:

   ```
   # /usr/share/bcc/tools/softirqs
   Tracing soft irq event time... Hit Ctrl-C to end.
   ^C
   SOFTIRQ          TOTAL_usecs
   tasklet                  166
   block                   9152
   net_rx                 12829
   rcu                    53140
   sched                 182360
   timer                 306256
   ```

2. Press `Ctrl+C` to stop the tracing process.

Additional resources

- `softirqs` man page
- `/usr/share/bcc/tools/doc/softirqs_example.txt`
- `mpstat(1)` man page

49.15. ADDITIONAL RESOURCES

- `/usr/share/doc/bcc/README.md` file
CHAPTER 50. GETTING STARTED WITH TIPC

Transparent Inter-process Communication (TIPC), which is also known as Cluster Domain Sockets, is an Inter-process Communication (IPC) service for cluster-wide operation.

Applications that are running in a high-available and dynamic cluster environment have special needs. The number of nodes in a cluster can vary, routers can fail, and, due to load balancing considerations, functionality can be moved to different nodes in the cluster. TIPC minimizes the effort by application developers to deal with such situations, and maximizes the chance that they are handled in a correct and optimal way. Additionally, TIPC provides a more efficient and fault-tolerant communication than general protocols, such as TCP.

50.1. THE ARCHITECTURE OF TIPC

TIPC is a layer between applications using TIPC and a packet transport service (bearer), and spans the level of transport, network, and signaling link layers. However, TIPC can use a different transport protocol as bearer, so that, for example, a TCP connection can serve as a bearer for a TIPC signaling link.

TIPC supports the following bearers:

- Ethernet
- InfiniBand
- UDP protocol

TIPC provides a reliable transfer of messages between TIPC ports, that are the endpoints of all TIPC communication.

The following is a diagram of the TIPC architecture:

![TIPC Architecture Diagram]

50.2. LOADING THE TIPC MODULE WHEN THE SYSTEM BOOTS

Before you can use the TIPC protocol, load the `tipc` kernel module. This section explains how to configure that RHEL loads this module automatically when the system boots.

Procedure

1. Create the `/etc/modules-load.d/tipc.conf` file with the following content:

   ```
   tipc
   ```

2. Restart the `systemd-modules-load` service to load the module without rebooting the system:
# systemctl start systemd-modules-load

**Verification steps**

1. Use the following command to verify that RHEL loaded the `tipc` module:

   ```
   # lsmod | grep tipc
   tipc 311296 0
   ```

   If the command shows no entry for the `tipc` module, RHEL failed to load it.

**Additional resources**

- `modules-load.d(5)` man page

---

**50.3. CREATING A TIPC NETWORK**

This section describes how to create a TIPC network.

**IMPORTANT**

The commands configure the TIPC network only temporarily. To permanently configure TIPC on a node, use the commands of this procedure in a script, and configure RHEL to execute that script when the system boots.

**Prerequisites**

- The `tipc` module has been loaded. For details, see [Loading the tipc module when the system boots](#)

**Procedure**

1. Optional: Set a unique node identity, such as a UUID or the node’s host name:

   ```
   # tipc node set identity host_name
   ```

   The identity can be any unique string consisting of a maximum 16 letters and numbers.

   You cannot set or change an identity after this step.

2. Add a bearer. For example, to use Ethernet as media and `enp0s1` device as physical bearer device, enter:

   ```
   # tipc bearer enable media eth device enp0s0
   ```

3. Optional: For redundancy and better performance, attach further bearers using the command from the previous step. You can configure up to three bearers, but not more than two on the same media.

4. Repeat all previous steps on each node that should join the TIPC network.

**Verification steps**
1. Display the link status for cluster members:

```
# tipc link list
broadcast-link: up
5254006b74be:enp1s0-525400df55d1:enp1s0: up
```

This output indicates that the link between bearer `enp1s0` on node `5254006b74be` and bearer `enp1s0` on node `525400df55d1` is `up`.

2. Display the TIPC publishing table:

```
# tipc nametable show
Type   Lower      Upper      Scope    Port       Node
0      1795222054 1795222054 cluster 0 5254006b74be
0      3741353223 3741353223 cluster 0 525400df55d1
1      1          1          node     2399405586 5254006b74be
2      3741353223 3741353223 node     0 5254006b74be
```

- The two entries with service type `0` indicate that two nodes are members of this cluster.
- The entry with service type `1` represents the built-in topology service tracking service.
- The entry with service type `2` displays the link as seen from the issuing node. The range limit `3741353223` represents peer endpoint’s address (a unique 32-bit hash value based on the node identity) in decimal format.

Additional resources
- `tipc-bearer(8)` man page
- `tipc-namespace(8)` man page

50.4. ADDITIONAL RESOURCES

- Red Hat recommends to use other bearer level protocols to encrypt the communication between nodes based on the transport media. For example:
  - MACSec: See Using MACsec to encrypt layer 2 traffic
  - IPsec: See Configuring a VPN with IPsec
- For examples of how to use TIPC, clone the upstream GIT repository using the `git clone` command. This repository contains the source code of demos and test programs that use TIPC features. Note that this repository is not provided by Red Hat.
CHAPTER 51. AUTOMATICALLY CONFIGURING NETWORK INTERFACES IN PUBLIC CLOUDS USING NM-CLOUD-SETUP

Normally, a virtual machine (VM) has only one interface that is configurable by DHCP. However, some VMs might have multiple network interfaces, IP addresses, and IP subnets on one interface that is not configurable by DHCP. Also, administrators can reconfigure the network while the machine is running. The **nm-cloud-setup** utility automatically retrieves configuration information from the metadata server of the cloud service provider and updates the network configurations of VM in public clouds.

51.1. CONFIGURING AND PRE-DEPLOYING NM-CLOUD-SETUP

To enable and configure network interfaces in public clouds, run **nm-cloud-setup** as a timer and service. The following procedure describes how to use **nm-cloud-setup** for Amazon EC2.

**NOTE**

On Red Hat Enterprise Linux On Demand and AWS golden images, **nm-cloud-setup** is already enabled and no action is required.

Prerequisite

- A network connection exists.
- The connection uses DHCP.
  
  By default, NetworkManager creates a connection profile which uses DHCP. If no profile was created because you set the **no-auto-default** parameter in `/etc/NetworkManager/NetworkManager.conf`, create this initial connection manually.

Procedure

1. Install the **nm-cloud-setup** package:

   ```bash
   # dnf install NetworkManager-cloud-setup
   ```

2. Create and run the snap-in file for the **nm-cloud-setup** service:

   a. Use the following command to start editing the snap-in file:

      ```bash
      # systemctl edit nm-cloud-setup.service
      ```

      It is important to either start the service explicitly or reboot the system to make configuration settings effective.

   b. Use the **systemd** snap-in file to configure the cloud provider in **nm-cloud-setup**. For example, to use Amazon EC2, enter:

      ```ini
      [Service]
      Environment=NM_CLOUD_SETUP_EC2=yes
      ```

      You can set the following environment variables to enable the cloud provider you use:

      - **NM_CLOUD_SETUP_AZURE** for Microsoft Azure
- **NM_CLOUD_SETUP_EC2** for Amazon EC2 (AWS)
- **NM_CLOUD_SETUP_GCP** for Google Cloud Platform (GCP)
- **NM_CLOUD_SETUP_ALIYUN** for Alibaba Cloud (Aliyun)

c. Save the file and quit the editor.

3. Reload the `systemd` configuration:

   ```
   # systemctl daemon-reload
   ```

4. Enable and start the **nm-cloud-setup** service:

   ```
   # systemctl enable --now nm-cloud-setup.service
   ```

5. Enable and start the **nm-cloud-setup** timer:

   ```
   # systemctl enable --now nm-cloud-setup.timer
   ```

Additional resources

- **nm-cloud-setup(8)** man page
- [Configuring an Ethernet connection](#)