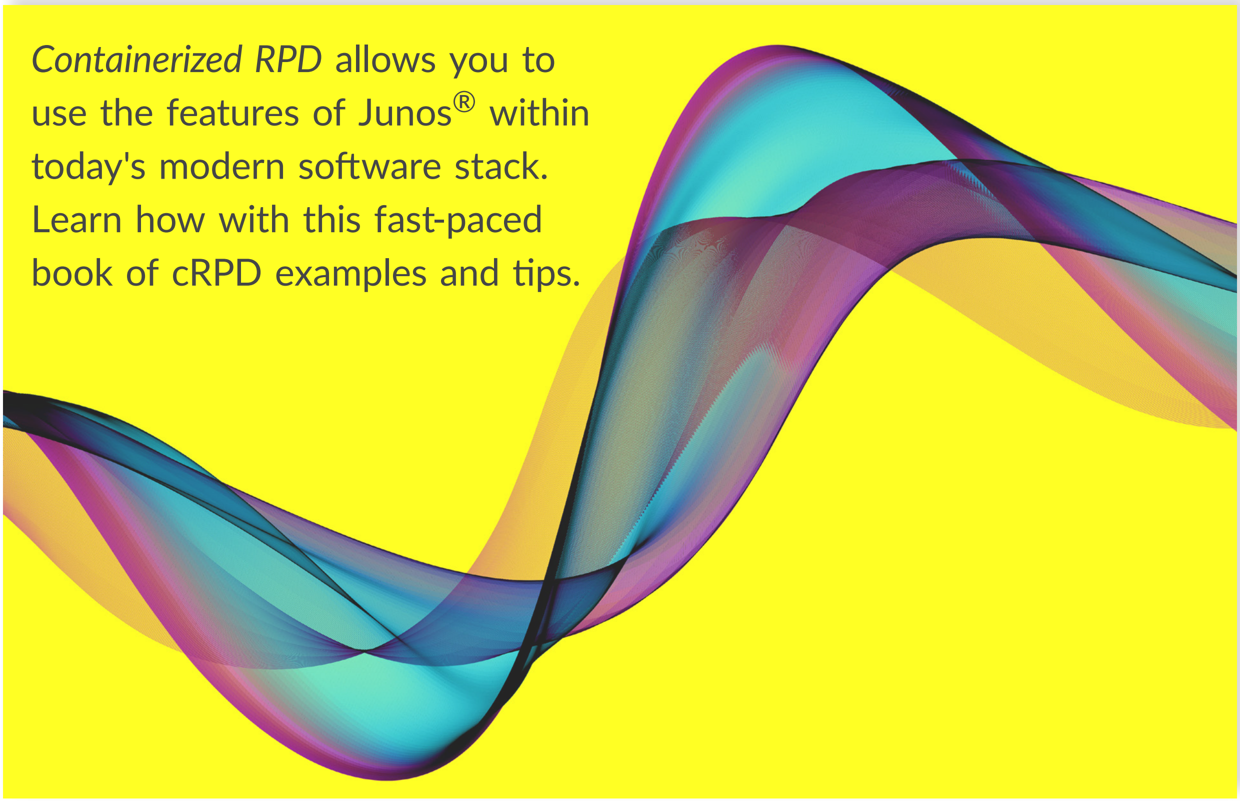
JUNIPER NETWORKS

DAY ONE: CLOUD NATIVE ROUTING WITH cRPD



Containerized RPD allows you to use the features of Junos® within today's modern software stack. Learn how with this fast-paced book of cRPD examples and tips.

By Hitesh Mali, Melchior Aelmans, Arijit Paul, Vinay K Nallamothu, Praveena Kodali, Valentijn Flik, Michel Tepper

DAY ONE: CLOUD NATIVE ROUTING WITH cRPD

This book focuses on containerized Routing Protocol Daemon (cRPD) and covers its characteristics, advantages, use cases, and installation, while also providing some perspective on containerized networking. Test out the trial version and follow along: https://www.juniper.net/us/en/dm/crpd-trial/.

"Containerized RPD brings the scalability and stability of Junos that was not previously seen into the modern software stack. It truly bridges the gap between software engineering and networking. Best of all, there is no need to reinvest in tools and monitoring systems. cRPD opens the door for creative system designs and many thanks to the Juniper engineering team to make this happen so seamlessly."

Kai Ren, Comcast

"This power-packed book provides many great examples that are easy to follow and that can help you accelerate your transition towards cloud native networking. The authors provide an excellent overview of the concepts and Juniper's RPD is a world-class product and it's great to see how easily it can be used in cloud environments. Above all, it was great fun to read and it inspired me for future projects."

Andree Toonk, Cloud Infrastructure Architect

"This Day One book gives meaningful and easy-to-understand insights into cRPD. The power of cRPD is its flexibility, which enables a variety of use cases across a range of customer segments, thanks to its Junos OS routing stack, automation, and manageability stack, and its ability to program third-party data planes. The authors present complex concepts in easily understandable tutorials and I highly recommended it for anyone who wants to get started with this powerful Juniper technology."

-Yogesh Kumar, Director of Product Management, Cloud Ready Data Center, Juniper Networks

IT'S DAY ONE AND YOU HAVE A JOB TO DO:

- Understand what cRPD is and what its architecture looks like.
- Work on and install cRPD.
- Deploy cRPD for various use cases.
- Troubleshoot and monitor cRPD.

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Juniper Networks Books are focused on network reliability and efficiency. Peruse the complete library at www.juniper.net/dayone.

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Mali, Aelmans, Paul, Kodali, Nallamothu, Filk, Tepper

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by Hitesh Mali, Melchior Aelmans, Arijit Paul, Vinay K Nallamothu, Praveena Kodali, Valentijn Flik, and Michel Tepper

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Welcome to Day One

This book is part of the *Day One* library, produced and published by Juniper Networks Books. *Day One* books cover the Junos OS and Juniper Networks network administration with straightforward explanations, step-by-step instructions, and practical examples that are easy to follow.

- Download a free PDF edition at https://www.juniper.net/dayone
- Purchase the paper edition at Vervante Corporation (www.vervante.com).

Key cRPD Resources

The authors of this book highly recommend the following cRPD resources, especially the Juniper TechLibrary and its up-to-date information and specifications:

- cRPD Deployment Guide for Linux Server: https://www.juniper.net/documentation/us/en/software/crpd/crpd-deployment/index.html
- Juniper cRPD Solutions page: https://www.juniper.net/us/en/solutions/crpd/.
- cRPD Free Trial: https://www.juniper.net/us/en/dm/crpd-trial/

What You Need to Know Before Reading This Book

Before reading this book, you need to be familiar with the basic administrative functions of Linux and the Junos operating system, including the ability to work with operational commands and to read, understand, and change Junos configurations. There are several books in the *Day One* library on learning the Junos OS: https://www.juniper.net/dayone.

This book makes a few assumptions about you, the reader:

- You are familiar and versed in using the Junos CLI for router configuration.
- You are familiar with basic Linux commands and configuration.
- You are familiar with SONiC and the concepts of disaggregated networking.
- You have a basic understanding of routing protocols.
- You can build out the lab topologies used in this book without detailed set up instructions, so you should be familiar with Docker, Kubernetes, etc.

The authors assume you have read these *Day One* books:

- *Day One: Building Containers with Docker and the cSRX*
- *Day One: Building Containers with Kubernetes and Contrail*

What You Will Learn by Reading This Book

After reading this book you will be able to:

- Understand what cRPD is and what its architecture looks like.
- Work on and install cRPD.
- Deploy cRPD for various use cases.
- Troubleshoot and monitor cRPD.

Additional Resources on Network Topology Simulation

cRPD is a lightweight virtual product that spins up in seconds and is perfect to simulate complex and extensive network topologies for troubleshooting purposes or testing out new feathers before deploying them in the live network.

Diving into all the different simulation tools and platforms is beyond the scope of this *Day One* book, hence it only provides a few pointers. The authors highly recommend those in need of network simulation to consider https://nrelabs.io, https://containerlab.srlinux.dev/, and https://gitlab.com/mwiget/honeycomb-crpd-mesh.

For Juniper cRPD 20.4 on Docker desktop: https://community.juniper.net/answers/blogs/marcel-wiget1/2021/02/17/juniper-crpd-204-on-docker-desktop.

To set up cRPD (Junos) CNI with KIND on Mac: https://github.com/qarham/q-crpd-cni/tree/main/mac-kind.

Chapter 1

Introduction to cRPD

A *data center* used to be a small room in an office building where a few servers that hosted business applications were placed. Switches connected those servers together in a Layer 2 domain, and routers forwarded them to other networks, as firewalls ensured that no traffic left or entered the network unless a policy determined otherwise.

Later, the dependency on these applications increased when companies switched over to digital transformation. To ensure better housing conditions—including cooling, redundant power, and physical security—these systems were placed at co-location facilities or in purpose-built rooms. A business could lose money every second the network was not available. This begot a new generation of data center networking hardware that introduced switches upgraded with Layer 3 routing features able to accommodate more traffic, and switch and route that traffic at higher speeds.

With the introduction of public cloud services like Amazon Web Services (AWS), Microsoft Azure, Google GCP, Alibaba Cloud, and many others; data center networking now involves much more than just connecting a few routers and switches together. At the same time, the scale of local (or co-located) data centers—now referred to as *private clouds*—grew tremendously, and data center networking designs had to change completely to accommodate the staggering growth of required resources. The biggest change in designing a data center network was that these networks were growing too big to keep supporting stretched Layer 2 networks. It didn't mean that Layer 2 networking was going away, but it no longer provided the right infrastructure on which to build the data center infrastructure. Now switching hardware is capable of IP routing at line-rate speeds. Today's modern data center infrastructure is based on Layer 3-routed IP networks and not on Layer 2 VLANs.

As applications may still require Layer 2 connectivity (VMware, VMotion, or other VM live migration technologies have long been the dominant use case for this requirement) the option still needs to be available. The ability to run *applications* other than traffic forwarding on the network, the desire to create smaller network segments to secure resources inside the data center and enable highly scalable multi-tenancy (one very important requirement for any cloud type deployment), and the requirement to build massively scalable data centers has sparked the need for a new type of data center networking.

One of the defining concepts behind software-defined networking (SDN) is separating the control plane from the data plane, thus separating traffic forwarding from higher level connectivity requirements, ensuring that the data center network transforms into a highly-scalable *fabric* architecture that supports many different *applications* to run on top of it. We typically refer to this as the underlay (the fabric) and the overlay (the applications).

With the advent of this evolution of SDN, vendors like Juniper Networks started to disaggregate hardware and software. Previously these were combined, and one would buy a box, a router, or a switch with software running on it. More or less by definition they couldn't be used separately, and software from vendor A couldn't run on vendor B's box. Today, those purchasing networking equipment have a wide variety of options to choose from with regard to hardware and its control plane, the software. It's not uncommon to run SONiC on a switch and replace the routing stack in SONiC with that from another vendor. This way operators can mix and match and tailor solutions to fit their networking demands.

This book focuses on containerized routing protocol daemon (cRPD), it covers characteristics, advantages, use cases, and installation, and gives some perspective on containerized networking. If you get as enthusiastic about cRPD as we did, we invite you to test it out yourself. A cRPD trial version is free to download via: https://www.juniper.net/us/en/dm/crpd-trial/.

Introduction to Linux Routing

cRPD leverages the Linux kernel to forward traffic and store the forwarding information base (FIB). Modern x86 hardware architectures and Linux implementation offer a great platform for routers and are capable in terms of throughput and performance. There will always be a place for dedicated, ASIC-based hardware to perform routing functions, but it is out of scope for this book to discuss the pros and cons of those differences.

This chapter isn't a deep dive into the Linux routing stack, but it does introduce concepts like the Netlink socket, which is the Linux kernel interface used for transferring information between kernel and userspace processes, that you need to understand. Netlink is used in this book to program routes into the Linux kernel.

Netlink

As stated, Netlink is a Linux kernel interface used for communication between both the kernel and user space processes, and between different userspace processes. cRPD is an example of a userspace process as Netlink communication in itself cannot traverse host boundaries.

Netlink provides a standard socket-based interface for userspace processes, and a kernel-side API for internal use by kernel modules.

Routing Protocol Daemons

Linux offers options to run daemons in userspace and have those control the Linux kernel forwarding. Some examples of the open-source daemons available are BIRD and FRRouting. The Juniper Networking routing daemon is cRPD.

cRPD runs as a userspace application maintaining the route state information in the RIB and forwards the routes into the FIB leveraging Netlink, based on local route selection criteria. It contains the RPD, PPMD, CLI, MGD, and BFD processes. cRPD also defines how routing protocols such as ISIS, OSPF, and BGP operate, including selecting routes and maintaining forwarding tables.

The network interfaces present in the underlying OS kernel are exposed to the cRPD container when running in host network mode. cRPD learns about all the network interfaces and adds route state for them. If there are additional Docker containers running in the system, all the containers and applications running in the same network namespace can access the same set of network interfaces and state.

When multiple cRPD instances are running on a system in the same namespace, containers are connected to the host network stack through bridges. cRPD is connected to the Linux OS using bridges. The host interfaces are connected to the container using bridges. Multiple containers can connect to the same bridge and communicate with one another. See Figure 1.1 for reference.

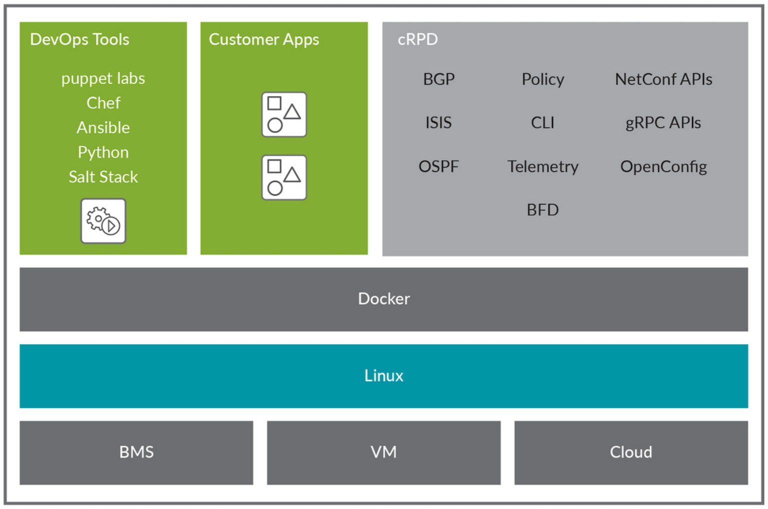


Figure 1.1 cRPD Overview

Further Reading

Here are some great resources that take you deeper into the working of routing on the Linux stack and Juniper Networks cRPD:

- https://www.techrepublic.com/article/understand-the-basics-of-linux-routing/
- https://opensource.com/business/16/8/introduction-linux-network-routing
- https://www.linuxjournal.com/article/7356
- https://www.juniper.net/documentation/us/en/software/crpd/crpd-deployment/topics/concept/understanding-crpd.html
- https://www.juniper.net/documentation/us/en/software/crpd/crpd-deployment/index.html
- https://containerlab.srlinux.dev/manual/kinds/crpd/
- https://iosonounrouter.wordpress.com/2020/11/24/transform-your-server-into-a-junos-powered-router-with-crpd/

Underlay and Overlay Networking

Now let's concentrate on underlay and overlay networking concepts to get a clear understanding of them for the remainder of the book. Let's also touch on some architectural decisions to be made when designing an IP fabric. Underlay, overlay, and IP fabric (also referred to as CLOS) concepts are used not only in today's data centers but also in edge routing use cases where customers build the edge routers using 'pizza boxes' interconnected by using IP fabrics.

Underlay Networking

The underlay network is a physical infrastructure over which an overlay network is built. In data center environments, the role of the physical underlay network is to provide Unicast IP connectivity from any physical device (server, storage device, router, or switch) to any other physical device.

As the underlying network responsible for delivery of packets across networks, an ideal underlay network provides low-latency, non-blocking, high-bandwidth connectivity from any point in the network to any other point in the network.

Overlay Networking

Overlay networking, often referred to as SDN, is a method of using software to create layers of network abstraction that can be used to run multiple, separate, discrete, and virtualized network layers on top of the physical network, often providing new application and security benefits.

All nodes in an overlay network are connected to one another by means of logical or virtual links and each of these links correspond to a path in the underlying network.

The purpose of the overlay network is to add functionality without a complete network redesign. Overlay network protocols include Virtual Extensible LAN (VXLAN), Network Virtualization using Generic Encapsulation (NVGRE), generic routing encapsulation (GRE), IP multicast, network virtualization overlays 3 (NVO3), MPLSoUPD, MPLSoGRE, SRoMPLS, and SRv6.

Common examples of an overlay network are distributed systems such as peer-to-peer networks and client server applications because their nodes run on top of the internet.

The nodes of the overlay network are interconnected using virtual or logical links, which form an overlay topology, although these nodes may be connected through physical links in the underlying networks. From an application perspective the overlay network 'looks and feels' as if it has a direct connection. In other words, two nodes may be connected with a logical connection (overlay tunnel) despite being several hops apart in the underlying network.

The overlay network interconnects all the application nodes and provides the connectivity between them.

Table 1.1 quickly compares underlay and overlay networks.

Table 1.1 Underlay Versus Overlay

	Underlay Network	Overlay Network
Description	An Underlay Network is a physical infrastructure above which an overlay network is built.	An Overlay Network is a virtual network that is built on top of an underlying Network infrastructure/Network layer (the underlay).
Traffic Flow	Transmits packets which traverse over network devices like switches and routers.	Transmits packets only along the virtual links between the overlay nodes.
Deployment Time	Time consuming activity to introduce new services and functions.	Ability to rapidly and incrementally deploy new functions through edge-centric innovations because connections are virtual (tunnels).
Packet Control	Hardware oriented.	Software oriented.
Packet Encapsulation and Overhead	Packet delivery and reliability occurs at layer-3 and layer-4.	Needs to encapsulate packets across source and destination, hence incurs additional overhead.
Multipath Forwarding	Less scalable options of multipath forwarding.	Support for multipath forwarding within virtual networks.
Multi Tenancy	Requires non-overlapping IP addressing.	Ability to manage overlapping IP addresses between multiple tenants.
Scalability	Less scalable. VLAN provides 4096 VLANs.	Designed to provide more scalability than underlay network. VXLAN e.g. provides up to 16 million identifiers.

Protocols	Underlay protocols include Ethernet Switching, VLAN, Routing, OSPF, ISIS, RIFT, etc.	Overlay network protocols include Virtual Extensible LAN (VXLAN), Network Virtualization using Generic Encapsulation (NVGRE), generic routing encapsulation (GRE), MPLS and Segment Routing, IP multicast, and Network Virtualization overlays 3 (NVO3).

MORE? This article published in the Internet Protocol Journal dives much deeper into the different protocols used in data center networking and the authors highly recommend it: https://ipj.dreamhosters.com/wp-content/uploads/2020/09/232-ipj-2.pdf.

Chapter 2

Junos cRPD

The Junos containerized routing protocol daemon (cRPD) offers deployment-hardened, feature-rich routing functionality in a container for cloud-native deployments. Decoupling the control plane from the data plane offers platform flexibility, simplicity, automation, elastic scalability, and operational efficiency, delivering a true "One Junos" experience in routers, servers, or any Linux-based device. By packaging the Junos operating system applications and their related routing stacks, such as a Docker container, Juniper extends traditional disaggregation by creating a flexible consumption model for network applications that can be easily scaled out. Service providers, cloud operators, and enterprises can deploy Junos cRPD in their existing server-based environments to address their unique requirements.

The containerized routing protocol process (cRPD) is Juniper's routing protocol process (RPD) decoupled from Junos OS and packaged as a Docker container to run in Linux-based environments. cRPD runs as a user space application and learns route state through various routing protocols and maintains the complete set in the routing information base (RIB), also known as the routing table. The RPD process is also responsible for downloading the routes into the forwarding information base (FIB), also known as forwarding table based on local selection criteria. In a Juniper Networks router the Packet Forwarding Engine (PFE) holds the FIB and does packet forwarding, whereas in cRPD on the host, the Linux kernel stores the FIB and performs packet forwarding. cRPD can also be deployed to provide control plane-only services such as BGP route reflection.

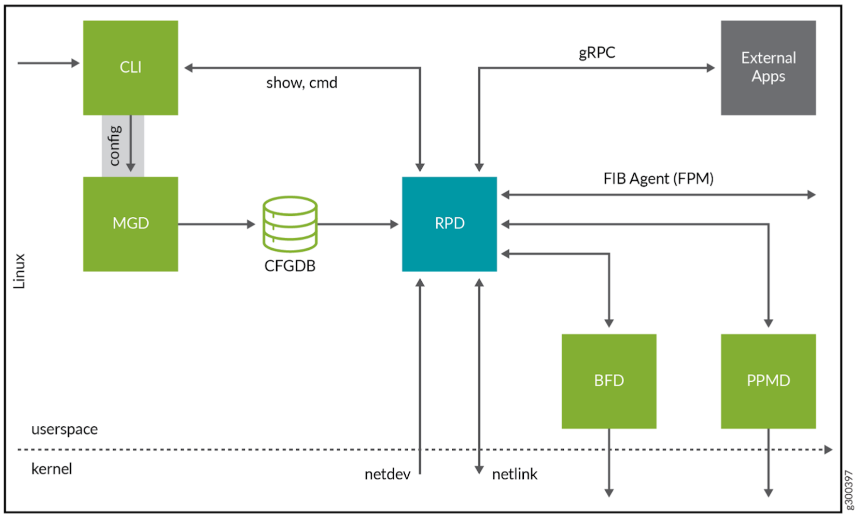


Figure 2.1 cRPD Architecture Components and How They Are Linked Together

cRPD supports the following features:

- Routing: IPv4, IPv6, MPLS, segment routing
- VPN: L3VPN, L2VPN, EVPN
- BGP route reflector in the Linux container
- BGP add-path, multipath, graceful restart helper mode
- BGP, OSPF, OSPFv3, IS-IS, and Static
- BGP-LU
- BGB Flowspec
- RIB Sharding, UpdIO
- BMP, BFD (centralized mode), and Linux-FIB
- MPLS LSP, L3VPN
- Multi-topology routing
- Equal-cost multipath (ECMP)
- JET for programmable RPD
- Junos CLI support
- Management using open interfaces NETCONF and SSH
- Kubernetes integration

NOTE A list of features supported in Junos cRPD appears in the 20.4R1 release, additional features will be added in later cRPD Junos releases.

This chapter shows you how to install Docker on different operating systems, how to set up docker networks, and how to spin up containers on the Docker platform.

Docker Installation

Let's install Docker on a couple of different platforms.

MAC OS System Requirements

MacOS El Capitan 10.11 and newer macOS releases are supported. At a minimum, Docker for Mac requires macOS Yosemite 10.10.3 or newer, with the caveat that going forward 10.10.x is a use-at-your-own risk proposition.

Docker has prepackaged all necessary parts including the Docker Engine, Docker CLI client, Docker Compose, Docker Machine, and Kitematic in one Mac installer (.dmg file) and you can download it from the Docker official website here: https://docs.docker.com/docker-for-mac/install/.

To download the Docker Desktop installation file, you have to get a DockerHub account. Registration of the DockerHub account is free with a valid email address.

Okay, once downloaded, install Docker Desktop.

Windows 10 System Requirements

You need Windows 10, 64 bit: Pro, Enterprise, or Education (1607 Anniversary Update, Build 14393 or later). For more details, see https://community.juniper.net/answers/blogs/marcel-wiget1/2021/02/17/juniper-crpd-204-on-docker-desktop.

Docker has prepackaged all necessary parts including Docker Engine, Docker CLI client, Docker Compose, Docker Machine, and Kitematic in one Windows installer (.exe file) and you can download it from the Docker official website through https://docs.docker.com/docker-for-windows/install/.

To download the Docker Desktop installation file, you need to log in to your Docker Hub account. Registration of a new Docker Hub account is free with a valid email address.

After the Docker installer has been downloaded, you can run it directly. After installation has succeeded, you need to log out of Windows to complete installation.

Docker does not start automatically after installation. To start it, search for Docker, select Docker Desktop for Windows in the search results, and click it.

Ubuntu System Requirements

To install Docker CE, you need the 64-bit version of one of these Ubuntu versions:

- Disco 19.04
- Cosmic 18.10
- Bionic 18.04 (LTS)
- Xenial 16.04 (LTS)

Docker CE is supported on x86_64 (or amd64), armhf, arm64, s390x (IBM Z), and ppc64le (IBM Power) architectures. For more details, see https://docs.docker.com/engine/install/ubuntu/.

To start, uninstall older versions of Docker called docker, docker.io, or docker engine. This can be done by running:

```
$ sudo apt-get remove docker docker-engine docker.io containerd runc
```

Now set up the repository:

1. Update the apt package index:

```
$ sudo apt-get update
```

2. Install packages to allow apt to use a repository over HTTPS:

```
$ sudo apt-get install \
> apt-transport-https \
> ca-certificates \
> curl \
> gnupg-agent \
> software-properties-common
```

3. Add Docker's official GPG key:

```
$ curl -fsSL https://download.docker.com/linux/ubuntu/gpg | sudo apt-key add -OK
```

4. Verify that you now have the key with the fingerprint 9DC8 5822 9FC7 DD38 854A E2D8 8D81 803C 0EBF CD88, by searching for the last eight characters of the fingerprint:

```
$ sudo apt-key fingerprint 0EBFCD88
pub rsa4096 2017-02-22 [SCEA] 9DC8 5822 9FC7 DD38 854A E2D8 8D81 803C 0EBF CD88
uid [ unknown] Docker Release (CE deb) <docker@docker.com>
sub rsa4096 2017-02-22 [S]
```

5. Use the following command to set up the stable repository. For x86_64/amd64, you can run:

```
$ sudo add-apt-repository \
> .deb [arch=amd64] https://download.docker.com/linux/ubuntu \
> $(lsb_release -cs) \
> stable.
```

Verification

After installing Docker on any OS, and the docker -v command in the command line, you can check the current docker version at the terminal:

```
# docker -v
Docker version 19.03.2, build 6a30dfc
```

This message shows that your installation appears to be working correctly.

Basic Docker Commands

The basic docker commands are:

To show the Docker version in detail, run:

```
# docker version
```

To list all Docker images:

```
# docker images
```

To create an image from a Docker file:

```
# docker build [OPTIONS] PATH | URL | -
```

To create an image from a .img or a .tar file:

```
# docker load [OPTIONS] PATH
```

To remove an image:

```
# docker rmi [OPTIONS] IMAGE [IMAGE...]
```

To tag an image to a name:

```
# docker tag SOURCE_IMAGE[:TAG] TARGET_IMAGE[:TAG]
```

Container-Related Commands

To create a container but not to start it:

```
# docker create [OPTIONS] IMAGE [COMMAND] [ARG...]
```

To rename a Docker container:

```
# docker rename OLD_NAME NEW_NAME
```

To create a container and to run a command with it:

```
# docker run [OPTIONS] IMAGE [COMMAND] [ARG...]
```

The container will stop after the command has finished command execution by default. For interactive processes (like a shell), you must use -i -t together to allocate a tty for the container process. To start a container in detached mode, option "-d" should be used. Detached mode means the container starts up and runs in the background.

To list all Docker containers:

```
# docker ps -a
```

To stop a container:

```
# docker stop [OPTIONS] CONTAINER [CONTAINER...]
```

To delete a container:

```
# docker rm [OPTIONS] CONTAINER [CONTAINER...]
```

Network-Related Commands

To create a network:

```
# docker network create [OPTIONS] NETWORK
```

To list all networks:

```
# docker network ls
```

To check the details of a network:

```
# docker network inspect [OPTIONS] NETWORK [NETWORK...]
```

To connect a container to a network:

```
# docker network connect [OPTIONS] NETWORK CONTAINER
```

To disconnect a container from a network:

```
# docker network disconnect [OPTIONS] NETWORK CONTAINER
```

To remove a network:

```
# docker network rm NETWORK [NETWORK...]
```

A network cannot be removed with a container attached to it. Before removing a network, please make sure all containers attached to it have been removed.

To show Docker container summary info:

```
# docker inspect [OPTIONS] NAME|ID [NAME|ID...]
```

To show container run logs:

```
# docker logs [OPTIONS] CONTAINER
```

To show container port exposure and mapping:

```
# docker port CONTAINER [PRIVATE_PORT[/PROTO]]
```

Docker Networking Options

Docker has developed a simple networking model called container network model (CNM), which defines how different containers can connect together while simplifying network implementation methods. The portability comes from CNM's powerful network drivers, pluggable interfaces for the Docker Engine, Swarm, and UCP (Docker universal control plane) that provide special capabilities like multi-host networking, network layer encryption, and service discovery. These drivers exist by default and provide core networking functionality:

- bridge: The default network driver. If you don't specify a driver, this is the type of network you are creating. Bridge networks are usually used when your applications run in standalone containers that need to communicate.
- host: For standalone containers, remove network isolation between the container and the Docker host, and use the host's networking directly. Host is only available for swarm services on Docker 17.06 and higher.

Running cRPD Instances

Setting up the cRPD requires:

- Ubuntu 14.04.2 or later
- Linux Kernel 4.15
- Docker Engine 18.09.1
- 1 CPU core
- 2 GB Memory
- 10 GB hard drive
- Host processor type is x86_64 multicore CPU
- 1 Ethernet port

Prepare the cRPD Image

Let's install the cRPD on a server running Ubuntu 14.04.2. There are only two steps for you to load the cRPD image on your machine: download the cRPD image, then import it.

Download the cRPD image. There are two ways to download the software:

- Juniper software download page
- Juniper Docker Registry

Download the cRPD software from the Juniper download URL

On a browser, navigate to https://support.juniper.net/support/downloads/, and type “ cRPD” in the textbox under “Find a Product.” The page will update itself and show up cRPD download resources with the latest version. Img format can be imported directly. Click on the “img” link and you will be redirected to a terms and conditions page. After choosing “I Agree” and “Next” the URL for downloading this image will be given. Copy the URL.

On your Ubuntu server, run this command to get the image:

```
# wget (paste the URL)
```

To check if the file has been downloaded to your server, run:

```
# ls
junos-crpd-docker-20.3R1.8.img
```

Load the image:

```
#docker load -i crpd-19.2R1.8.tgz
#docker images
REPOSITORY      TAG         IMAGE ID            CREATED         SIZE
crpd           19.2R1.8    4156a807054a        6 days ago       278MB
```

Download the cRPD software using the Juniper Docker Registry. Follow the instructions listed here: https://www.juniper.net/documentation/us/en/software/crpd21.1/crpd-deployment/topics/task/crpd-linux-server-install.html.

Running the cRPD

To create data volume for configuration:

```
# docker volume create crpd01-config
```

To create data volume for var logs:

```
# docker volume create crpd01-varlog
```

To start the cRPD in bridge mode:

```
# docker run --rm --detach --name crpd01 -h crpd01 --net=bridge --privileged -v crpd01-config:/
config -v crpd01-varlog:/var/log -it crpd:19.2R1.8
```

To start the cRPD in host networking mode:

```
# docker run --rm --detach --name crpd01 -h crpd01 --privileged --net=host -v crpd01-config:/
config -v crpd01-varlog:/var/log -it crpd:19.2R1.8
```

To configure the cRPD using the CLI:

```
# docker exec -it crpd01 cli
```

```
root@crpd01> configure
Entering configuration mode
[edit]
root@crpd01# show
## Last changed: 2019-02-13 19:28:26 UTC
version "19.2I20190125_1733_rbu-builder [rbu-builder]";
system {
    root-authentication {
        encrypted-password "$6$JEc/p$QOUpqi2ew4tVJNKXZYiCKT8CjnlP3SLu16BRIxvtz0CyBMc57WGu2oCyg/
lTr0iR8oJMDumtEKi0HVo2NNFEJ."; ## SECRET-DATA
    }
}
routing-options {
    forwarding-table {
        export pplb;
    }
    router-id 90.90.90.20;
    autonomous-system 100;
}
protocols {
    bgp {
        group test {
            type internal;
            local-address 90.90.90.20;
            family inet {
                unicast;
            }
            neighbor 90.90.90.10 {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
            neighbor 90.90.90.30 {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
        }
        group test6 {
            type internal;
            local-address abcd::90:90:90:20;
            family inet6 {
                unicast;
            }
            neighbor abcd::90:90:90:10 {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
            neighbor abcd::90:90:90:30 {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
        }
    }
    isis {
        level 1 disable;
        interface all {
            family inet {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
            family inet6 {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
        }
    }
    ospf {
        area 0.0.0.0 {
            interface all {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
        }
    }
    ospf3 {
        area 0.0.0.0 {
            interface all {
                bfd-liveness-detection {
                    minimum-interval 100;
                }
            }
        }
    }
}
policy-options {
    policy-statement pplb {
        then {
            load-balance per-packet;
        }
    }
}
interfaces {
    lo0 {
        unit 0 {
            family iso {
                address 49.0005.1111.2222.3333.00;
            }
        }
    }
}
```

Licensing for cRPD

Table 2.1 lists the licensing support for Routing Stack for Host on cRPD.

Table 2.1 Routing Stack for Host Features on cRPD

License Model	Routing Stack for Host SKUs	Use Case Examples or Solutions
Advanced	S-CRPD-A-HR-1/3/5 S-CRPD-100-A-HR-1/3/5 S-CRPD-1K-A-HR-1/3/5 S-CRPD-10K-A-HR-1/3/5	Layer 3 deployments with MPLS or SR starting at the host
Standard	S-CRPD-S-HR-1/3/5 S-CRPD-100-S-HR-1/3/5 S-CRPD-1K-S-HR-1/3/5 S-CRPD-10K-S-HR-1/3/5	Layer 3 to the IP host

Next, Table 2.2 lists the licensing support with use case examples Route Reflector on cRPD.

Table 2.2 Route Reflector Features on cRPD

License Model	Route Reflector SKUs	Use Case Examples or Solutions
Advanced	S-CRPD-S-RR-1 S-CRPD-S-RR-3 S-CRPD-S-RR-5	Route Reflector or Route Server

And Table 2.3 lists the SKU definitions.

Table 2.3 cRPD SKU Definition

SKU	SKU Character Description	
S-CRPD-S/A-HR-1/3/5 S-CRPD-100/1K/10K-S/A-HR-1/3/5 S-CRPD-S-RR-1/3/5	S—Software CRPD—Product name cRPD S—Standard software subscription A—Advanced software subscription HR—Host Routing	RR—Route Reflector 100—Bundle of 100 software licenses 1K—Bundle of 1000 software licenses 10K—Bundle of 10000 software licenses 1/3/5—Subscription term 1, 3, or 5 years

To configure and add the license to the cRPD using CLI:

```
# docker exec -it crpd01 cli
===>
Entering Containerized Routing Protocols Daemon (CRPD beta)
Copyright (c), Juniper Networks, Inc. All rights reserved.
                                                     <===
root@crpd01> request system license add terminal
/* Paste the key */

root@crpd01> show system license detail

     Licenses     Licenses    Licenses     Licenses    Expiry
  Feature name                       used     installed      needed     available
  containerized-rpd-standard            0           10            0           10    2019-12-
01 23:59:00 UTC

Licenses installed:
  License identifier: 6fc1139b-ed66-4923-b55b-8ccb99508714
  License SKU: S-CRPD-S-3
  License version: 1
  Order Type: commercial
  Customer ID: TEXAS STATE UNIV.-SAN MARCOS
  License Lease End Date: 2019-12-01 23:59:00 UTC
  Features:
    containerized-rpd-standard - Containerized routing protocol daemon with standard features
      date-based, 2019-10-02 00:00:00 UTC - 2019-12-01 23:59:00 UTC

Licensing Mode: Agile Licensing Network
Last server sync time: 2019-10-31 13:47:07 UTC
```

Packaging Additional Utilities in cRPD

cRPD comes with some Linux utilities, but there may be cases where some extra utilities that are not available in the official cRPD docker image are needed. In such a scenario, there may be a need to add additional packages.

There are multiple ways to bundle additional packages in cRPD:

- Using Linux package manager utilities to download new packages from the internet, or
- Using a custom cRPD image which houses the additional utilities.

Using Linux Package Manager

Use apt package manager for Ubuntu to download required packages after bringing up cRPD container. The packages need to be installed from the Linux shell of the cRPD.

The following example shows how to install 'tree' Linux utilities in the Linux shell of cRPD:

```
root@node-2:~# apt-get install tree
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following package was automatically installed and is no longer required:
  grub-pc-bin
Use 'apt autoremove' to remove it.
The following NEW packages will be installed:
  tree
0 upgraded, 1 newly installed, 0 to remove and 23 not upgraded.
Need to get 40.7 kB of archives.
After this operation, 105 kB of additional disk space will be used.
Get:1 http://archive.ubuntu.com/ubuntu bionic/universe amd64 tree amd64 1.7.0-5 [40.7 kB]
Fetched 40.7 kB in 1s (65.0 kB/s)
Selecting previously unselected package tree.
(Reading database ... 137961 files and directories currently installed.)
Preparing to unpack .../tree_1.7.0-5_amd64.deb ...
Unpacking tree (1.7.0-5) ...
Setting up tree (1.7.0-5) ...
Processing triggers for man-db (2.8.3-2ubuntu0.1) ...
root@node-2:~#
```

Build a Custom cRPD Docker Image With All Utilities

You can build a custom cRPD image by defining your own Dockerfile. In a large-scale deployment you may need to add some additional Linux tool utilities to the cRPD. Having your own cRPD container with custom utilities helps in such scenarios.

Define Docker file as follows. In this dockerfile we are adding 'ethtool' to the cRPD base container running cRPD version of 20.3R1.8:

```
FROM crpd:20.3R1.8
RUN apt-get update \
 && apt-get -y --no-install-recommends install ethtool \
 && rm -rf /var/lib/apt/lists/*

COPY runit-init.sh /sbin/
RUN chmod +x /sbin/runit-init.sh
WORKDIR /root
STOPSIGNAL 35
```

Below is the content of runit-int.sh file and this file should be present in the same directory as Dockerfile when building modified cRPD image. You can easily extend this idea to build various custom cRPD images per your deployment needs.

```
#!/bin/bash
export > /etc/envvars
exec /sbin/runit-init 0
```

cRPD Installation in Kubernetes

NOTE It is assumed that the reader already has a working Kubernetes cluster. In this section show how you can bring up cRPD in the Kubernetes cluster as an application POD.

Please ensure that you have docker images for cRPD available on each kubernetes cluster node. You can do that either by setting up a local registry for cRPD image or you can individually copy a cRPD docker image on each Kubernetes node.

cRPD Running as an Application POD

Below is the YAML definition for bringing up cRPD as a POD:

```
apiVersion: v1
kind: Pod
metadata:
          name: crpd
          labels:
          app: crpd
spec:
          containers:
          - name: crpd
          image: crpd:latest
imagePullPolicy: Never
resources:
          limits:
          memory: "200Mi"
          cpu: "100"
          requests:
          memory: "100Mi"
          cpu: "100"

          ports:
          - containerPort: 179
          securityContext:
          privileged: true
volumeMounts:
          - name: crpd-storage
          mountPath: /var/log/crpd-storage
volumes:
  - name: crpd-storage
    persistentVolumeClaim:
      claimName: crpd-pv-claim
```

You can see it is important to have `containerPort: 179` to ensure that cRPD is able to install routes in the kernel.

You can limit resource usage by cRPD by allocating resources as in the `resource` section of the above POD manifest file.

If you don't want to lose some data, for example a configuration if the cRPD POD dies, then you can define persistent volume and attach it in the POD manifest file.

You can create `Persistent Volume` as shown here and attach it in the POD manifest file under the volumes section listed above:

```
apiVersion: v1
kind: PersistentVolume
metadata:
  name: crpd-pv-volume
  labels:
    type: local
spec:
  storageClassName: manual
  capacity:
          storage: 10Gi
  accessModes:
          - ReadWriteOnce
  hostPath:
          path: "/mnt/data"
---
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: crpd-pv-claim
spec:
  storageClassName: manual
  accessModes:
          - ReadWriteOnce
  resources:
          requests:
          storage: 3Gi
```

cRPD Running as a Kubernetes Deployment

Below is a sample manifest file to run cRPD as a Kubernetes deployment. The good thing about Kubernetes deployment is that Kubernetes control plane takes care of the application life cycle and can automatically scale up or scale down the number of PODs at the run time based on the number of replicas needed:

```
apiVersion: apps/v1
kind: Deployment
  labels:
          run: crpd
  name: crpd
  namespace: default
spec:
  replicas: 3
  selector:
          matchLabels:
          run: crpd
  template:
          metadata:
          labels:
          run: crpd
          spec:
          containers:
          - name: crpd
          image: crpd:latest
          imagePullPolicy: Never
```

This manifest file is an example of how to define cRPD deployment. The important thing to note is that you can dynamically bring the number of cRPD PODs up and down by changing the value of replicas defined in the YAML file. We also need to have a Kubernetes service abstraction and expose the deployment using Kubernetes services.

Chapter 3

cRPD Use Cases

This chapter provides an overview of some of the aforementioned use cases where cRPD can play a role. Some use cases will contain just an overview of an idea, others go into great detail and cover complete solutions. You can tailor these cases to your own situation as we suggest new directions and new ways to deploy cRPD.

Multi-homing Hosts to an IP-fabric

Eliminating Layer 2 connections in WANs has been good practice for a couple of years now. The authors also believe that it makes good sense to avoid as many Layer 2 connections inside the data center as possible. Routing on the host (ROTH) is a process that has become reality with the availability of virtualized routing daemons. Juniper cRPD is the perfect solution for this task as it can *speak* to all current popular routing protocols.

With these options available the host becomes part of the IP fabric underlay and could terminate tunnels natively on the host, removing much of the demand from the ToR or access switch.

The underlay routing protocol options operators can choose from several IGPs like OSPF and ISIS to BGP and even more recent additions like RIFT. In the overlay there are many options to choose from as well: MPLS-based tunnels, segment routing, and VXLAN, just to name a few.

Overlay / Underlay

The way data centers are designed is changing rapidly. Until recently a lot of Layer 2 designs were being used, and even though these are designs understood by most network engineers there are some huge disadvantages, namely:

- Loop prevention can become complex
- Ethernet switching tables can grow rapidly and become a limiting factor
- Traffic engineering is hardly possible

To overcome these limitations MPLS is sometimes used in data centers because it already proved itself in the service provider world. But using this technology means you need MPLS routers everywhere in your network, quickly making it an expensive solution. Most of the time EVPN is used in the control plane for the MPLS solution, and obviously MPLS is used in the data plane. But now the same EVPN control plane is available using VXLAN in the data plane. To further reduce Layer 2 in the infrastructure you can terminate the VXLAN tunnels in the hosts/hypervisors using software VTEPs instead of terminating them in the hardware of the TOR switches. In this model you use a routed underlay network to set up VXLAN overlay tunnels.

EVPN uses an address type (NLRI) in MBGP to advertise MAC addresses in the data plane, replacing the flooding mechanism used by switches and VPLS. So when you want to connect all your end nodes (hosts or hypervisors) on Layer 3, you need BGP on every end node. The cRPD offers you this. You can run MBGP in it for the overlay functionality. The same cRPD container can handle the routing for the underlay network. This can be done with different routing protocols but when scaling is an issue the only suitable choices are probably BGP or a protocol specially designed for situations like this: RIFT (Routing in Fat Trees). More about that later in this chapter.

Egress Peering Engineering From the Host

Egress peer traffic engineering (EPE) allows a host or central controller to instruct an ingress router within a domain to direct traffic towards a specific egress router and external interface to reach a particular destination outside the network. cRPD enables egress peer traffic engineering to select the best advertised egress route and map that route to a specific egress point. Load balancing is implemented at the ingress, ensuring optimum utilization of the advertised egress routes.

In Figure 3.1 the ingress functionality is run on a Linux device that is hosting a Juniper Networks cRPD.

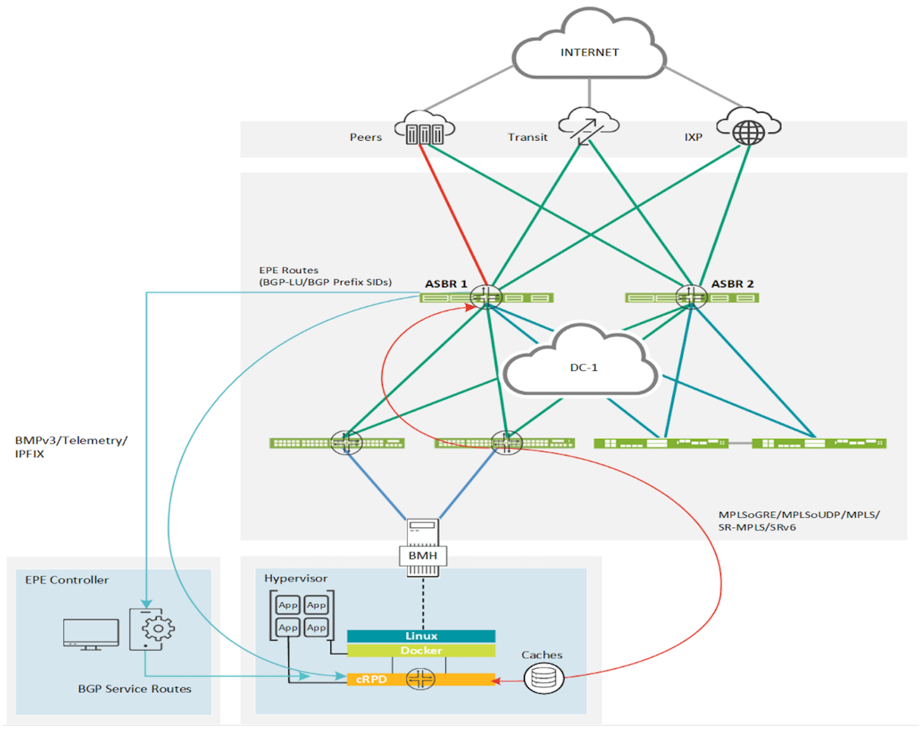


Figure 3.1 *A Typical Use Case Where cRPD Uses BGP-LU to Signal Its Upstream Routers Which Path to Take Further Up the Network*

Requirements

This example uses the following hardware and software components in a topology illustrated by Figure 3.2:

- Linux VM (H0), that simulates the data center server and hosts the cRPD docker container
- Linux server running:
  - Linux OS Ubuntu 18.04 (or newer)
  - Linux Kernel 4.15 (or newer)
  - Docker Engine 18.09.1(or newer)
- Other nodes in the topology are vMX routers running Junos Release 19.2R2.2
- R0 is a vMX that simulates the ASBR PR1
- R1 is a separate vMX that simulates the rest of the routers (ToR, RR, P, Peer, U1) as logical systems

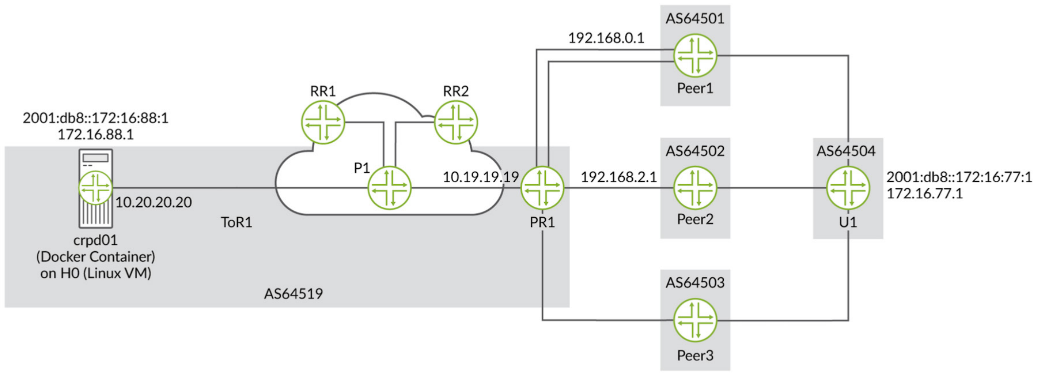


Figure 3.2 Topology Used in this Example with BGP Labeled Unicast Egress Peer Traffic Engineering on Ingress Using cRPD

Configuration

This section shows how to enable egress traffic engineering on the ASBR R0 and demonstrates ingress functionality on the cRPD. Configuration of other routers is generic and is omitted to focus on the details relevant to this example.

MORE? This example is based on a Juniper TechLibrary example that you can use as a reference to configure the other routers in the network: Configuring Egress Peer Traffic Engineering Using BGP Labeled Unicast.

Configure R0 (ASBR) to Facilitate Egress Traffic Engineering in the Network

1. Configure a GRE tunnel on VMX R0 toward crpd01:

```
set chassis fpc 0 pic 0 tunnel-services
set interfaces gr-0/0/0 unit 0 tunnel source 10.19.19.19
set interfaces gr-0/0/0 unit 0 tunnel destination 10.20.20.20
set interfaces gr-0/0/0 unit 0 family inet address 10.19.19.1/32
set interfaces gr-0/0/0 unit 0 family inet6
set interfaces gr-0/0/0 unit 0 family mpls
```

2. Enable egress traffic engineering toward the external peers:

```
set protocols bgp group toPeer1Link1 egress-te
set protocols bgp group toPeer1Link1V6 egress-te
set protocols bgp group toPeer1Link2 egress-te
set protocols bgp group toPeer1Link2V6 egress-te
set protocols bgp group toPeer2 egress-te
set protocols bgp group toPeer2V6 egress-te
```

3. Create policies that export the ARP routes that egress traffic engineering created and apply them to the IBGP core in the labeled unicast family:

```
set policy-options policy-statement export_to_rrs term a from protocol arp
set policy-options policy-statement export_to_rrs term a from rib inet.3
set policy-options policy-statement export_to_rrs term a then next-hop self
set policy-options policy-statement export_to_rrs term a then accept
set policy-options policy-statement export_to_rrs term b from protocol arp
set policy-options policy-statement export_to_rrs term b from rib inet6.3
set policy-options policy-statement export_to_rrs term b then next-hop self
set policy-options policy-statement export_to_rrs term b then accept
set policy-options policy-statement export_to_rrs term c from protocol bgp
set policy-options policy-statement export_to_rrs term c then accept
set policy-options policy-statement export_to_rrs term default then reject
set protocols bgp group toRRs type internal
set protocols bgp group toRRs local-address 10.19.19.19
set protocols bgp group toRRs family inet labeled-unicast rib inet.3
set protocols bgp group toRRs family inet6 labeled-unicast rib inet6.3
set protocols bgp group toRRs export export_to_rrs
set protocols bgp group toRRs neighbor 10.6.6.6
set protocols bgp group toRRs neighbor 10.7.7.7
set protocols bgp group toRRs export export_to_rrs
```

4. Re-advertise Internet routes from external peers with the next hop unchanged:

```
set protocols bgp group toRRs family inet unicast add-path receive
set protocols bgp group toRRs family inet unicast add-path send path-count 6
set protocols bgp group toRRs family inet6 unicast add-path receive
set protocols bgp group toRRs family inet6 unicast add-path send path-count 6
set protocols bgp group toRRs export export_to_rrs
```

Configure the cRPD (Ingress Node) to Control EPE Decisions in the Network

1. On the Linux shell create the IP tunnel:

```
host@h0:~# ip tunnel add gre1 mode gre remote 10.19.19.19 local 10.20.20.20 ttl 255
host@h0:~# ip link set gre1 up
```

2. Enter the cRPD Junos CLI and configure the protocols. These will bring up OSPF and BGP sessions at cRPD01. The routes installed on the cRPD will bring up the GRE tunnel in Linux:

```
set policy-options prefix-list SvrV6Pfxes 2001:db8::172:16:88:1/128
set policy-options prefix-list SvrV4Pfxes 172.16.88.1/32
set policy-options prefix-list SvrV4lo 10.20.20.20/32
set policy-options policy-statement export_lo1 term a from prefix-list SvrV4lo
set policy-options policy-statement export_lo1 term a then accept
set policy-options policy-statement export_lo1 term def then reject
set policy-options policy-statement export_to_peers term a from prefix-list SvrV4Pfxes
set policy-options policy-statement export_to_peers term a then accept
set policy-options policy-statement export_to_peers term b from prefix-list SvrV6Pfxes
set policy-options policy-statement export_to_peers term b then accept
set policy-options policy-statement export_to_peers term def then reject
set routing-options router-id 10.20.20.20
set routing-options autonomous-system 19
set routing-options rib inet.3 static route 10.19.19.19/32 next-hop gre1
set routing-options rib inet6.3 static route ::ffff:10.19.19.19/128 next-hop gre1
set protocols bgp group toRRs type internal
set protocols bgp group toRRs local-address 10.20.20.20
set protocols bgp group toRRs family inet labeled-unicast rib inet.3
set protocols bgp group toRRs family inet unicast add-path receive
set protocols bgp group toRRs family inet unicast add-path send path-count 6
set protocols bgp group toRRs family inet6 labeled-unicast rib inet6.3
set protocols bgp group toRRs family inet6 unicast add-path receive
set protocols bgp group toRRs family inet6 unicast add-path send path-count 6
set protocols bgp group toRRs neighbor 10.6.6.6
set protocols bgp group toRRs neighbor 10.7.7.7
set protocols bgp connect-retry-interval 1
set protocols bgp hold-time 6
set protocols bgp export export_to_peers
set protocols ospf export export_lo1
set protocols ospf area 0.0.0.0 interface ens3f1
```

Verification

1. On crpd01, verify that the routing protocol sessions are up:

```
host@crpd01> show ospf neighbor

Address          Interface              State     ID               Pri  Dead
10.20.21.2       ens3f1                 Full      8.8.8.8          128    36

host@crpd01> show bgp summary
Threading mode: BGP I/O
Groups: 1 Peers: 2 Down peers: 0
Table          Tot Paths  Act Paths Suppressed    History Damp State    Pending
inet.0
                      40          5          0          0          0          0
inet.3
                       8          4          0          0          0          0
inet6.0
                      42          5          0          0          0          0
inet6.3
                       8          4          0          0          0          0
Peer                     AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Accepted/Damped...
10.6.6.6                 19         31          9       0       0           6 Establ
  inet.0: 5/20/20/0
  inet.3: 4/4/4/0
  inet6.0: 5/21/21/0
  inet6.3: 4/4/4/0
```

2. On crpd01, verify that IPv4 routes for U1 are installed. You should see the BGP routes with all available next hops: 192.168.0.1, 192.168.1.1, 192.168.2.1, and 192.168.3.1:

```
host@crpd01> show route 172.16.77.1/32

inet.0: 27 destinations, 44 routes (25 active, 0 holddown, 2 hidden)
+ = Active Route, - = Last Active, * = Both

172.16.77.1/32     *[BGP/170] 00:05:25, localpref 100, from 10.6.6.6
```

```
                   AS path: 1 4 I, validation-state: unverified
                    >  via gre1, Push 300912
                    [BGP/170] 00:05:25, localpref 100, from 10.6.6.6
                      AS path: 1 4 I, validation-state: unverified
                    >  via gre1, Push 301040
                    [BGP/170] 00:05:25, localpref 100, from 10.6.6.6
                      AS path: 2 4 I, validation-state: unverified
                    >  via gre1, Push 301056
                    [BGP/170] 00:05:25, localpref 100, from 10.6.6.6
                      AS path: 3 4 I, validation-state: unverified
                    >  via gre1, Push 300976
```

3. On crpd01, verify that IPv6 routes for U1 are installed:

```
host@crpd01> show route 2001:db8::172:16:77:1
inet6.0: 15 destinations, 31 routes (13 active, 0 holddown, 2 hidden)
+ = Active Route, - = Last Active, * = Both

2001:db8::172:16:77:1/128
                   *[BGP/170] 00:09:45, localpref 100, from 10.6.6.6
                      AS path: 1 4 I, validation-state: unverified
                    >  via gre1, Push 301072
                    [BGP/170] 00:09:45, localpref 100, from 10.6.6.6
                      AS path: 1 4 I, validation-state: unverified
                    >  via gre1, Push 301088
                    [BGP/170] 00:09:45, localpref 100, from 10.6.6.6
                      AS path: 2 4 I, validation-state: unverified
                    >  via gre1, Push 301104
                    [BGP/170] 00:09:45, localpref 100, from 10.6.6.6
                      AS path: 3 4 I, validation-state: unverified
                    >  via gre1, Push 301120
```

4. On crpd01, verify next-hop resolution for IPv4:

```
host@crpd01> show route 172.16.77.1 extensive

inet.0: 27 destinations, 44 routes (25 active, 0 holddown, 2 hidden)
172.16.77.1/32 (4 entries, 1 announced)
TSI:
KRT in-kernel 172.16.77.1/32 -> {indirect(-)}
        *BGP    Preference: 170/-101
                Next hop type: Indirect, Next hop index: 0
                Address: 0x4c4a3bc
                Next-hop reference count: 10
                Source: 10.6.6.6
                Next hop type: Router, Next hop index: 0
                Next hop: via gre1, selected
                Label operation: Push 300912
```

5. On crpd01, verify next-hop resolution for IPv6:

```
host@crpd01> show route 2001:db8::172:16:77:1 extensive

inet6.0: 15 destinations, 31 routes (13 active, 0 holddown, 2 hidden)
2001:db8::172:16:77:1/128 (4 entries, 1 announced)
TSI:
KRT in-kernel 2001:db8::172:16:77:1/128 -> {indirect(-)}
        *BGP    Preference: 170/-101
```

```
                Next hop type: Indirect, Next hop index: 0
                Address: 0x4c4aa7c
                Next-hop reference count: 10
                Source: 10.6.6.6
                Next hop type: Router, Next hop index: 0
                Next hop: via gre1, selected
.
.
.
                Addpath Path ID: 1
                Indirect next hops: 1
                        Protocol next hop: 19:1::1 Metric: 0
                        Indirect next hop: 0x6512208 - INH Session ID: 0x0
                        Indirect path forwarding next hops: 1
                                Next hop type: Router
                                Next hop: via gre1
                                Session Id: 0x0
                                19:1::1/128 Originating RIB: inet6.3
                                  Metric: 0     Node path count: 1
                                  Indirect nexthops: 1
                                        Protocol Nexthop: ::ffff:10.19.19.19 Push 301072
                                        Indirect nexthop: 0x6511208 - INH Session ID: 0x0
                                         Path forwarding nexthops link: 0x4c49bc0
                                         Path inh link: (nil)
                                        Indirect path forwarding nexthops: 1
                                                Nexthop: via gre1
                                                Session Id: 0
                                        ::ffff:10.19.19.19/128 Originating RIB: inet6.3
                                          Node path count: 1
                                          Forwarding nexthops: 1
                                                Nexthop: via gre1
                                                Session Id: 0
```

6. On H0, verify that IPv4 routes are installed in THE Linux FIB with MPLS encapsulation:

```
host@h0:~# ip route | grep 172.16.77.1

172.16.77.1  encap mpls  300912 dev gre1 proto 22
172.16.77.12  encap mpls  300912 dev gre1 proto 22
```

7. On H0, verify that IPv6 routes are installed in Linux FIB accordingly, with MPLS encapsulation:

```
host@h0:~# ip -6 route | grep 172:16:77:1

2001:db8::172:16:77:1  encap mpls  301072 dev gre1 proto 22 metric 1024 pref medium
2001:db8::172:16:77:12  encap mpls  301072 dev gre1 proto 22 metric 1024 pref medium
```

7. Run ping from R0 to R6 on IPv4 and IPv6:

```
host@h0:~# ping 172.16.77.1 -I 172.16.88.1 -f

PING 172.16.77.1 (172.16.77.1) from 172.16.88.1 : 56(84) bytes of data.
.^C
--- 172.16.77.1 ping statistics ---
900 packets transmitted, 899 received, 0% packet loss, time 2618ms
```

```
rtt min/avg/max/mdev = 2.209/2.864/10.980/0.619 ms, ipg/ewma 2.913/3.223 ms

host@h0:~# ping 2001:db8::172:16:77:1 -I 2001:db8::172:16:88:1 -f

PING 2001:db8::172:16:77:1(2001:db8::172:16:77:1) from 2001:db8::172:16:88:1 : 56 data bytes
.^
--- 2001:db8::172:16:77:1 ping statistics ---
437 packets transmitted, 437 received, 0% packet loss, time 1304ms
rtt min/avg/max/mdev = 2.300/2.925/7.535/0.599 ms, ipg/ewma 2.991/3.442 ms
```

8. Keep the ping running and monitor interface statistics at R3. Verify that traffic is exiting toward Peer1:

```
host@10.53.33.247> monitor interface ge-0/0/0.0

10.53.33.247                      Seconds: 8                   Time: 19:25:11
                                                         Delay: 42/1/42
Interface: ge-0/0/0.0, Enabled, Link is Up
Flags: SNMP-Traps 0x4000
Encapsulation: ENET2
VLAN-Tag [ 0x8100.11 ]
Local statistics:                                                     Current delta
  Input bytes:                   1006749                                     [1216]
  Output bytes:                  1254088                                     [1541]
  Input packets:                   13917                                       [17]
  Output packets:                  13949                                       [17]
Remote statistics:
  Input bytes:                     29000 (568 bps)                              [0]
  Output bytes:                 28219976 (513064 bps)                      [511568]
  Input packets:                     400 (1 pps)                                [0]
  Output packets:                 300048 (682 pps)                           [5442]
IPv6 statistics:
  Input bytes:                     22952 (632 bps)                              [0]
  Output bytes:                 15789896 (282912 bps)                      [283088]
  Input packets:                     292 (0 pps)                                [0]
  Output packets:                 152026 (340 pps)                           [2722]
Traffic statistics:
  Input bytes:                   1035749                                     [1216]
  Output bytes:                 29474064                                   [513109]
  Input packets:                   14317                                       [17]
  Output packets:                 313997                                     [5459]
Protocol: inet, MTU: 1500, Flags: None

host@10.53.33.247> monitor interface ge-0/0/0.2

10.53.33.247                      Seconds: 6                   Time: 19:24:25
                                                           Delay: 1/1/1
Interface: ge-0/0/0.2, Enabled, Link is Up
Flags: SNMP-Traps 0x4000
Encapsulation: ENET2
VLAN-Tag [ 0x8100.13 ]
Local statistics:                                                     Current delta
  Input bytes:                    998771                                      [858]
  Output bytes:                  1247597                                      [934]
  Input packets:                   13781                                       [12]
  Output packets:                  13857                                       [10]
Remote statistics:
  Input bytes:                 41009996 (495704 bps)                [386714]
  Output bytes:                15769092 (0 bps)                          [0]
  Input packets:                 436234 (660 pps)                     [4116]
  Output packets:                168027 (0 pps)                          [0]
IPv6 statistics:
  Input bytes:                 22853256 (271656 bps)                [213467]
  Output bytes:                 8703312 (0 bps)                          [0]
  Input packets:                 220035 (326 pps)                     [2053]
  Output packets:                 83874 (0 pps)                          [0]
Traffic statistics:
  Input bytes:                 42008767                             [387572]
  Output bytes:                17016689                                [934]
  Input packets:                 450015                               [4128]
  Output packets:                181884                                 [10]
Protocol: inet, MTU: 1500, Flags: None
```

9. Add the following configuration to install a static route at R0 for R6/32 destination, with next hop of Peer2, with the resolve option. This configuration simulates a Controller API installed route to move the traffic to Peer2:

```
host@crpd01# edit routing-options

   rib inet6.3 {
    rib inet6.0 { . . .}
       static {
           route 2001:db8::172:16:77:1/128 {
               next-hop 19:2::2;
               resolve;
           }
       }
   }

edit routing-options
        static {
          route 172.16.77.1/32 {
             next-hop 192.168.2.1;
             resolve;
       }
   }
```

10. On H0, observe routes in the Linux FIB changes to encapsulate toward the new next hop:

```
host@h0:~# ip route | grep 172.16.77.1

172.16.77.1  encap mpls  301056 dev gre1 proto 22
172.16.77.12  encap mpls  300912 dev gre1 proto 22
host@h0:~# ip -6 route | grep 172:16:77:1
2001:db8::172:16:77:1  encap mpls  301104 dev gre1 proto 22 metric 1024 pref medium
2001:db8::172:16:77:12  encap mpls  301072 dev gre1 proto 22 metric 1024 pref medium
```

11. Run ping from R0 to R6. Traffic is steered toward Peer2, as directed by the controller installed static route:

```
host@10.53.33.247> monitor interface ge-0/0/0.0

10.53.33.247                      Seconds: 247                Time: 19:29:10
```

```
                                                        Delay: 1/0/150
Interface: ge-0/0/0.0, Enabled, Link is Up
Flags: SNMP-Traps 0x4000
Encapsulation: ENET2
VLAN-Tag [ 0x8100.11 ]
Local statistics:                                               Current delta
  Input bytes:                 1043286                                [37753]
  Output bytes:                1298727                                [46180]
  Input packets:                 14427                                  [527]
  Output packets:                14447                                  [515]
Remote statistics:
  Input bytes:                   29000 (0 bps)                            [0]
  Output bytes:               38398552 (0 bps)                     [10690144]
  Input packets:                   400 (0 pps)                            [0]
  Output packets:               408337 (0 pps)                       [113731]
IPv6 statistics:
  Input bytes:                   22952 (640 bps)                          [0]
  Output bytes:               21417856 (0 bps)                      [5911048]
  Input packets:                   292 (0 pps)                            [0]
  Output packets:               206141 (0 pps)                        [56837]
Traffic statistics:
  Input bytes:                 1072286                                [37753]
  Output bytes:               39697279                             [10736324]
  Input packets:                 14827                                  [527]
  Output packets:               422784                               [114246]
Protocol: inet, MTU: 1500, Flags: None


host@10.53.33.247> monitor interface ge-0/0/0.2


10.53.33.247                      Seconds: 346                Time: 19:30:05
                                                       Delay: 23/0/166
Interface: ge-0/0/0.2, Enabled, Link is Up
Flags: SNMP-Traps 0x4000
Encapsulation: ENET2
VLAN-Tag [ 0x8100.13 ]
Local statistics:                                               Current delta
  Input bytes:                 1050215                                [52302]
  Output bytes:                1312403                                [65740]
  Input packets:                 14498                                  [729]
  Output packets:                14581                                  [734]
Remote statistics:
  Input bytes:                62583536 (506896 bps)                [21960254]
 Output bytes:            24189032 (506328 bps)            [8419940]  Input packets:
665769 (675 pps)              [233651]
  Output packets:               257617 (673 pps)                      [89590]
IPv6 statistics:
  Input bytes:                34774776 (281456 bps)                [12134987]
  Output bytes:               13354088 (280456 bps)                 [4650776]
  Input packets:                334665 (338 pps)                     [116683]
  Output packets:               128593 (337 pps)                      [44719]
Traffic statistics:
  Input bytes:                63633751                             [22012556]
  Output bytes:               25501435                              [8485680]
  Input packets:                680267                               [234380]
  Output packets:               272198                                [90324]
Protocol: inet, MTU: 1500, Flags: None
```

L3VPN in MSP

This use case discusses the configuration of Layer 3 VPN (VRF) on a cRPD instance with an MPLS Segment Routing data plane. In edge cloud infrastructure application-specific PE routers are replaced by a cloud-native workload, such as the cRPD for routing function with Linux forwarding plane, to provide Layer 3 overlay services. The cRPD Layer 3 VPN feature leverages the support provided in Linux for VRF and MPLS, and enables the routing instance functionality along the Junos RPD multiprotocol BGP support to allow Layer 3 overlay functionality.

Using cRPD's multiprotocol BGP functionality, the local prefixes and the learned prefixes in the VRF are advertised and received. Corresponding MPLS routes are added into the Linux MPLS forwarding table. The prefixes learned from remote PEs get into the VRF routing table based on route-target policy.

Linux VRF

A VRF in the Linux kernel is represented by a network device handled by a VRF driver. When a VRF device is created, it is associated with a routing table and network interfaces are then assigned to a VRF device as shown in Figure 3.3.

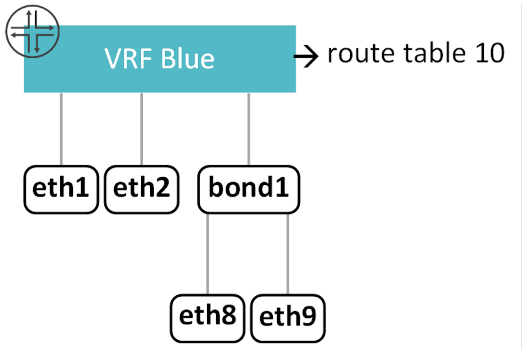


Figure 3.3 *VRF in Linux Kernel*

Packets that come in through such devices to the VRF are looked up in the routing table associated with the VRF device. Similarly egress routing rules are used to send packets to the VRF driver before sending it out on the actual interface.

MORE? Please refer to the Linux documentation at https://www.kernel.org/doc/Documentation/networking/vrf.txt for more information on Linux VRF.

MPLS in Linux

The MPLS configuration is supported in cRPD, including SR-MPLS, for forwarding packets to the destination in the MPLS network. To leverage cRPD's MPLS capability, it's advised to run the containers on a system running Linux kernel version 4.8 or later. The MPLS kernel module `mpls_router` must be installed in the container for MPLS to work in the Linux kernel.

The steps to load the MPLS module on Linux host are:

Load the MPLS modules in the container using `modprobe`:

```
lab@poc-server-20:~$ modprobe mpls_iptunnel
lab@poc-server-20:~$ modprobe mpls_router
```

Verify the MPLS modules loaded in host OS:

```
lab@poc-server-20:~$ lsmod | grep mpls
mpls_iptunnel          16384  1
mpls_router            28672  2 mpls_iptunnel,pw
ip_tunnel              24576  4 mpls_router,ip_gre,ipip,sit
```

After loading the `mpls_router` on the host, configure the following commands to activate MPLS on the interface:

```
lab@poc-server-20:~$ sudo sysctl -w net.mpls.platform_labels=1048575
```

Okay, now that's done, the *Day One* topology for this use case is illustrated in Figure 3.4.

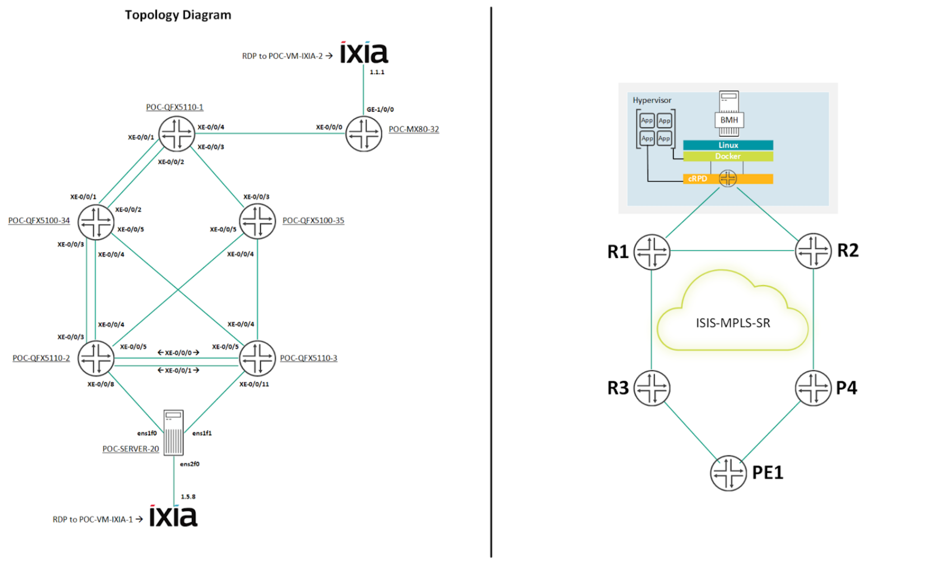


Figure 3.4 Topology Used in this Example for L3VPN Using cRPD

Before you configure a Layer 3 VPN (VRF), MPLS modules need to be installed on the host OS on which the cRPD instance is created. Here we will configure IGP and MPLS protocols on cRPD.

When cRPD is launched in host networking mode, the server host interface and IP address is visible to the cRPD container. You do not have to configure the interface IP address in cRPD, but the IGP and MPLS protocol is a required configuration on cRPD.

In this example ISIS IGP and MPLS segment routing is used for the data plane:

```
root@crpd01# show |display set
set protocols isis interface ens1f0
set protocols isis interface lo.0 passive
set protocols isis source-packet-routing srgb start-label 8000
set protocols isis source-packet-routing srgb index-range 100000
set protocols isis source-packet-routing node-segment ipv4-index 10
set protocols isis source-packet-routing node-segment ipv6-index 11
set protocols isis level 1 disable
```

Let's verify ISIS IGP:

```
root@crpd01# run show isis adjacency
Interface             System         L State        Hold (secs) SNPA
ens1f0                poc-qfx5110-2  2  Up                    7  44:aa:50:c8:8c:6b

[edit]
root@crpd01#
```

Notice the cRPD learned the remote PE lo0 address 10.10.10.6 through ISI:

```
root@crpd01# run show route protocol isis 10.10.10.6/32

inet.0: 25 destinations, 25 routes (25 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.10.6/32      *[IS-IS/18] 4w1d 20:17:09, metric 40
                    >  to 1.1.1.73 via ens1f0

inet.3: 6 destinations, 6 routes (6 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.10.6/32      *[L-ISIS/14] 3w2d 18:57:50, metric 40
                    >  to 1.1.1.73 via ens1f0, Push 1032

[edit]
root@crpd01#
```

On the Linux host the forwarding table is programed with the correct information:

```
lab@poc-server-20:~$ ip route | grep 10.10.10.6
10.10.10.6 via 1.1.1.73 dev ens1f0 proto 22
lab@poc-server-20:~$
```

Now let's verify the MPLS. In a typical Junos router the family MPLS configuration is required on the interface. In the Linux host family an MPLS configuration is not required. As the MPLS modules have been loaded, MPLS will be enabled on all host interfaces which will be used for MPLS forwarding.

Junos uses MPLS.0 table for the label route but cRPD by default does not create MPLS.0 table and this needs to be explicitly enabled in cRPD:

```
root@crpd01# set routing-options rib mpls.0
```

We're using ISIS to signal MPLS segment routing in this example:

```
set protocols isis source-packet-routing srgb start-label 8000
set protocols isis source-packet-routing srgb index-range 100000
set protocols isis source-packet-routing node-segment ipv4-index 10
set protocols isis source-packet-routing node-segment ipv6-index 11
```

Let's enable protocol MPLS on the Linux host interface:

```
set protocols mpls interface ens1f0
```

Now verify the MPLS SR and MPLS route table is on the cRPD:

```
root@crpd01# run show isis overview
Instance: master
  Router ID: 10.10.10.10
  Hostname: crpd01
  Sysid: 0010.0010.0010
  Areaid: 49.0010
  Adjacency holddown: enabled
  Maximum Areas: 3
  LSP life time: 1200
  Attached bit evaluation: enabled
  SPF delay: 200 msec, SPF holddown: 5000 msec, SPF rapid runs: 3
  IPv4 is enabled, IPv6 is enabled, SPRING based MPLS is enabled
  Traffic engineering: enabled
  Restart: Disabled
    Helper mode: Enabled
  Layer2-map: Disabled
  Source Packet Routing (SPRING): Enabled
    SRGB Config Range :
      SRGB Start-Label : 8000, SRGB Index-Range : 100000
    SRGB Block Allocation: Success
      SRGB Start Index : 8000, SRGB Size : 100000, Label-Range: [ 8000, 107999 ]
    Node Segments: Enabled
      Ipv4 Index : 10, Ipv6 Index : 11
    SRv6: Disabled
  Post Convergence Backup: Disabled
  Level 1
    Internal route preference: 15
    External route preference: 160
    Prefix export count: 0
    Wide metrics are enabled, Narrow metrics are enabled
    Source Packet Routing is enabled
  Level 2
    Internal route preference: 18
    External route preference: 165
    Prefix export count: 0
    Wide metrics are enabled, Narrow metrics are enabled
    Source Packet Routing is enabled

[edit]
root@crpd01#

root@crpd01# run show route table inet.3

inet.3: 6 destinations, 6 routes (6 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.10.1/32      *[L-ISIS/14] 3w2d 19:17:08, metric 30
                    >  to 1.1.1.73 via ens1f0, Push 1001
10.10.10.2/32      *[L-ISIS/14] 3w2d 19:16:32, metric 20
                    >  to 1.1.1.73 via ens1f0, Push 1034
10.10.10.3/32      *[L-ISIS/14] 3w2d 19:17:08, metric 20
                    >  to 1.1.1.73 via ens1f0, Push 1035
10.10.10.4/32      *[L-ISIS/14] 3w2d 19:16:32, metric 10
                    >  to 1.1.1.73 via ens1f0
10.10.10.5/32      *[L-ISIS/14] 3w2d 19:17:08, metric 20
                    >  to 1.1.1.73 via ens1f0, Push 1003
10.10.10.6/32      *[L-ISIS/14] 3w2d 19:17:08, metric 40
                    >  to 1.1.1.73 via ens1f0, Push 1032

[edit]
root@crpd01#
```

Okay, now let's check the mpls.0 table on cRPD and the mpls.0 label route for the remote PE 10.10.10.6 in the table. cRPD will push MPLS SR label 8034 to reach to the remote PE 10.10.10.6:

```
root@crpd01# run show route table mpls.0

mpls.0: 19 destinations, 19 routes (18 active, 1 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0                  *[MPLS/0] 4w1d 20:38:24, metric 1
                       Receive
1                  *[MPLS/0] 4w1d 20:38:24, metric 1
                       Receive
2                  *[MPLS/0] 4w1d 20:38:24, metric 1
                       Receive
13                 *[MPLS/0] 4w1d 20:38:24, metric 1
                       Receive
18                 *[EVPN/7] 4w1d 18:10:05
                    >  via ens2f0, Pop
19                 *[L-ISIS/14] 4w1d 20:38:17, metric 0
                    >  to 1.1.1.73 via ens1f0, Pop
19(S=0)            *[L-ISIS/14] 4w1d 20:38:17, metric 0
                    >  to 1.1.1.73 via ens1f0, Pop
20                 *[L-ISIS/14] 4w1d 20:38:17, metric 0
                    >  to fe80::46aa:50ff:fec8:8c6b via ens1f0, Pop
20(S=0)            *[L-ISIS/14] 4w1d 20:38:17, metric 0
                    >  to fe80::46aa:50ff:fec8:8c6b via ens1f0, Pop
                    >  to 1.1.1.73 via ens1f0, Push 300436, Push 1032(top)
8001               *[L-ISIS/14] 3w2d 19:18:43, metric 30
```

```
                    >  to 1.1.1.73 via ens1f0, Swap 1001
8002               *[L-ISIS/14] 3w2d 19:18:07, metric 10
                    >  to 1.1.1.73 via ens1f0, Pop
8002(S=0)          *[L-ISIS/14] 3w2d 19:18:07, metric 10
                    >  to 1.1.1.73 via ens1f0, Pop
8003               *[L-ISIS/14] 3w2d 19:18:43, metric 20
                    >  to 1.1.1.73 via ens1f0, Swap 1003
8004(S=0)           [L-ISIS/14] 3w2d 19:18:43, metric 10
                    >  to 1.1.1.73 via ens1f0, Pop
8032               *[L-ISIS/14] 3w2d 19:18:43, metric 40
                    >  to 1.1.1.73 via ens1f0, Swap 1032
8034               *[L-ISIS/14] 3w2d 19:18:07, metric 20
                    >  to 1.1.1.73 via ens1f0, Swap 1034
8035               *[L-ISIS/14] 3w2d 19:18:43, metric 20
                    >  to 1.1.1.73 via ens1f0, Swap 1035
```

Label 8034 information is also available in the Linux host:

```
lab@poc-server-20:~$ ip -f mpls route
18 dev ens2f0 proto 22
19 via inet 1.1.1.73 dev ens1f0 proto 22
20 via inet6 fe80::46aa:50ff:fec8:8c6b dev ens1f0 proto 22
21 as to 1032/300436 via inet 1.1.1.73 dev ens1f0 proto 22
8001 as to 1001 via inet 1.1.1.73 dev ens1f0 proto 22
8002 via inet 1.1.1.73 dev ens1f0 proto 22
8003 as to 1003 via inet 1.1.1.73 dev ens1f0 proto 22
8032 as to 1032 via inet 1.1.1.73 dev ens1f0 proto 22
8034 as to 1034 via inet 1.1.1.73 dev ens1f0 proto 22
8035 as to 1035 via inet 1.1.1.73 dev ens1f0 proto 22
lab@poc-server-20:~$
```

Now that there is an IGP and MPLS path between cRPD and remote PE, you can configure a Layer 3 VPN between them:

```
root@crpd01# show protocols bgp
group vpn {
    type internal;
    family inet-vpn {
        unicast;
    }
       neighbor 10.10.10.6 {
        local-address 10.10.10.10;
    }
}

[edit]
root@crpd01#

root@crpd01# show routing-instances l3vpn
instance-type vrf;
interface ens2f0;
route-distinguisher 10.10.10.10:100;
vrf-target target:65000:100;
vrf-table-label;
```

```
[edit]
root@crpd01#

root@crpd01# run show bgp summary
Threading mode: BGP I/O
Default eBGP mode: advertise - accept, receive - accept
Groups: 1 Peers: 1 Down peers: 0
Table          Tot Paths  Act Paths Suppressed    History Damp State    Pending
bgp.l3vpn.0
                       0          0          0          0          0          0
Peer                     AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Accepted/Damped...
10.10.10.6            65000      95629      95619       0       0 4w1d 20:50:29 Establ
  bgp.l3vpn.0: 0/0/0/0

[edit]
root@crpd01#
```

DDoS Protection

Distributed Denial of Service (DDoS) is a common attack launched against network services/infrastructure by directing many compromised hosts on the Internet to send simultaneous requests toward a target site or service, typically through the use of bots. The attack overwhelms the system's resources or network bandwidth and prevents legitimate requests to be serviced. Often DDoS attacks are hard to defend as the attacks originate from random IP addresses. To mitigate these attacks, threat detection systems analyze the traffic and build the IP addresses and services to be blocked or redirected to traffic scrubbers using firewall filter rules, but distribution and applying these rules throughout the network in real time is challenging and error prone.

BGP flowspec provides a way to dynamically distribute firewall rules to all network devices across the network. Supporting implementations can install these filters into their forwarding planes and filter the packets. The advantage of using BGP flowspec over other mechanisms to distribute the filters is that it is based on interoperable standards and works in multivendor environments.

cRPD can be used as the centralized station to inject these rules into the network. The cRPD CLI can be used to configure these filters statically, which can then be advertised over BGP.

cRPD also provides JET APIs that a controller or DDoS protection application can use to add these rules dynamically as shown in Figures 3.5 and 3.6. As a receiver of these flowspec rules, cRPD can also install them to the Linux kernel where BGP flow rules are translated to equivalent Linux rules.

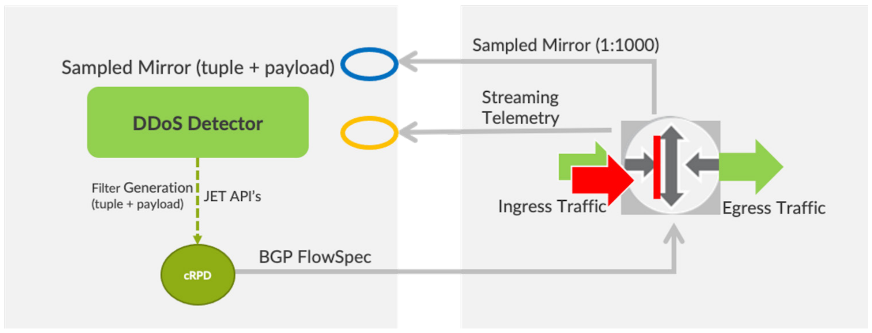


Figure 3.5 cRPD BGP FlowSpec Use Case Diagram

Configure BGP to Distribute Flow Routes

This configuration is required on all the BGP speakers intended to receive the flow routes and apply them locally. It is also applicable to the centralized BGP station used to distribute the flow rules:

```
[edit protocols bgp]
group <name> {
family inet flow;
family inet6 flow;
   neighbor <a.b.c.d> {
        family inet flow;
        family inet6 flow;
   }
}
```

Configure Flow Routes

Similar to adding static route entries for IPv4 and IPv6 routes, the cRPD CLI can be used to configure the flow routes. These routes are then added to the flow route tables, one for IPv4 and one for IPv6. These flow routes can be installed into the local system's forwarding table and/or advertised to BGP peers. For ease of management, it is recommended to add these routes on a centralized BGP station:

```
root@r2> show configuration routing-options
flow {
          route sample {
          match {
          protocol [ 1-10 13-15 30 ];
          destination-port [ 1234 4321 ];
               source-port [ 4321 1234 ];
          tcp-flags [ ack syn ];
          packet-length 1000;
          dscp [ 1 2 4 8 ];
          inactive: fragment [ dont-fragment is-fragment ];
          destination 2.2.2.2/32;
          source 1.1.1.1/32;
          icmp-code [ destination-host-unknown host-unreachable ];
          icmp-type [ echo-reply echo-request ];
          }
               then accept;
          }
}
```

Integration with Controller or Threat Detector

cRPD also includes support for gRPC based APIs (called JET), which allows for programmatic injection of flow routes into the centralized BGP station or a route reflector. This makes it possible to integrate with threat detector systems that can update the flow route in RPD:

```
root@r2> show route table inetflow.0 extensive
inetflow.0: 1 destinations, 1 routes (1 active, 0 holddown, 0 hidden)
2.2.2.2,1.1.1.1,proto>=1&<=10,>=13&<=15,=30,dstport=1234,=4321,srcport=4321,=1234,icmp-
type=0,=8,icmp-code=7,=1,tcp-flag:10,:02,len=1000,dscp=1,=2,=4,=8/term:1 (1 entry, 1 announced)
TSI:
KRT in dfwd;
Action(s): accept,count
          *Flow   Preference: 5
            Next hop type: Fictitious, Next hop index: 0
            Address: 0x52147d4
            Next-hop reference count: 4
            Next hop:
            State: <Active SendNhToPFE>
            Age: 1:19
            Validation State: unverified
            Task: RT Flow
            Announcement bits (1): 0-Flow
            AS path: I
```

Flow Route in Kernel

When cRPD is deployed on a server, it can also receive the BGP flow routes and apply them to the Linux kernel-based forwarding plane. Flow routes are installed into the kernel as nftable rules. The standard `nft` utility can be used to view these routes in the kernel:

```
root@r2:/# nft list ruleset
table ip __dfwd_default_inet__ {
          set tcp/udp {
            type inet_proto
            flags constant
            elements = { 6, 17 }
          }

          chain input {
            type filter hook input priority 0; policy accept;
            goto __flowspec_default_inet__ comment "__flowspec_default_inet__"
          }

          chain __flowspec_default_inet__ {
          ip length 1000 ip dscp { 1-2, 4-4, 8-8 } ip protocol { 1-10, 13-15, 30 } icmp type { echo-
reply, echo-request } icmp code { host-unreachable, 7 } meta l4proto @tcp/udp payload @th,0,16 { 1234,
4321 } meta l4proto @tcp/udp icmp checksum { 1234, 4321 } ip saddr 1.1.1.1 ip daddr 2.2.2.2 tcp flags
syn,ack counter packets 0 bytes 0 accept comment "2.2.2.2,1.1.1.1,proto>=1&<=10,>=13&<=15,=30,dstport
=1234,=4321,srcport=4321,=1234,icmp-type=0,=8,icmp-code=7,=1,tcp-flag:10,#I1"
          }
}
```

Route Reflector / Route Server

Generally, internal BGP (IBGP) enabled devices need to be fully meshed because IBGP does not re-advertise BGP updates to other IBGP-enabled devices. The full mesh is a logical mesh achieved through configuration of multiple neighbor statements on each IBGP-enabled device.

A full mesh is not necessarily a physical full mesh. Maintaining a full mesh (logical or physical) does not scale well in large deployments. Hence RFC4456 (https://tools.ietf.org/html/rfc4456) describes "An Alternative to Full Mesh Internal BGP (IBGP)" *namely* "BGP Route Reflection."

Juniper has been offering a virtual Route Reflector (vRR) product that allows you to implement route reflector capability using a general purpose virtual machine (VM) that can be run on a 64-bit Intel-based blade server or appliance.

Because a route reflector works in the control plane, it can run in a virtualized environment. A vRR on an Intel-based blade server or appliance works the same as a route reflector on a router, providing a scalable alternative to full mesh IBGP peering.

The vRR product has the following features:

- Scalability: By implementing the vRR feature, you can gain scalability improvements, depending on the server core hardware on which the feature runs. Also, you can implement vRRs at multiple locations in the network, which helps scale the BGP network with lower cost.
- Faster and more flexible deployment: You can install the vRR feature on an Intel serve using open-source tools, which reduces your router maintenance.
- Space savings: Hardware-based RRs require central office space. You can deploy the vRR feature on any server that is available in the server infrastructure or in the data centers, saving space.

cRPD, however, provides some advantages over Juniper's vRR product. The most significant difference between vRR and cRPD operating as a RR is boot-up time. In the case of cRPD it takes a few seconds to bring it up, whereas vRR can take a few minutes to come up.

Also, cRPD is highly scalable compared to vRR when run against the RR use case of one of the hyperscalers for their network. Table 3.1 lists some RR requirements in terms of scale:

Table 3.1 Sample Scale Numbers for cRPD as Route Reflector

Number of BGP groups	32
BGP peers per group	16
Total number of BGP peers	512
Route scale	32 Peers advertising full internet routing table
	32 Peers advertising 200K BGP routes each
	16 Peers advertising 200K VPNv4 routes each
	448 peers as receivers
Add-Path	16 BGP Addpath multipath configured.

In order to scale cRPD to the numbers in Table 3.1 Juniper uses the lab setup shown in Figure 3.6. But we didn't want to get bottlenecked by protocol implementation on commercial traffic generators, so we used cRPD wherever possible to pump routes into the DUT, which was also a cRPD.

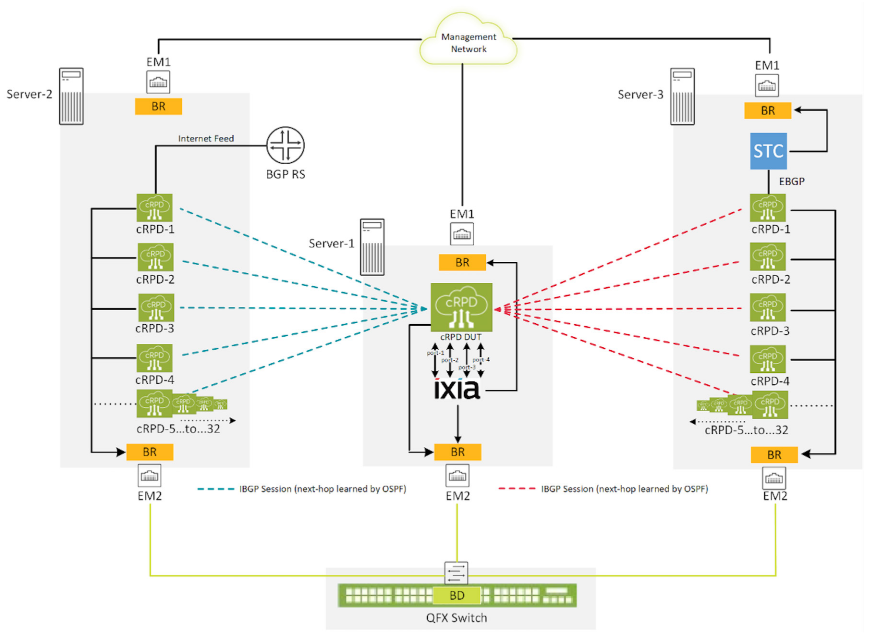
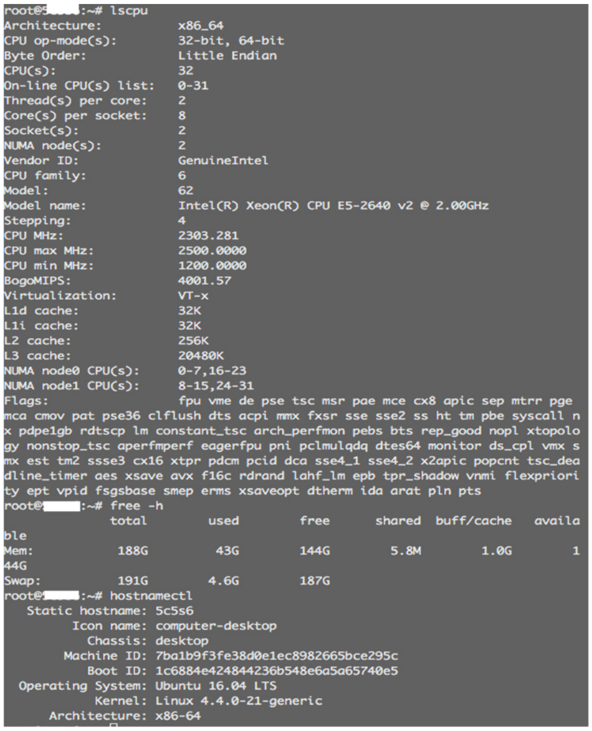


Figure 3.6 Lab Setup Details

In Figure 3.6 you can see:

- Server 1 is running cRPD DUT. It has 16 BGP peer groups configured. It has 32 BGP neighbors towards server1 and another 32 towards server 3. Server 1 also has vIXIA running and it has 448 BGP peers with cRPD DUT and 16 peers out of these are pumping 200K VPNv4 routes towards cRPD DUT.
- There are 32 cRPD instances running on server 2. One of these 32 cRPDs is getting the entire internet routing table by connecting to the Juniper Lab route-server. It is giving this internet feed to cRPD DUT running in server 1 and the other 31 cRPDs running in server 2.
- Similarly, server 2 had 32 cRPDs and one vSTC running. vSTC is pumping 200K BGP routes towards one cRPD. These 200K routes are getting distributed across other 32 cRPDs running on server 3.

The server that was used for this setup had the resource specifications shown in screen capture of Figure 3.7.



```
root@[redacted]:~# lscpu
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
CPU(s):                32
On-line CPU(s) list:   0-31
Thread(s) per core:    2
Core(s) per socket:    8
Socket(s):             2
NUMA node(s):          2
Vendor ID:             GenuineIntel
CPU family:            6
Model:                 62
Model name:            Intel(R) Xeon(R) CPU E5-2640 v2 @ 2.00GHz
Stepping:              4
CPU MHz:               2303.281
CPU max MHz:           2500.0000
CPU min MHz:           1200.0000
BogoMIPS:              4001.57
Virtualization:        VT-x
L1d cache:             32K
L1i cache:             32K
L2 cache:              256K
L3 cache:              20480K
NUMA node0 CPU(s):     0-7,16-23
NUMA node1 CPU(s):     8-15,24-31
Flags:                 fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge
mca cmov pat pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall n
x pdpe1gb rdtscp lm constant_tsc arch_perfmon pebs bts rep_good nopl xtopolo
gy nonstop_tsc aperfmperf eagerfpu pni pclmulqdq dtes64 monitor ds_cpl vmx s
mx est tm2 ssse3 cx16 xtpr pdcm pcid dca sse4_1 sse4_2 x2apic popcnt tsc_dea
dline_timer aes xsave avx f16c rdrand lahf_lm epb tpr_shadow vnmi flexpriori
ty ept vpid fsgsbase smep erms xsaveopt dtherm ida arat pln pts
root@[redacted]:~# free -h
              total        used        free      shared  buff/cache   availa
ble
Mem:           188G         43G        144G        5.8M        1.0G         1
44G
Swap:          191G        4.6G        187G
root@[redacted]:~# hostnamectl
   Static hostname: 5c5s6
         Icon name: computer-desktop
           Chassis: desktop
        Machine ID: 7ba1b9f3fe38d0e1ec8982665bce295c
           Boot ID: 1c6884e424844236b548e6a5a65740e5
  Operating System: Ubuntu 16.04 LTS
            Kernel: Linux 4.4.0-21-generic
      Architecture: x86-64
```

Figure 3.7 Sample Server Specification

While deploying this scale customers will have multiple RRs sharing the load, but it was a handy use case for cRPD to validate its stability given enough CPU and memory. We were able to bring it up to scale with a cRPD acting as a DUT with this configuration for BGP:

```
protocols {
          bgp {
          path-selection external-router-id;
          update-threading;
          family inet {
          unicast {
            add-path {
                send {
                    path-count 16;
                    multipath;
                }
            }
            no-install;
          }
          }
          group group1 {
          type internal;
          local-address 5.5.5.5;
          peer-as 64512;
          local-as 64512 loops 2;
          neighbor 1.1.1.2;
          neighbor 1.1.1.3;
          neighbor 1.1.1.4;
          neighbor 1.1.1.5;
          neighbor 1.1.1.6;
          neighbor 1.1.1.7;
          neighbor 1.1.1.8;
          neighbor 1.1.1.9;
          neighbor 1.1.1.10;
          neighbor 1.1.1.11;
          neighbor 1.1.1.12;
          neighbor 1.1.1.13;
          neighbor 1.1.1.14;
          neighbor 1.1.1.15;
          neighbor 1.1.1.16;
          neighbor 1.1.1.17;
          }
.
.
.
.
          local-address 5.5.5.5;
          advertise-inactive;
          mtu-discovery;
          log-updown;
          drop-path-attributes 128;
          cluster 5.5.5.5;
          multipath;
          multipath-build-priority {
          low;
          }
}
```

Let's bring up the cRPD DUT.

1. Add the Docker image:

```
docker load < junos-routing-crpd-docker-20.3R1.tgz
```

2. Create the Docker volume for persistent storage for cRPD configuration and log messages:

```
docker volume create dut-config
docker volume create dut-varlog
```

3. Bring up cRPD container:

```
docker run --rm --detach --name crpdDUT -h crpdDUT --net=bridge --privileged -v dut-config:/
config -v crpd-varlog:/var/log -it crpd:latest
```

4. Add `ovs-` Docker bridges:

```
            sudo ovs-vsctl add-br ixia_port1
sudo ovs-vsctl add-br ixia_port2
            sudo ovs-vsctl add-br ixia_port3
sudo ovs-vsctl add-br ixia_port4
sudo ovs-vsctl add-br route_feed
```

5. Connect cRPD to those bridges:

```
sudo ovs-docker add-port ixia_port1 eth1 crpdDUT
sudo ovs-docker add-port ixia_port2 eth2 crpdDUT
sudo ovs-docker add-port ixia_port3 eth3 crpdDUT
sudo ovs-docker add-port ixia_port4 eth4 crpdDUT
```

6. Connect cRPD to another bridge to get route feed:

```
sudo ovs-docker add-port route_feed eth5 crpdDUT
```

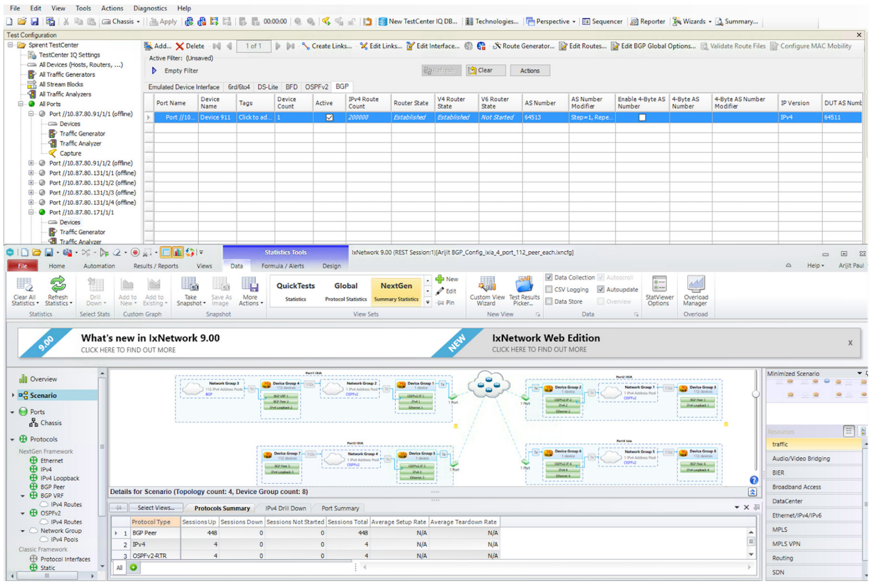
7. Connect physical port em2 of server1 to `route_feed` bridge:

```
ovs-vsctl add-port route_feed em2
```

8. Configure the IP address of interfaces under cRPD:

```
sudo docker exec -d crpdDUT ifconfig eth1 1.1.1.1/24
sudo docker exec -d crpdDUT ifconfig eth2 2.1.1.1/24
sudo docker exec -d crpdDUT ifconfig eth3 3.1.1.1/24
sudo docker exec -d crpdDUT ifconfig eth4 4.1.1.1/24
sudo docker exec -d crpdDUT ifconfig eth5 5.1.1.1/24
```

Figure 3.8 displays screenshots of traffic generators vIXIA and vSpirent after all the sessions came up with DUT.



Active Filter: (Unsaved)

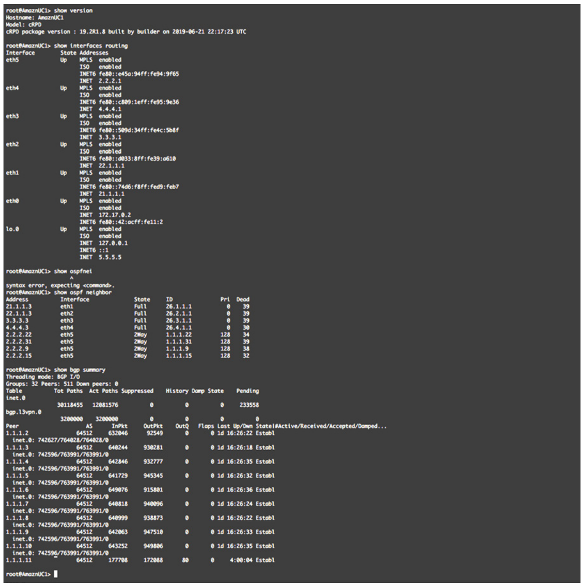
Port Name	Device Name	Tags	Device Count	Active	IPv4 Route Count	Router State	V4 Router State	V6 Router State	AS Number	AS Number Modifier	Enable 4-Byte AS Number	4-Byte AS Number	4-Byte AS Number Modifier	IP Version	DUT AS Numb
Port //10...	Device 911	Click to ad...	1	✓	200000	Established	Established	Not Started	64513	Step=1, Repe...	☐			IPv4	64511

Details for Scenario (Topology count: 4, Device Group count: 8)

	Protocol Type	Sessions Up	Sessions Down	Sessions Not Started	Sessions Total	Average Setup Rate	Average Teardown Rate
1	BGP Peer	448	0	0	448	N/A	N/A
2	IPv4	4	0	0	4	N/A	N/A
3	OSPFv2-RTR	4	0	0	4	N/A	N/A

Figure 3.8 *IXIA and Spirent Configuration Snapshot*

And Figure 3.9 captures output from the DUT after everything came up.



```
root@AmaznUC1> show version
Hostname: AmaznUC1
Model: cRPD
cRPD package version : 19.2R1.8 built by builder on 2019-06-21 22:17:23 UTC

root@AmaznUC1> show interfaces routing
Interface        State Addresses
eth5             Up    MPLS  enabled
                       ISO   enabled
                       INET6 fe80::e45a:94ff:fe94:9f65
                       INET  2.2.2.1
eth4             Up    MPLS  enabled
                       ISO   enabled
                       INET6 fe80::c809:1eff:fe95:9e36
                       INET  4.4.4.1
eth3             Up    MPLS  enabled
                       ISO   enabled
                       INET6 fe80::509d:34ff:fe4c:5b8f
                       INET  3.3.3.1
eth2             Up    MPLS  enabled
                       ISO   enabled
                       INET6 fe80::d033:8ff:fe39:a610
                       INET  22.1.1.1
eth1             Up    MPLS  enabled
                       ISO   enabled
                       INET6 fe80::74d6:f8ff:fed9:feb7
                       INET  21.1.1.1
eth0             Up    MPLS  enabled
                       ISO   enabled
                       INET  172.17.0.2
                       INET6 fe80::42:acff:fe11:2
lo.0             Up    MPLS  enabled
                       ISO   enabled
                       INET  127.0.0.1
                       INET6 ::1
                       INET  5.5.5.5

root@AmaznUC1> show ospfnei
                        ^
syntax error, expecting <command>.
root@AmaznUC1> show ospf neighbor
Address          Interface              State     ID               Pri  Dead
21.1.1.3         eth1                   Full      26.1.1.1           0    39
22.1.1.3         eth2                   Full      26.2.1.1           0    39
3.3.3.3          eth3                   Full      26.3.1.1           0    39
4.4.4.3          eth4                   Full      26.4.1.1           0    30
2.2.2.22         eth5                   2Way      1.1.1.22         128    34
2.2.2.31         eth5                   2Way      1.1.1.31         128    39
2.2.2.9          eth5                   2Way      1.1.1.9          128    38
2.2.2.15         eth5                   2Way      1.1.1.15         128    32

root@AmaznUC1> show bgp summary
Threading mode: BGP I/O
Groups: 32 Peers: 511 Down peers: 0
Table          Tot Paths  Act Paths Suppressed    History Damp State    Pending
inet.0
               30118455   12081576          0          0          0     233558
bgp.l3vpn.0
                3200000    3200000          0          0          0          0
Peer                     AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/Received/Accepted/Damped...
1.1.1.2               64512     632046      92549       0       0 1d 16:26:22 Establ
  inet.0: 742627/764028/764028/0
1.1.1.3               64512     640244     930281       0       0 1d 16:26:18 Establ
  inet.0: 742596/763991/763991/0
1.1.1.4               64512     642846     932777       0       0 1d 16:26:35 Establ
  inet.0: 742596/763991/763991/0
1.1.1.5               64512     641729     945345       0       0 1d 16:26:32 Establ
  inet.0: 742596/763991/763991/0
1.1.1.6               64512     649076     915801       0       0 1d 16:26:36 Establ
  inet.0: 742596/763991/763991/0
1.1.1.7               64512     640818     940096       0       0 1d 16:26:24 Establ
  inet.0: 742596/763991/763991/0
1.1.1.8               64512     640999     938873       0       0 1d 16:26:22 Establ
  inet.0: 742596/763991/763991/0
1.1.1.9               64512     642063     947510       0       0 1d 16:26:33 Establ
  inet.0: 742596/763991/763991/0
1.1.1.10              64512     643252     949806       0       0 1d 16:26:35 Establ
  inet.0: 742596/763991/763991/0
1.1.1.11              64512     177708     172088      80       0    4:00:04 Establ

root@AmaznUC1> █
```

Figure 3.9 *cRPD Control Plane States*

Whitebox/SONiC

Traditionally networking gear is sold as a fully integrated product. Vendors often use in-house designed ASICs and software and hardware tightly coupled with their proprietary network OS.

These proprietary networking products are often deployed across a wide variety of networks catering to different complex use cases. So they must be feature rich, but can also be expensive to build and develop. Given the number of features that they pack, any new feature must go through long and rigorous qualification cycles to ensure backwards compatibility.

The hyper-scale data centers use CLOS architecture for the data center network fabric, so they typically don't require many of the advanced routing features such as MPLS and IGP routing protocols. Most of the deployments just use single-hop EBGP to bring up the CLOS underlay. However, these network operators have the challenge of rapidly changing requirements as new applications are onboarded. Most often their requirements are so unique to their network and dynamic in nature that traditional routing protocols are not suited and often require SDN controllers to orchestrate the network. These network operators found that proprietary closed systems are not suited for their rapidly changing requirements and moved toward a model where they can better operate.

A whitebox router/switch is a networking product whose hardware and software are disaggregated and made available by different vendors. This gives flexibility to customers who don't always want the rich features of a proprietary OS but still allows them to build and run their own software.

SONiC is an Opensource Network Operating System (NOS) for whitebox routing and switching platforms. Initiated by Microsoft, it has been open sourced and currently sponsored by ONF with many players from the networking, telco, and data center world participating in its development. It's gaining popularity. Originally intended for deployment in data centers as a TOR device, it has since found its way into diverse roles in the spine as cell site routers in 5G RAN.

MORE? If you want to learn more about SONiC visit the following URLs:

- https://azure.github.io/SONiC/
- https://github.com/Azure/SONiC/wiki/Architecture

SONiC comes with the Free Range Routing (FRR) routing stack as the default routing stack. cRPD can be used as an alternative routing stack for SONiC platforms as shown in Figure 3.10.

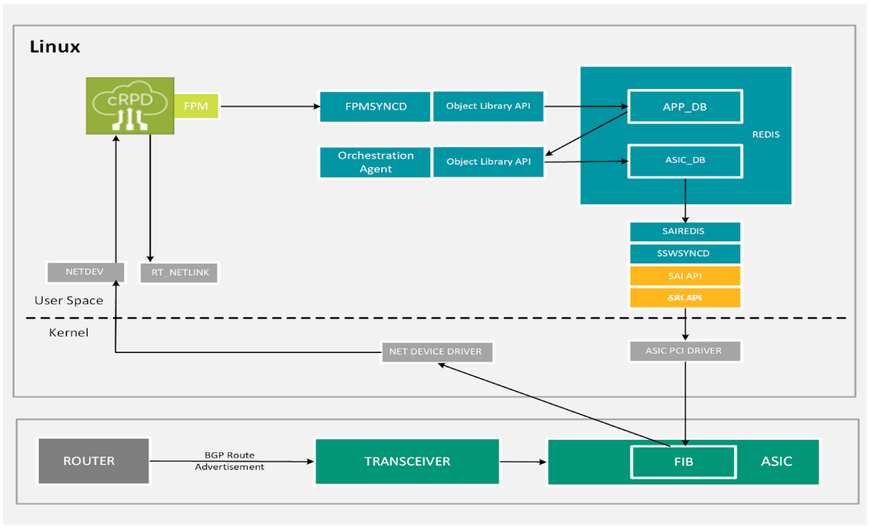


Figure 3.10 cRPD on SONiC Architecture Diagram

Architecture

SONiC uses Docker containers to host various control-plane applications making it possible to upgrade and replace individual components. SONiC maintains the device and route state in a *redis* database. A pub/sub model is used where each service consumes state from the database published by other components, and then it publishes its own objects and state.

An interesting detail about SONiC architecture is that routes must be programmed to two FIBs: a FIB in the Linux kernel to manage packet I/O for the control plane and an FIB in the data plane. To publish route state to the SONiC database, the routing application uses the FPM channel to push route state to *fpmsyncd,* which then publishes it to the redis database.

Deployment

Juniper SONiC devices include cRPD as the default routing stack. It can also be installed on any SONiC device with x86-64 based control planes. SONiC uses container-based architecture to host the control plane services and cRPD is a natural fit.

To deploy, transfer the cRPD image onto a SONiC device and perform these installation steps.

1.Install the image:

```
docker load -i crpd-19.2R1.8.tgz
```

2. Create volumes to store the configs and logs:

```
sudo mkdir -p /etc/sonic/crpd /var/log/crpd
```

3. Create the cRPD container:

```
docker create --name crpd -h crpd --net=host --privileged \
             -v /etc/sonic/crpd:/config -v /var/log/crpd:/var/log \
             -it crpd:latest
```

4. Disable quagga/bgp if already running:

```
docker exec bgp supervisorctl stop zebra bgpd
```

5. Start the container:

```
docker start crpd
```

6. Access the container:

```
docker exec -it crpd cli
```

7. Add an FIB channel for installing routes to SONiC redis-db:

```
edit routing-options forwarding-table
set channel fpm protocol protocol-type netlink-fpm
set channel fpm protocol destination 127.0.0.1:2620
commit
```

Upgrading cRPD Image

Use the followng steps to upgrade.

1. Stop and remove existing cRPD container image:

```
    docker stop crpd
    docker rm crpd
```

2. Load the new cRPD image:

```
    docker load -i crpd-20.1R1.11.tgz
```

3. Create the cRPD container:

```
    docker create --name crpd -h crpd --net=host --privileged \
                  -v /etc/sonic/crpd:/config -v /var/log/crpd:/var/log \
                  -it crpd:latest

    docker tag crpd:latest docker-fpm-crpd
```

4. Start cRPD:

```
    docker start crpd
```

Troubleshooting

To troubleshoot the FPM channel these commands will come in useful.

To check fpm channel state:

```
    cli> show krt state channel fpm
```

```
root@wf-scapa-a> show krt state channel fpm
General state:
        FIB Channel status: TCP connection established and ready to program SONiC
        KRT RE mode: Master
        Install job is not running
        KRT io tx job is not running
        Number of operations queued: 337069
                Routing table adds: 0
                Interface routes: 0
                High pri multicast   Adds/Changes: 0
                Indirect Next Hop    Adds/Changes: 0       Deletes: 0
                MPLS        Adds: 0       Changes: 0
                High pri    Adds: 0       Changes: 0       Deletes: 0
                Normal pri Indirects: 0
                Normal pri  Adds: 0       Changes: 0       Deletes: 337069
                GMP GENCFG Objects: 0
                Routing Table deletes: 0
        Number of operations deferred: 0
        Number of operations canceled: 0
        Number of async queue entries: 0
        Number of async non queue entries: 0
        Time until next queue run: 0
        Routes learned from kernel: 0

Routing socket lossage:
        Time until next scan:
```

To check KRT queue for any stuck routes:

```
     cli> show krt queue channel fpm
```

To enable fpmsyncd logging to /var/log/syslog:

```
    swssloglevel -l INFO -c fpmsyncd
```

To check if FPM channel is up:

```
    netstat -antp | grep 2620
```

To check tcpdump:

```
    tcpdump -nvi lo tcp port 2620
```

To enable tracelogs in Juniper CLI:

```
    set routing-options traceoptions file rpd.log size 100m
    set routing-options traceoptions flag all
```

To add routes learned from RPD to the redis-db:

```
fpmsyncd
```

To use redis-cli to examine entries:

```
]
    $ sudo redis-cli
```

To fetch the route table keys:

```
127.0.0.1:6379> keys ROUTE_TABLE:*
1) "ROUTE_TABLE:fc00:1::32"
2) "ROUTE_TABLE:10.0.0.58/31"
3) "ROUTE_TABLE:::1"
4) "ROUTE_TABLE:fc00::70/126"
5) "ROUTE_TABLE:fc00::78/126"
6) "ROUTE_TABLE:1.1.1.1
7) "ROUTE_TABLE:10.216.32.0/20"
8) "ROUTE_TABLE:10.1.0.32"
9) "ROUTE_TABLE:fc00::74/126"
10) "ROUTE_TABLE:240.127.1.0/24"
```

To fetch the attributes for a given route key:

```
127.0.0.1:6379> hgetall "ROUTE_TABLE:10.51.128.0/19"
1) "nexthop"
2) "0.0.0.0"
3) "ifname"
4) "eth0"
```

To display all keys:

```
127.0.0.1:6379> keys *
```

To live monitor operations on redis-db (can be very noisy):

```
sudo redis-cli monitor
```

Routing in Fat Trees (RIFT)

One of the newest protocols on the block is RIFT which claims to solve multiple issues, combining both Link-State and Distance-Vector protocol advantages and mitigating its respective challenges. A brief way to describe the protocol is that it is Distance-Vector southbound and Link-State northbound, hence advertising a default route downwards in the fabric and only more specific routes upwards.

MORE? This chapter isn't a full deep dive into the RIFT protocol so the authors suggest reading all about RIFT in the following *Day One* book: https://www.juniper.net/documentation/en_US/day-one-books/DO_RIFT.pdf. It covers not only the Juniper RIFT implementation but also the open-source implementation, the RIFT Wireshark dissector, and troubleshooting tips and tricks.

Work in IETF

Work on this new protocol started in IETF when the RIFT workgroup charter was approved in February, 2018. As stated in the charter: *"The Routing in Fat Trees (RIFT) protocol addresses the demands of routing in Clos and Fat-Tree networks via a mixture of both link-state and distance-vector techniques colloquially described as 'link-state towards the spine and distance vector towards the leafs'. RIFT uses this hybrid approach to focus on networks with regular topologies with a high degree of connectivity, a defined directionality, and large scale."*

In the charter the protocol will:

- Deal with automatic construction of fat-tree topologies based on detection of links,
- Minimize the amount of routing state held at each topology level,
- Automatically prune topology distribution exchanges to a sufficient subset of links,
- Support automatic disaggregation of prefixes on link and node failures to prevent black-holing and suboptimal routing,
- Allow traffic steering and re-routing policies,
- And provide mechanisms to synchronize a limited key-value data store that can be used after protocol convergence.

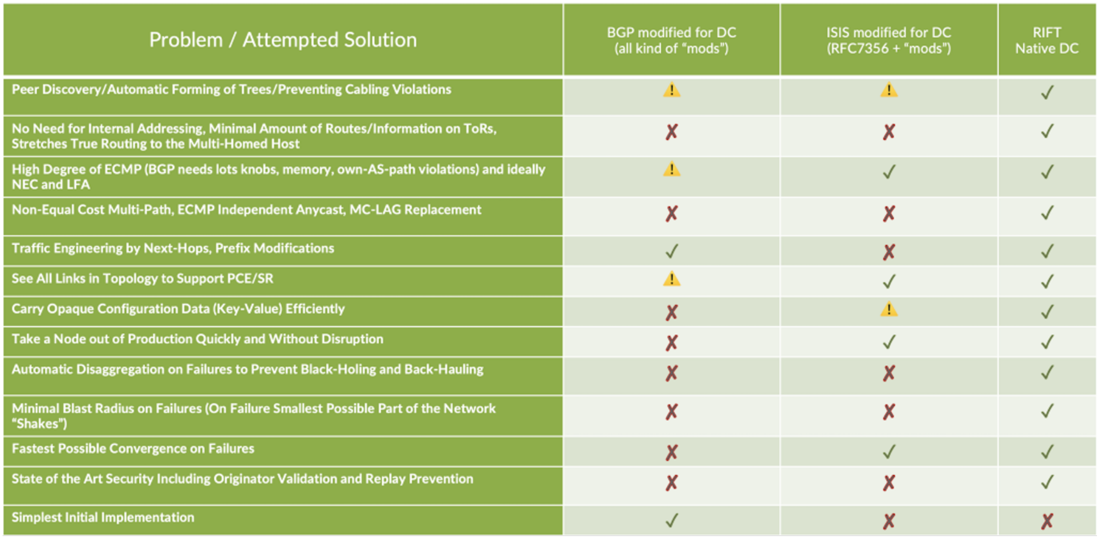
It is important that nodes participating in the protocol should only need very light configuration and should be able to join a network as leaf nodes simply by connecting to the network using default configuration.

The protocol must support IPv6 as well as IPv4.

Addressing Challenges

RIFT doesn't just solve a few spot issues but addresses a whole set of problems. Basically, instead of adjusting and modifying an existing protocol, one could say that RIFT is designed with today's requirements in mind.

Figure 3.11 summarizes the issues modified ISIS and BGP have, and shows how RIFT solves them quite nicely. It also displays some unique challenges RIFT solves which currently cannot be addressed in Link-State or Distance-Vector protocols.



Problem / Attempted Solution	BGP modified for DC (all kind of "mods")	ISIS modified for DC (RFC7356 + "mods")	RIFT Native DC
Peer Discovery/Automatic Forming of Trees/Preventing Cabling Violations	⚠	⚠	✓
No Need for Internal Addressing, Minimal Amount of Routes/Information on ToRs, Stretches True Routing to the Multi-Homed Host	✗	✗	✓
High Degree of ECMP (BGP needs lots knobs, memory, own-AS-path violations) and ideally NEC and LFA	⚠	✓	✓
Non-Equal Cost Multi-Path, ECMP Independent Anycast, MC-LAG Replacement	✗	✗	✓
Traffic Engineering by Next-Hops, Prefix Modifications	✓	✗	✓
See All Links in Topology to Support PCE/SR	⚠	✓	✓
Carry Opaque Configuration Data (Key-Value) Efficiently	✗	⚠	✓
Take a Node out of Production Quickly and Without Disruption	✗	✓	✓
Automatic Disaggregation on Failures to Prevent Black-Holing and Back-Hauling	✗	✗	✓
Minimal Blast Radius on Failures (On Failure Smallest Possible Part of the Network "Shakes")	✗	✗	✓
Fastest Possible Convergence on Failures	✗	✓	✓
State of the Art Security Including Originator Validation and Replay Prevention	✗	✗	✓
Simplest Initial Implementation	✓	✗	✗

Figure 3.11 Comparing the Use of BGP, ISIS and RIFT for Data Center Underlay

Basic Operations

As briefly described earlier in this chapter, RIFT combines concepts from both Link-State and Distance-Vector protocols. A Topology Information Element (TIE) is used to carry topology and reachability information; this is like an OSPF LSA or an IS-IS LSP. Figure 3.12 illustrates the advertisement of reachability and topology information in RIFT.

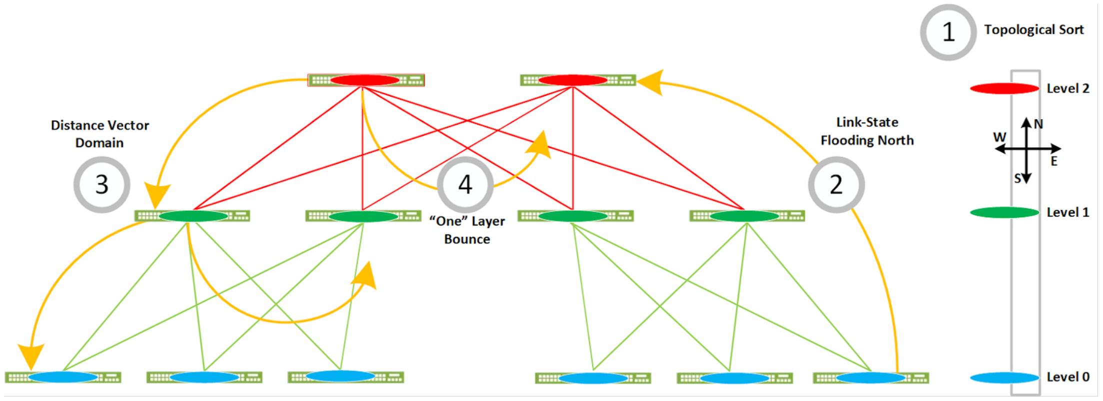


Figure 3.12 RIFT North- and Southbound Behavior and Lateral "one layer bounce" Behavior in Case of Link Failure

Okay, with those definitions and a drawing in our pocket, let's look at how the protocol works:

- The topology in Figure 3.12 shows a 5-stage CLOS or a fabric with three levels; Top of Fabric (ToF) in red, spines in green, and the leaf switches are blue.
- Looking at the leaf routing table one can observe, in normal operations, only default routes towards the higher level in the fabric. This is somewhat comparable to a Level 1 router's routing table in IS-IS or a totally stubby area in OSPF.
- The higher up into the fabric, the more routes one will see in their respective switches routing table with the ToF holding every route in its routing table. Hence, spines will partially, and ToF will have full knowledge of the complete fabric and thread routes as a distance-vector protocol would.
- Routing information sent down into the fabric is only bounced up again one layer. This is used for automatic disaggregation and flood reduction. We'll get to the specifics of that later on.

It's interesting to note that in contrast to some other protocols, RIFT currently doesn't require anything *new* from a forwarding plane and ASIC perspective – it's a *control plane protocol*. Routes installed into forwarding are just like those we are used to.

Operational Advantages

Authors from Cisco, Juniper, Yandex, and Comcast have worked on the specifications, hence RIFT is, just like IS-IS and BGP, an open standard. So it is by nature multivendor and interoperable, and besides fixing existing routing protocol issues it aims to add some very appealing features.

Automatic Disaggregation

In normal circumstances, devices other than those in the ToF stage rely on the default route to forward packets towards the ToF, while more specific routes are available to forward packets towards the ToR switches. What happens in Figure 3.13 if the C3—>D2 link fails? B2, B6, and D6 will continue forwarding traffic towards C3 based on the default route being advertised in the TIE flooded by C3, but C3 will no longer have a route by which it can reach 2001:db8:3e8:100::/64—so this traffic will be dropped at C3.

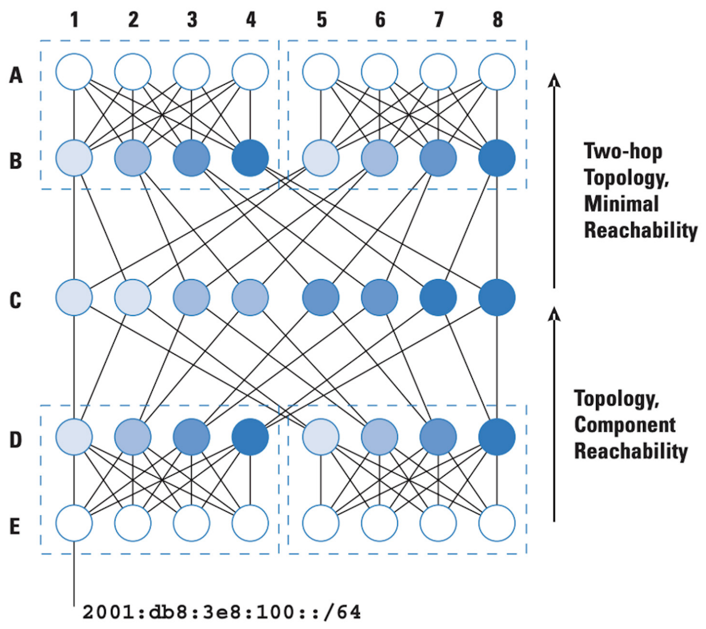

1
2
3
4
5
6
7
8
A
B
C
D
E
Two-hop Topology, Minimal Reachability
Topology, Component Reachability
2001:db8:3e8:100::/64

Figure 3.13 RIFT Operation in a Butterfly Fabric

To resolve this problem RIFT uses the two-hop neighbors advertised to all routers to automatically determine when there is a failed link and push the required routes along with the default route down the fabric. In this case, C4 can determine D3 should have an adjacency with D2, but the adjacency does not exist. Because of the failed adjacency, C4 can flood reachability to 2001:db8:3e8:100::/64 alongside the default route it is already sending to all its neighbors. This more specific route will draw any traffic destined to the 100::/64 route, so C3 no longer receives this traffic. The default route will continue to draw traffic towards C3 for the other destinations it can still reach.

Other RIFT Features

When ToF fabric switches are configured, fabric devices running RIFT can compute their fabric location and largely self-configure (there are exceptions for devices requiring Layer 2 support and leaf nodes in the topology). This self-configuration includes the use of IPv6 Neighbor Discovery (ND) to determine local IPv6 addresses, so no addressing plan or distribution protocols are required for pure IPv6 operation. If native IPv4 forwarding is required in the underlay, those addresses must be managed and configured in some way.

RIFT also offers the ability to perform unequal-cost load balancing from the ToR towards the ToF. Since each node has only the default route, and the stages closer to the ToF have more complete routing information, it is not possible for the ToR to cause a routing loop by choosing one possible path over another, or unequally sharing traffic along its available links.

RIFT in the Cloud Native Data Center

Service outages or degradation can easily cause revenue loss. Therefore a significant investment is normally committed to ensure that services remain highly available. That availability can be incorporated into the network, the applications, or infrastructure subsystems such as power and cooling plants. The degree of availability ("how many nines are desired") also adds complexity and further increases cost.

Most services and applications hold state to perform their work, state that cannot be moved or accessed when the network has failed. Real-time replication of application state across the network in real time or near-real time is available for some classes of services, like databases, but it is generally difficult to implement and affects application performance. Building truly stateless services unaffected by infrastructure failures is incredibly difficult and ultimately shifts the problem to messaging systems holding service state. These messaging systems become very fragile if the delay and loss characteristics of the underlying network are not nearly perfect.

Many operators, as the first step, focus on increasing resilience in the physical infrastructure, such as power and cooling systems. This is obviously never a bad idea but is incredibly expensive and still leaves ToR switches as a single point of failure and the weakest link in fabric resiliency. The failure or upgrade of a ToR switch to which a server is single-homed results in the application losing state.

It is possible to multihome servers to different ToRs to mitigate that problem, but unfortunately doing so requires the use of fragile or proprietary protocols such as STP variants or MC-LAG. Running these protocols means that software and hardware requirements for the ToRs go up, which could mean increased hardware and licensing cost. This is especially true if Active-Active load balancing is required.

Even if those solutions are deployed, they force the use of Level 2 homing with Level 3 starting at the ToR level leading to a security 'air-gap' and to stacked tunneling architectures if the server is originating native Level 3 services, which becomes more pronounced with virtualization technologies and micro-segmentation.

Deploying native IP routing on the hosts with cRPD would solve these and many other problems such as choosing the correct outgoing link to route around failures. Further, it would introduce advantages like load balancing traffic depending on available bandwidth, complete ZTP, and visibility of servers being introduced into the fabric in the routing databases. Lastly, it would also extend a Level 3 trust model all the way to the leaf where the overlay can originate encrypted tunnels utilizing the capabilities of smart NICs.

As good as the idea sounds, the introduction of servers into Level 3 routing multiplies the necessary scale of the routing architecture by a very significant multiplier roughly equivalent to the number of servers on a ToR. This is not an insignificant number and pretty quickly puts traditional IGPs out of the picture and makes deployment of complicated, band-aided BGP even more torturous to address.

Since RIFT has been designed from day one with the vision of supporting servers being part of the underlay or "Routing on the Host" (ROTH), deploying it on servers is possible and addresses all the concerns above.

Servers, as well as any other RIFT nodes, would also benefit from other RIFT-native benefits. To start with, RIFT introduces bidirectional equal and weighted unequal cost load balancing. This means that once failures occur RIFT will weight flows across the remaining links to account for the reduced bandwidth. OSPF and IS-IS are simply not capable of doing this and while BGP can to an extent, it is far from easy.

Further, RIFT is designed to run on hosts without any configuration altogether, which is not only convenient but goes a long way to minimize the attack surface in security terms. RIFT even allows you to rollover a whole fabric to a new key and prevent connection of compromised, pre-factored servers. Lastly, in operation terms, it is a distinct advantage to see all the servers attached to the fabric including, for example, their IP/MAC bindings, without use of out-of-band tools.

Security

From the RIFT daemon perspective, it doesn't really matter whether it is running on a network device (switch) or 'compute host.' The RIFT daemon will use the forwarding capabilities of its host to program routes into and it will advertise its local routes upstream into the fabric. From the RIFT daemon perspective, the 'compute host' is "just a leaf."

Hosts are usually more exposed to security vulnerabilities. So when routing on the host is configured, extra steps are advised in order to increase the security (authentication, message integrity and anti-replay). You can configure the interface protection (outer key) to secure RIFT with the host:

```
protocols {
rift {
authentication-key 12 {
key ""; ## SECRET-DATA
}
interface ge-0/0/0.0 {
```

```
lie-authentication strict;
allowed-authentication-keys 12; # (Example using key-id 12)
lie-origination-key 12;
}
}
}
```

The most interesting part of ROTH using RIFT is probably that it eliminates the need for Layer 2 connectivity between the host and fabric because by nature RIFT will advertise its routes on all available links and load-balance traffic over those links. It will also receive default routes from its northbound tier and load-balance egress traffic over those links. Hence there is no need for Layer 2 anymore.

MORE? The authors realize these few pages don't even come close covering all the aspects of the RIFT protocol. Hence, we strongly recommend reading https://www.juniper.net/documentation/en_US/day-one-books/DO_RIFT.pdf which gives a full 360 degree view of the protocol.

cRPD as Cloud Native Routing Stack in 5G

Before we get into cRPD deployment as Cloud Native Routing Stack, let's quickly review the xHaul transport network for 5G.

Going back two decades, in order to support different applications service providers had multiple networks that were built around many different technologies like TDM, X.25, ATM , Frame Relay, SONET, and IP. It was quickly realized that running so many different types of networks was not financially viable and everyone eventually settled on IP.

Going by the same principle, when various network functions are getting virtualized service providers want to build a common cloud platform to host all virtual network functions from different vendors while building the network.

4G was all about addressing bandwidth requirements for the end user. 5G is going to provide more network agility and an immersive experience for the end user. The specification for Next Generation RAN (NG-RAN) evolved in OpenRAN (Open Radio Access Networks). The full potential of 5G networks can only be realized with the right combination of hardware and software. This is possible once the service providers fully align themselves towards OpenRAN, which is an approach where service providers are disaggregating mobile front-haul and mid-haul networks by building them around cloud native principles. This approach allows service providers to mix and match technologies from different vendors that can help deliver new capabilities in a cost-effective manner. It also helps transform traditional radio access networks by making them open, resilient, and scalable.

OpenRAN-based networks use specialized hardware which are COTS-based (x86 based systems), and the various functions are implemented by software running inside it. Baseband unit (BBU) found in traditional telco networks is decomposed into three functional components, a Radio Unit (RU), a Distributed Unit (DU), and a Central Unit (CU). Based on control user plane separation (CUPS) construct, CU can be further segregated into distinct control plane (CU-CP) and user plane (CU-UP) functions. This decoupling helps bring flexibility to deployment – you can either co-locate RU, DU, and CU together, or you can deploy them at different locations. If latency is the concern, RU, DU, and CU can be placed together at the edge.

A RU in 5G consists of an LO PHY and a RF transmitter. The LO PHY part is implemented using a FPGA or ASIC to get high-packet performance. The connection between RU and DU is known as fronthaul, which connects LO PHY and HI PHY. It is also known as an F2 interface. DU manages the packet transmission of radio to and from the RU over the fronthaul link conforming to eCPRI (enhanced CPRI) standard.

DU is connected to CU using the F1 mid-haul interface. An implementation of DU CTOS would consist of a server chassis with hardware acceleration PCIe cards and an open-source MAC/RLC stack. Deploying OpenRAN functions on x86 hardware in a cloud native environment using Container Network Functions (CNF) requires data plane acceleration and it has to be delivered at the application level as these network functions will not have access to the kernel. Some of the data plane acceleration techniques like XDP/DPDK/SmartNic are suitable to address that requirement.

Why Cloud Native?

5G is going to bring in many innovations, network fungibility, and agility into traditional telco networks. To quickly iterate and provide value to customers, cloud native is the way to go. Four benefits of cloud native are:

- Microservices - This means the software will be modular in nature and each of the components can be managed, updated, and deployed independently.
- Containers - CNF is highly portable and lightweight, easy to deploy compared to VNF which uses the VM format of delivering the application.
- Continuous Delivery - You can take advantage of various CI/CD pipelines to quickly push changes to deployment.
- DevOps - You can automate many of the day one and day two deployment challenges.

Figure 3.14 illustrates 5G RAN network evolution.

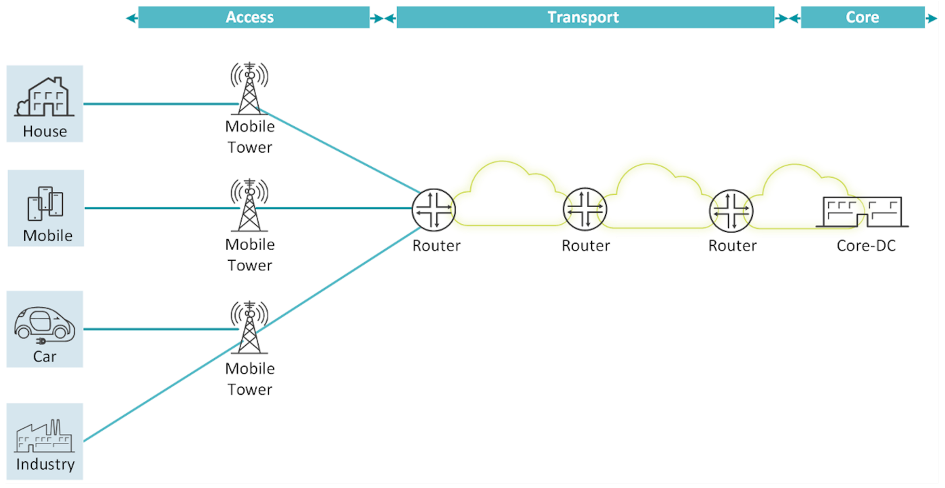


Figure 3.14 Typical Mobile Network

If you break down Figure 3.14 further, you get the deployment scenario shown in Figure 3.15.

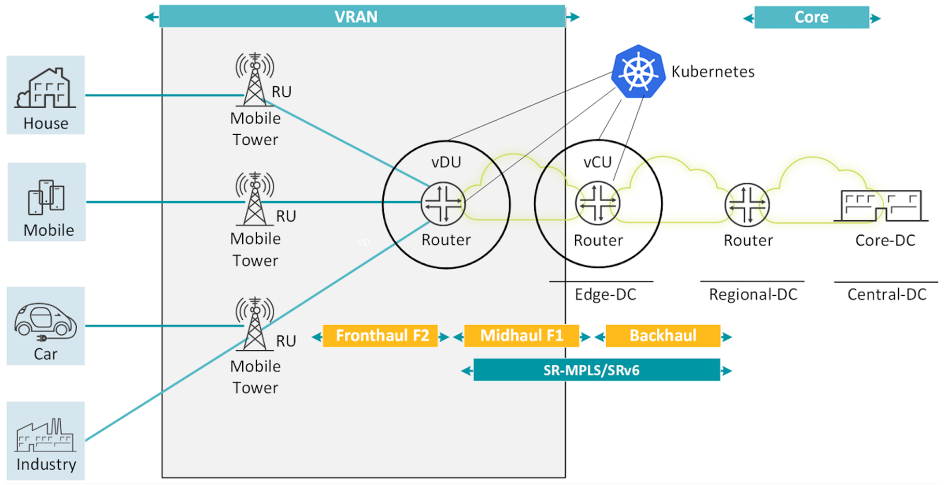


Figure 3.15 5G ORAN Deployment

You can see in Figure 3.15 that vRAN can be implemented using a Kubernetes environment with DU, CU, and a router running as a CNF. There is a strict latency requirement for the fronthaul, which is around 70 microseconds, and the F2 link can terminate on a SmartNIC. The latency requirement for F1 link or mid-haul is not that strict (in terms of milliseconds) and a DPDK forwarding plane could be used in the implementation.

Let's do a lab demonstration, where the vRAN part is being implemented and:

- The router is being replaced by cRPD as the cloud native routing stack in Kubernetes deployments, DU, and CU.
- The DU and CU application is simulated using Kubernetes pod running busybox application.
- Instead of an enhanced data plane like DPDK, the Linux kernel is used to showcase the demonstration.
- Calico is used as the primary Kubernetes CNI but in principle any CNI could be used.
- The DU and CU application pods are acting as CE device to the cRPD (which is acting as a router).
- Communication between DU and CU is facilitated by using SR-MPLS transport.
- The lab is capable to bringing up both IPv4/IPv6 transport. Please keep in mind that operators are mostly inclined towards IPv6 for vRAN infrastructure.

The lab topology is shown in Figure 3.16:

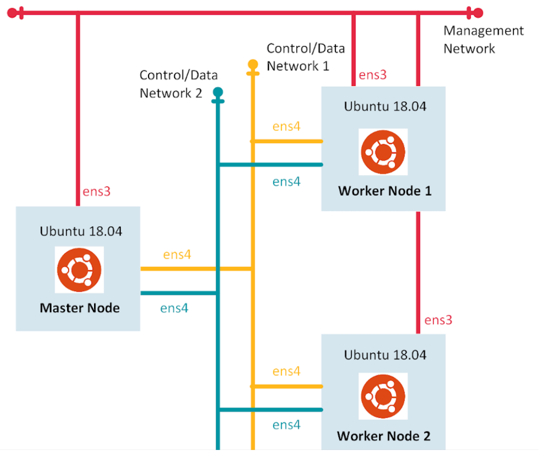


Figure 3.16 Sample Kubernetes Cluster with Three Nodes – Physical Connectivity

1. Bring up Ubuntu VMs with following properties:

- Management interface (ens3) will be in the subnet 192.168.122.0/24
- Control/data 1 network (ens4) will be in the subnet 172.16.122.0/24 and 2001:db9:122::0/64
- Control/data 2 network (ens5) will be in the subnet 172.16.123.0/24 and 2001:db9:123::0/64
- The Ubuntu VMs will use three vCPUs per VM and 32768KB memory per VM
- The OS running in the VM will be Ubuntu 18.04
- In this lab only two worker nodes are shown but you can bring-up as many as you need

2. Once the VMs are up and connected, install Kubernetes with one master and worker nodes. There are various ways to bring up the Kubernetes cluster (kubeadm, kind, minikube etc.). It is assumed that the Kubernetes setup is ready to be used with a primary CNI of your choice.

3. You want to install cRPD to act as a cloud native routing stack for all the PODs that want to use the transport network for communication and take care of route exchange and installing forwarding state. Figure 3.17 depicts the deployment.

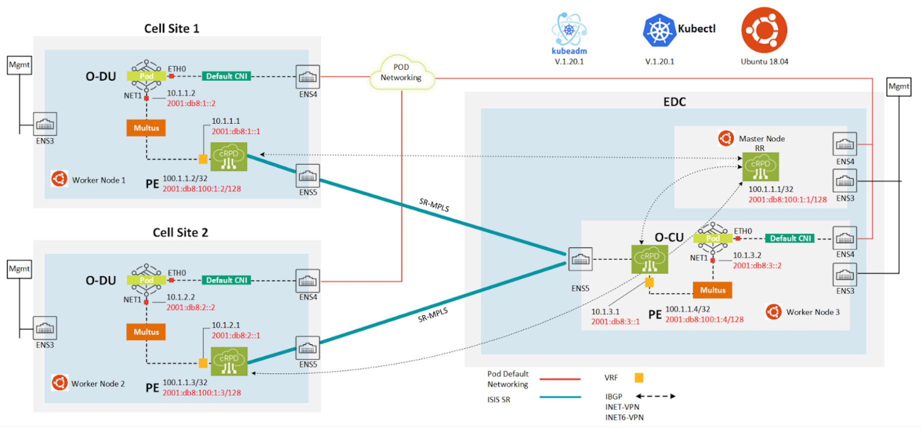


Figure 3.17 Lab Deployment of oCU and oDU Application in a 3 Nodes Kubernetes Cluster

In order to activate this, you need to:

- Run cRPD as a daemonset in all the Kubernetes nodes in the kube-system namespace having access to the host network.
- Make sure that when the Application PODs come up, they come up with two interfaces: one is being used by kubernetes(eth0) for POD networking and other will be connected to cRPD as a PE-CE link to cRPD. Here the cRPD is acting like a PE.
- Ensure that the kernel end of the veth pair is configured as CE link under routing-instance configuration in cRPD.
- The cRPD control plane for the cloud native deployment should come up automatically.

Let's go step-by-step to deploy.

1. Install `multus`:

```
root@kubernetes-master:~# git clone https://github.com/intel/multus-cni.git && cd multus-cni
root@kubernetes-master:~# cat ./images/multus-daemonset.yml | kubectl apply -f -
customresourcedefinition.apiextensions.k8s.io/network-attachment-definitions.k8s.cni.cncf.io created
clusterrole.rbac.authorization.k8s.io/multus created
clusterrolebinding.rbac.authorization.k8s.io/multus created
serviceaccount/multus created
configmap/multus-cni-config created
daemonset.apps/kube-multus-ds-amd64 created
daemonset.apps/kube-multus-ds-ppc64le created
daemonset.apps/kube-multus-ds-arm64v8 created
root@kubernetes-master:~

root@kubernetes-master:~# kubectl get ds -A
NAMESPACE    NAME               DESIRED   CURRENT   READY   UP-TO-DATE   AVAILABLE   NODE SELECTOR
AGE
kube-system   calico-node          4      4      4      4        4       kubernetes.io/os=linux
107d
kube-system   kube-multus-ds-amd64   4      4      4      4        4       kubernetes.io/arch=amd64
50s
kube-system   kube-multus-ds-arm64v8   0      0      0      0        0       kubernetes.io/arch=arm64
49s
kube-system   kube-multus-ds-ppc64le   0      0      0      0        0       kubernetes.io/arch=ppc64le
50s
kube-system   kube-proxy           4      4      4      4        4       kubernetes.io/os=linux
107d
root@kubernetes-master:~#
```

2. Add cRPD License and append the cRPD license to the manifest file:

```
kubectl create secret generic crpd-license -n kube-system --from-
literal=CRPDLICENSE="ENTIRE LICENSE STRING GOES HERE" --dry-run=client -o yaml >> crpd_cni_
secondary_asymmetric.yml
```

3. Install crpd_secondary_cni and cRPD docker image:

```
root@kubernetes-master:~# docker images| grep crpd
crpd_secondary_cni   latest                         b6b304f7a49f   3 days ago   448MB
crpd                20.4I-20200912_dev_common.0.1727 6046a86a7755   3 months ago352MB
crpd                 latest                          6046a86a7755   3 months ago352MB
crpd_cni              latest                          1ccbaa8a7831   5 months ago  527MB
root@kubernetes-master:~#
```

4. Apply tags to Kubernetes worker nodes:

```
root@kubernetes-master:~# kubectl label nodes node-1 site=cell1
node/node-1 labeled
root@kubernetes-master:~# kubectl label nodes node-3 nocrpd=yes
node/node-3 labeled
root@kubernetes-master:~# kubectl get nodes --show-labels
NAME              STATUS   ROLES    AGE VERSION   LABELS
kubernetes-master   Ready    master   107d   v1.20.1   beta.kubernetes.io/arch=amd64,beta.
kubernetes.io/os=linux,kubernetes.io/arch=amd64,kubernetes.io/hostname=kubernetes-master,kubernetes.
io/os=linux,node-role.kubernetes.io/master=
node-1           Ready  <none>   107d   v1.20.1   beta.kubernetes.io/arch=amd64,beta.kubernetes.io/
os=linux,kubernetes.io/arch=amd64,kubernetes.io/hostname=node-1,kubernetes.io/os=linux,site=cell1
node-2           Ready  <none>   107d   v1.20.1   beta.kubernetes.io/arch=amd64,beta.kubernetes.io/
os=linux,kubernetes.io/arch=amd64,kubernetes.io/hostname=node-2,kubernetes.io/os=linux,site=cell
node-3              Ready <none>   107d   v1.20.1   beta.kubernetes.io/arch=amd64,beta.kubernetes.io/
os=linux,kubernetes.io/arch=amd64,kubernetes.io/hostname=node-3,kubernetes.io/
os=linux,nocrpd=yes,site=edc
root@kubernetes-master:~#
```

5. Apply cRPD manifest file:

```
root@kubernetes-master:~# kubectl apply -f crpd_cni_secondary.yml
Warning: rbac.authorization.k8s.io/
v1beta1 ClusterRole is deprecated in v1.17+, unavailable in v1.22+; use rbac.authorization.k8s.io/
v1 ClusterRole
clusterrole.rbac.authorization.k8s.io/crpd created
Warning: rbac.authorization.k8s.io/
v1beta1 ClusterRoleBinding is deprecated in v1.17+, unavailable in v1.22+; use rbac.authorization.
k8s.io/v1 ClusterRoleBinding
clusterrolebinding.rbac.authorization.k8s.io/crpd created
serviceaccount/crpd created
configmap/crpd-configmap created
secret/crpd-license created
daemonset.apps/kube-crpd-worker-ds created
daemonset.apps/kube-crpd-master-ds created

root@kubernetes-master:~# kubectl get ds -A
NAMESPACE  NAME                  DESIRED   CURRENT   READY   UP-TO-DATE   AVAILABLE   NODE SELECTOR
AGE
kube-system   calico-node           4      4      3       4        3        kubernetes.io/os=linux
107d
kube-system   kube-crpd-master-ds   1         1       1       1        1        <none>
20s
kube-system   kube-crpd-worker-ds   2         2       2    2           2        <none>   20s
kube-system   kube-multus-ds-amd64  4         4       4    4           4        kubernetes.io/
arch=amd64   5h23m
kube-system   kube-multus-ds-arm64v8   0         0      0    0           0        kubernetes.io/
arch=arm64   5h23m
kube-system   kube-multus-ds-ppc64le   0         0         0    0          0        kubernetes.io/
arch=ppc64le   5h23m
kube-system   kube-proxy            4      4      4       4        4        kubernetes.io/os=linux
107d
```

```
root@kubernetes-master:~# kubectl get pods -A -o wide | grep crpd
kube-system   kube-crpd-master-ds-2svfx                1/1 Running   0      81s 172.16.122.1
kubernetes-master   <none>        <none>
kube-system   kube-crpd-worker-ds-n9fg5                1/1 Running   0       81s     172.16.122.3
node-2           <none>        <none>
kube-system   kube-crpd-worker-ds-s86f6                1/1 Running   0      81s 172.16.122.2
<none>        <none>
root@kubernetes-master:~#

root@kubernetes-master:~# docker ps | grep crpd
ffb4696bf4d4   6046a86a7755       "/sbin/runit-init.sh"
About a minute ago   Up About a minute            k8s_kube-crpd-master_kube-crpd-master-ds-2svfx_
kube-system_d21174ce-7dd4-41b8-8123-156a54bb3dc1_0
b634ddfd235b   k8s.gcr.io/pause:3.2   "/pause"
About a minute ago   Up About a minute            k8s_POD_kube-crpd-master-ds-2svfx_kube-system_
d21174ce-7dd4-41b8-8123-156a54bb3dc1_0
root@kubernetes-master:~# docker exec -it k8s_kube-crpd-master_kube-crpd-master-ds-2svfx_kube-
system_d21174ce-7dd4-41b8-8123-156a54bb3dc1_0 bash


===>
          Containerized Routing Protocols Daemon (CRPD)
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                                                                  <===

root@kubernetes-master:/# cli
root@kubernetes-master> show bgp summary
Threading mode: BGP I/O
Default eBGP mode: advertise - accept, receive - accept
Groups: 2 Peers: 5 Down peers: 0
Unconfigured peers: 5
Table        Tot Paths  Act Paths Suppressed History Damp State  Pending
bgp.l3vpn.0
                   0        0        0        0        0       0
bgp.l3vpn-inet6.0
                   1        1        0        0        0        0
Peer                 AS   InPkt     OutPkt OutQ   Flaps Last Up/Dwn State|#Active/Received/Accepted/
Damped...
100.1.1.2          64512       17         16   0   0        7:45 Establ
  bgp.l3vpn.0: 0/0/0/0
100.1.1.3          64512      18       17    0       0      6:48 Establ
  bgp.l3vpn.0: 0/0/0/0
2001:db8:100:1::2    64512      17       18    0       0      7:43 Establ
  bgp.l3vpn-inet6.0: 0/0/0/0
2001:db8:100:1::3    64512      18       17    0       0      6:47 Establ
  bgp.l3vpn-inet6.0: 0/0/0/0
2001:db8:100:1::4    64512        5        3   0       0        30 Establ
  bgp.l3vpn-inet6.0: 1/1/1/0
```

6. Apply POD definitions:

```
root@kubernetes-master:~# cat empty_net_def.conf
apiVersion: "k8s.cni.cncf.io/v1"
kind: NetworkAttachmentDefinition
metadata:
  name: netattach1
root@kubernetes-master:~#
```

```
root@kubernetes-master:~# kubectl apply -f  empty_net_def.conf
networkattachmentdefinition.k8s.cni.cncf.io/netattach1 created
root@kubernetes-master:~# kubectl get net-attach-def
NAME       AGE
netattach1   7s
root@kubernetes-master:~#


root@kubernetes-master:~# cat O_DU_pod_cell_site.yml
apiVersion: v1
kind: Pod
metadata:
  name: du-node-1
  annotations:
          k8s.v1.cni.cncf.io/networks: netattach1
spec:
  containers:
  - name: bx
          image: busybox
          command:
          - sleep
          - "360000000"
          imagePullPolicy: Always
  nodeSelector:
          site: cell
root@kubernetes-master:~#



root@kubernetes-master:~# kubectl apply -f O_DU_pod_cell_site.yml
pod/du-node-1 created
root@kubernetes-master:~# kubectl get pods
NAME       READY   STATUS            RESTARTS   AGE
du-node-1   0/1     ContainerCreating   0        5s
root@kubernetes-master:~# kubectl get pods -o wide
NAME       READY   STATUS RESTARTS   AGE   IP            NODE   NOMINATED NODE   READINESS GATES
du-node-1   1/1     Running   0       22s   10.244.247.11   node-2   <none>        <none>
root@kubernetes-master:~#



root@kubernetes-master:~# cat O_CU_pod_edc_site.yml
apiVersion: v1
kind: Pod
metadata:
  name: cu-node-1
  annotations:
    k8s.v1.cni.cncf.io/networks: netattach1
spec:
  containers:
  - name: bx
          image: busybox
          command:
          - sleep
          - "360000000"
          imagePullPolicy: Always
  nodeSelector:
          site: edc
root@kubernetes-master:~#
```

```
root@kubernetes-master:~# kubectl apply -f O_CU_pod_edc_site.yml
pod/cu-node-1 created
root@kubernetes-master:~# kubectl get pods
NAME       READY   STATUS            RESTARTS   AGE
cu-node-1   0/1     ContainerCreating   0        8s
du-node-1   1/1     Running         0       53m
root@kubernetes-master:~# kubectl get pods -o wide
NAME       READY   STATUS RESTARTS   AGE   IP           NODE  NOMINATED NODE   READINESS GATES
cu-node-1   1/1     Running   0       17s   10.244.139.75   node-3   <none>           <none>
du-node-1   1/1     Running   0       53m   10.244.247.11   node-2   <none>        <none>
root@kubernetes-master:~#


root@kubernetes-master:~# kubectl exec du-node-1 -- ip addr list net1
11: net1@if18: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1500 qdisc noqueue
           link/ether b6:a0:cd:d8:aa:60 brd ff:ff:ff:ff:ff:ff
           inet 10.1.2.2/24 brd 10.1.2.255 scope global net1
           valid_lft forever preferred_lft forever
           inet6 2001:db8:2::2/64 scope global
       valid_lft forever preferred_lft forever
           inet6 fe80::b4a0:cdff:fed8:aa60/64 scope link
           valid_lft forever preferred_lft forever

root@kubernetes-master:~# kubectl exec cu-node-1 -- ping 10.1.2.2 -c 3
PING 10.1.2.2 (10.1.2.2): 56 data bytes
64 bytes from 10.1.2.2: seq=0 ttl=62 time=0.852 ms
64 bytes from 10.1.2.2: seq=1 ttl=62 time=0.684 ms
64 bytes from 10.1.2.2: seq=2 ttl=62 time=0.798 ms

--- 10.1.2.2 ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max = 0.684/0.778/0.852 ms
root@kubernetes-master:~#


root@kubernetes-master:~# kubectl exec cu-node-1 -- ping -6 2001:db8:2::2 -c 3

PING 2001:db8:2::2 (2001:db8:2::2): 56 data bytes
64 bytes from 2001:db8:2::2: seq=0 ttl=62 time=1.087 ms
64 bytes from 2001:db8:2::2: seq=1 ttl=62 time=1.008 ms
64 bytes from 2001:db8:2::2: seq=2 ttl=62 time=9.067 ms

--- 2001:db8:2::2 ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max = 1.008/3.720/9.067 ms
```

Here's a packet capture of Ping packets:

```
04:19:19.189213 52:54:00:0b:0a:5a > 52:54:00:4d:c5:09, ethertype MPLS unicast (0x8847), length 102:
MPLS (label 16, exp 0, [S], ttl 63) 10.1.3.2 > 10.1.2.2: ICMP echo request, id 178, seq 0, length 64
04:19:19.189593 52:54:00:4d:c5:09 > 52:54:00:0b:0a:5a, ethertype MPLS unicast (0x8847), length 102:
MPLS (label 16, exp 0, [S], ttl 63) 10.1.2.2 > 10.1.3.2: ICMP echo reply, id 178, seq 0, length 64
04:19:20.189430 52:54:00:0b:0a:5a > 52:54:00:4d:c5:09, ethertype MPLS unicast (0x8847), length 102:
MPLS (label 16, exp 0, [S], ttl 63) 10.1.3.2 > 10.1.2.2: ICMP echo request, id 178, seq 1, length 64
04:19:20.189617 52:54:00:4d:c5:09 > 52:54:00:0b:0a:5a, ethertype MPLS unicast (0x8847), length 102:
MPLS (label 16, exp 0, [S], ttl 63) 10.1.2.2 > 10.1.3.2: ICMP echo reply, id 178, seq 1, length 64
```

```
04:19:21.189652 52:54:00:0b:0a:5a > 52:54:00:4d:c5:09, ethertype MPLS unicast (0x8847), length 102:
MPLS (label 16, exp 0, [S], ttl 63) 10.1.3.2 > 10.1.2.2: ICMP echo request, id 178, seq 2, length 64
04:19:21.189879 52:54:00:4d:c5:09 > 52:54:00:0b:0a:5a, ethertype MPLS unicast (0x8847), length 102:
MPLS (label 16, exp 0, [S], ttl 63) 10.1.2.2 > 10.1.3.2: ICMP echo reply, id 178, seq 2, length 64
```

```
04:17:32.199816 52:54:00:0b:0a:5a > 52:54:00:4d:c5:09, ethertype MPLS unicast (0x8847), length 122:
MPLS (label 16, exp 0, [S], ttl 63) 2001:db8:3::2 > 20
01:db8:2::2: ICMP6, echo request, seq 0, length 64
04:17:32.200059 52:54:00:4d:c5:09 > 52:54:00:0b:0a:5a, ethertype MPLS unicast (0x8847), length 122:
MPLS (label 16, exp 0, [S], ttl 63) 2001:db8:2::2 > 20
01:db8:3::2: ICMP6, echo reply, seq 0, length 64
04:17:33.200038 52:54:00:0b:0a:5a > 52:54:00:4d:c5:09, ethertype MPLS unicast (0x8847), length 122:
MPLS (label 16, exp 0, [S], ttl 63) 2001:db8:3::2 > 20
01:db8:2::2: ICMP6, echo request, seq 1, length 64
04:17:33.200406 52:54:00:4d:c5:09 > 52:54:00:0b:0a:5a, ethertype MPLS unicast (0x8847), length 122:
MPLS (label 16, exp 0, [S], ttl 63) 2001:db8:2::2 > 2001:db8:3::2: ICMP6, echo reply, seq 1, length 64
04:17:34.200203 52:54:00:0b:0a:5a > 52:54:00:4d:c5:09, ethertype MPLS unicast (0x8847), length 122:
MPLS (label 16, exp 0, [S], ttl 63) 2001:db8:3::2 > 2001:db8:2::2: ICMP6, echo request, seq 2, length
64
04:17:34.200488 52:54:00:4d:c5:09 > 52:54:00:0b:0a:5a, ethertype MPLS unicast (0x8847), length 122:
MPLS (label 16, exp 0, [S], ttl 63) 2001:db8:2::2 > 2001:db8:3::2: ICMP6, echo reply, seq 2, length 64
```

Chapter 4

Monitoring and Telemetry

cRPD supports various automation and telemetry frameworks like JET, YANG-based model-driven streaming telemetry, openconfig, NetConf, PyEz, and gRPC. This chapter shows you how to set up a monitoring solution using open-source tools. The entire setup can be defined using a single Docker-composed file. Let's use a very simple network topology using three cRPDs as shown in Figure 4.1.

The aim of this lab is to showcase how to set up a cloud-native monitoring framework for cRPD using:

1. Grafana as a Dashboard

2. Prometheus as a collector for node-exporter and cAdvisor

3. Telegraf as a collector for cRPD Junos OpenConfig Telemetry

In this setup:

- There are iBGP sessions among three cRPDs: Test-cRPD, baseline-cRPD, and Internet-cRPD
- Test-cRPD is our DUT
- Baseline-cRPD is another cRPD running a different release
- Internet-cRPD is pulling the internet routing table from the lab and reflecting it to Test-cRPD and baseline-cRPD

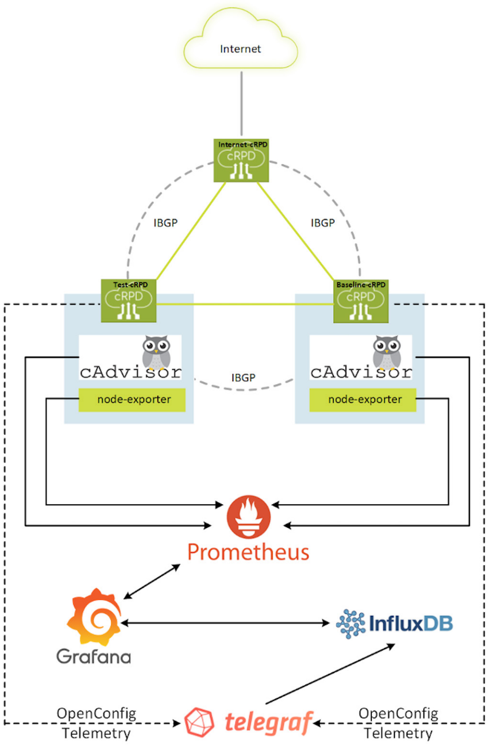


Figure 4.1 Lab Setup for Monitoring Solution

To bring up the above network topology along with monitoring the infrastructure let's use this Docker-composed YAML file:

```
---
version: "3"
networks:
 tig:

services:
 influxdb:
   container_name: influxdb
   expose:
     - 8086
     - 8083
   networks:
     - tig
   image: influxdb:1.8.0
 telegraf:
   container_name: telegraf
   image: telegraf:1.15.1
   networks:
     - tig
```

```
    volumes:
      - $PWD/telegraf.conf:/etc/telegraf/telegraf.conf:ro
      - /var/run/docker.sock:/var/run/docker.sock
    depends_on:
      - influxdb
  grafana:
    container_name: grafana
    environment:
      GF_SECURITY_ADMIN_USER: jnpr
      GF_SECURITY_ADMIN_PASSWORD: jnpr
    ports:
      - "3000:3000"
    networks:
      - tig
    image: grafana/grafana:7.0.3
    volumes:
      - $PWD/datasource.yaml:/etc/grafana/provisioning/datasources/datasource.yaml:ro
    depends_on:
      - influxdb
      - prometheus
  prometheus:
    image: prom/prometheus:latest
    container_name: prometheus
    networks:
      - tig
    ports:
      - 9090:9090
    command:
      - --config.file=/etc/prometheus/prometheus.yml
    volumes:
      - ./prometheus.yml:/etc/prometheus/prometheus.yml:ro
    links:
      - cadvisor:cadvisor
      - nodeexporter:nodeexporter
  cadvisor:
    privileged: true
    image: gcr.io/google-containers/cadvisor:latest
    container_name: cadvisor
    networks:
      - tig
    ports:
      - 8080:8080
    volumes:
      - /:/rootfs:ro
      - /var/run:/var/run:rw
      - /sys:/sys:ro
      - /var/lib/docker/:/var/lib/docker:ro
      - /dev/disk/:/dev/disk:ro
      - /sys/fs/cgroup:/sys/fs/cgroup:ro
  nodeexporter:
    privileged: true
    image: prom/node-exporter:v1.0.1
    container_name: nodeexporter
    networks:
      - tig
    ports:
      - 9100:9100
    volumes:
      - /proc:/host/proc:ro
      - /sys:/host/sys:ro
      - /:/rootfs:ro
      - ${PWD}/crpd_image_size:/host/crpd_image_size
    command:
      - '--path.procfs=/host/proc'
      - '--path.rootfs=/rootfs'
      - '--path.sysfs=/host/sys'
      - '--collector.filesystem.ignored-mount-points=^/(sys|proc|dev|host|etc)($$|/)'
      - '--collector.textfile.directory=/host/crpd_image_size'
    restart: unless-stopped
  testcrpd:
    privileged: true
    image: crpd:20.4I-20201227.0.1259
    container_name: crpdtest
    networks:
      - tig
    volumes:
      - ${PWD}/testcrpd:/config
      - ${PWD}/license:/config/license
  baselinecrpd:
    privileged: true
    image: crpd:20.3R1.4
    container_name: crpdbaseline
    networks:
      - tig
    volumes:
      - ${PWD}/baselinecrpd:/config
      - ${PWD}/license:/config/license
  internetcrpd:
    privileged: true
    image: crpd:20.3R1.4
    container_name: internetcrpd
    network_mode: bridge
    volumes:
      - ${PWD}/internetcrpd:/config
      - ${PWD}/license:/config/license
```

NOTE A network “tig” is defined, which is accessible by all services.

In the docker-compose file the following services are brought up:

InfluxDb: This one uses influxdb:1.8.0 image version, exposes ports 8086 and 8083 over network tig.

Telegraf: This one is used as a collector for Junos OpenConfig Telemetry and stores the sensor values in InfluxDB TSDB. It uses telegraf version 1.15.1 and mounts preconfigured telegraf.conf when the container comes up. An excerpt from the telegraf.conf file given below:

```
..
[[outputs.influxdb]]
  urls = ["http://influxdb:8086"]
  database = "jnpr"
  username = "jnpr"
  password = "jnpr"
  retention_policy = ""
  write_consistency = "any"
  timeout = "5s"
[[inputs.jti_openconfig_telemetry]]
  ## List of device addresses to collect telemetry from
  servers = ["testcrpd:50051", "baselinecrpd:50051"]
  sample_frequency = "2000ms"
  sensors = [
   "/network-instances/network-instance/protocols/protocol/bgp/neighbors",
   "/bgp-rib",
  ]
  retry_delay = "1000ms"

..
```

In this configuration file 50051 is the gRPC port number that cRPD is exposing for streaming telemetry, and here is the relevant configuration snapshot from cRPD in order to demonstrate the same:

```
system {
..
        extension-service {
            request-response {
                grpc {
                    clear-text {
                        address 0.0.0.0;
                        port 50051;
                    }
                    max-connections 8;
                    skip-authentication;
                }
            }
            ##
            ## Warning: configuration block ignored: unsupported platform (crpd)
            ##
            notification {
                allow-clients {
                    address 0.0.0.0/0;
                }
            }
        }
..
```

Grafana: As discussed, Grafana is used to build the dashboard GUI. It uses InfluxDB and Prometheus as data sources. Here the Grafana version of 7.0.3 is used. It exposes port 3000 for any HTTP connection via a web browser. A username and password to log in to the browser are also provided in the service definition.

Datasource.yml provides credentials for Grafana to automatically fetch data from influxdb and Prometheus.

Prometheus: Prometheus is a widely adopted open-source metrics-based monitoring and alerting system. It has inbuilt TSDB and scrapes the endpoints defined in its configuration file for available metrics. Here the configuration file `Prometheus.yml` gets mounted when the container comes up. Excerpts from the configuration file are given below for an endpoint scraping configuration:

```
..

scrape_configs:

  # The job name is added as a label `job=<job_name>` to any timeseries scraped from this config.
  - job_name: 'prometheus'
    # Override the global default and scrape targets from this job every 5 seconds.

    scrape_interval: 5s
    static_configs:
            - targets: ['prometheus:9090','cadvisor:8080','nodeexporter:9100','pushgateway:9091']
```

CAdvisor: This provides insights about the resource usage and performance characteristics of running containers in a system.

Nodeexporter: This provides server level details about various system parameters like memory, CPU, etc. and can be used to visualize server health in the dashboard.

The remainder of this chapter shows various cRPD container services used to match the topology. Let's run this command to bring up the setup:

```
docker-compose -f docker-compose.yml up
```

The following containers are running:

```
root@server# docker ps
CONTAINER ID      IMAGE                              COMMAND              CREATED  STATUS
PORTS                       NAMES
53eb0284a9e0      grafana/grafana:7.0.3                 "/run.sh"             14 seconds ago     Up
12 seconds                     0.0.0.0:3000->3000/tcp            grafana
1a3545a58f3d        prom/prometheus:latest                   "/bin/prometheus --c…
"   16 seconds ago      Up 14 seconds                     0.0.0.0:9090->9090/
tcp            prometheus
e9e341da31e0        telegraf:1.15.1                          "/entrypoint.
sh tele…"   17 seconds ago      Up 13 seconds                         8092/udp, 8125/udp, 8094/
tcp      telegraf
10a039df2b48        influxdb:1.8.0                           "/entrypoint.
sh infl…"   23 seconds ago      Up 17 seconds                         8083/tcp, 8086/
tcp                influxdb
6b782911159b        crpd:20.4I-20201227.0.1259               "/sbin/runit-init.
sh"    23 seconds ago      Up 21 seconds                      22/tcp, 179/tcp, 830/tcp, 3784/
tcp, 4784/tcp, 6784/tcp, 7784/tcp, 50051/tcp   crpdtest
e1ea4c9a4747        prom/pushgateway                         "/bin/
pushgateway"       23 seconds ago      Up 19 seconds                        0.0.0.0:9091->9091/
tcp            pushgateway
736ce19cbb8e        gcr.io/google-containers/cadvisor:latest   "/usr/bin/
cadvisor -…"   23 seconds ago      Up 16 seconds (health: starting)   0.0.0.0:8080->8080/
tcp            cadvisor
5f36b4a45088        crpd:20.3R1.4                            "/sbin/runit-init.
sh"    23 seconds ago      Up 22 seconds                      22/tcp, 179/tcp, 830/tcp, 3784/
tcp, 4784/tcp, 6784/tcp, 7784/tcp, 50051/tcp   internetcrpd
697c750514fb        prom/node-exporter:v1.0.1                "/bin/node_
exporter …"   23 seconds ago      Up 18 seconds                         0.0.0.0:9100->9100/
tcp            nodeexporter
```

```
8f5a25d90c65        crpd:20.3R1.4                              "/sbin/runit-init.
sh"    23 seconds ago      Up 20 seconds                         22/tcp, 179/tcp, 830/tcp, 3784/
tcp, 4784/tcp, 6784/tcp, 7784/tcp, 50051/tcp   crpdbaseline
b237f0c58f09        932d15951c1e                               "/sbin/runit-init.sh"
```

Here is a configuration for pushing the open-config telemetry from the cRPD baseline:

```
openconfig-network-instance:network-instances {
   network-instance default {
       config {
           type DEFAULT_INSTANCE;
       }
       protocols {
           protocol BGP bgp-1 {
               bgp {
                   global {
                       config {
                           as 100;
                           router-id 2.2.2.2;
                       }
                   }
                   neighbors {
                       neighbor 53.1.1.2 {
                           config {
                               peer-group qtest1;
                               neighbor-address 53.1.1.2;
                               peer-as 100;
                           }
                           route-reflector {
                               config {
                                   route-reflector-cluster-id 2;
                                   route-reflector-client true;
                               }
                           }
                           apply-policy {
                               config {
                                   export-policy ibgp-export-internet;
                               }
                           }
                       }
                       neighbor 52.1.1.2 {
                           config {
                               peer-group qtest2;
                               neighbor-address 52.1.1.2;
                               peer-as 100;
                           }
                           route-reflector {
                               config {
                                   route-reflector-cluster-id 2;
                                   route-reflector-client true;
                               }
                           }
                       }
                   }
```

```
                }
            }
        }
    }
}
```

One way to quickly check if cRPD is streaming telemetry is by using JTIMON. To install JTIMON:

1. Clone git repository:

```
git clone https://github.com/nileshsimaria/jtimon.git
```

2. Install GO using apt install golang-go:

```
Cd
mkdir go
export GOPATH=$HOME/go
go get -v github.com/golang/protobuf/proto
go get -v github.com/gorilla/mux
go get -v github.com/influxdata/influxdb1-client/v2
go get -v github.com/prometheus/client_golang/prometheus/promhttp
go get -v github.com/spf13/pflag
go get -v golang.org/x/net/context
go get -v google.golang.org/grpc
go get -v github.com/nileshsimaria/jtimon/authentication
```

3. Change the package path in influx.go and subscribe_gnmi.go from github.com/influxdata/influxdb/client/v2 to github.com/influxdata/influxdb1-client/v2:

```
cd $GOPATH/src/github.com/nileshsimaria/jtimon/vendor/google.golang.org/
mv grpc GRPC_BKUP
cd root/jtimon/jtimon/
Go build

root@ubuntu:~/jtimon/jtimon# ./jtimon -h
Usage of ./jtimon:
          --compression string      Enable HTTP/2 compression (gzip)
          --config strings          Config file name(s)
          --config-file-list string List of Config files
          --consume-test-data       Consume test data
          --explore-config          Explore full config of JTIMON and exit
          --generate-test-data      Generate test data
          --json                    Convert telemetry packet into JSON
          --log-mux-stdout          All logs to stdout
          --max-run int             Max run time in seconds
          --no-per-packet-goroutines   Spawn per packet go routines
          --pprof                   Profile JTIMON
          --pprof-port int32        Profile port (default 6060)
          --prefix-check            Report missing __prefix__ in telemetry packet
          --print                   Print Telemetry data
          --prometheus              Stats for prometheus monitoring system
          --prometheus-host string  IP to bind Prometheus service to (default "127.0.0.1")
          --prometheus-port int32   Prometheus port (default 8090)
          --stats-handler           Use GRPC statshandler
          --version                 Print version and build-time of the binary and exit
pflag: help requested
root@ubuntur:~/jtimon/jtimon#
```

4. Create a json file for testing sensors:

```
root@ubuntu:~/jtimon/jtimon# cat test.json
{
          "host": "172.17.0.1",
          "port": 50051,
          "paths": [{
          "path": "/network-instances/network-instance/protocols/protocol/bgp/",
          "freq": 2000
          }]
}

root@ubuntu:~/jtimon/jtimon#
```

Make sure port 50051 is exposed on the local host. You can do that by either running cRPD on the host networking mode or you can map the cRPD telemetry port to the local port 50051.

5. Once set up, run the following commands to check if BGP sensors are exported by cRPD:

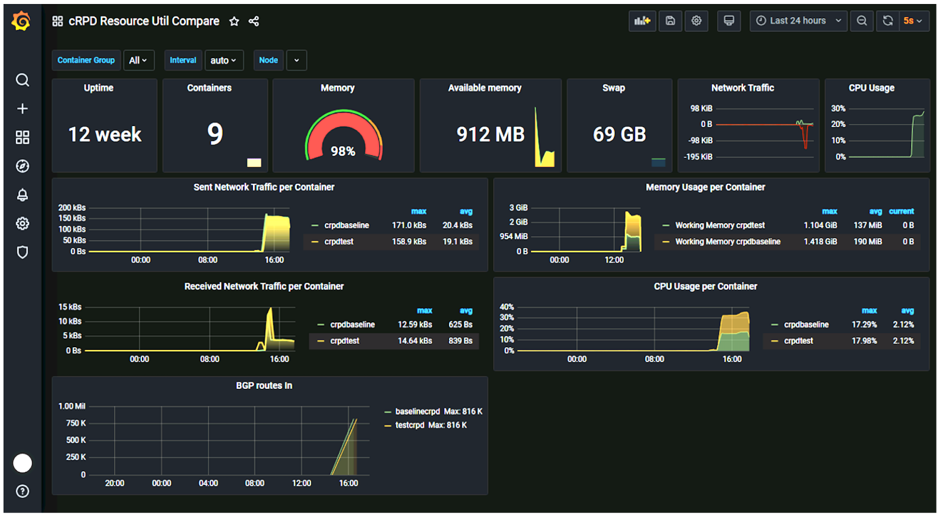
```
root@hyderabad:~/jtimon/jtimon# ./jtimon --config ./test.json --print
2020/12/28 19:15:27 Version: v2.3.0-79d878c471c92ce67477c662c1d31fd49b74301f-master BuildTime 2020-
12-23T13:40:23-0800
2020/12/28 19:15:27 logging in  for 172.17.0.1:50051 [periodic stats every 0 seconds]
Running config of JTIMON:
 {
          "port": 50051,
          "host": "172.17.0.1",
          "user": "",
          "password": "",
          "cid": "",
          "meta": false,
          "eos": false,
          "grpc": {
          "ws": 1048576
          },
          "tls": {
          "clientcrt": "",
          "clientkey": "",
          "ca": "",
          "servername": ""
          },
          "influx": {
          "server": "",
          "port": 0,
          "dbname": "",
          "user": "",
          "password": "",
          "recreate": false,
          "measurement": "",
          "batchsize": 102400,
          "batchfrequency": 2000,
           "http-timeout": 30,
           "retention-policy": "",
           "accumulator-frequency": 2000,
           "write-per-measurement": false
           },
           "paths": [
           {
           "path": "/network-instances/network-instance/protocols/protocol/bgp/",
           "freq": 2000,
           "mode": ""
           }
           ],
           "log": {
           "file": "",
           "periodic-stats": 0,
           "verbose": false
           },
           "vendor": {
           "name": "",
           "remove-namespace": false,
           "schema": null,
           "gnmi": null
           },
           "alias": "",
           "password-decoder": ""
}
invoking getInfluxClient for init
invoking getInfluxClient
compression = none
Connecting to 172.17.0.1:50051
Calling subscribe() ::: ./test.json
gRPC headers from host 172.17.0.1:50051
  init-response: [response { subscription_id: 1 } path_list { path: "/network-instances/network-
instance/protocols/protocol/bgp/" sample_frequency: 2000 } ]
  content-type: [application/grpc]
  grpc-accept-encoding: [identity,deflate,gzip]
  accept-encoding: [identity,gzip]
Receiving telemetry data from 172.17.0.1:50051
system_id: grpc
component_id: 65535
sub_component_id: 0
path: sensor_1000:/network-instances/network-instance/protocols/protocol/bgp/:/network-instances/
network-instance/protocols/protocol/bgp/:rpd
sequence_number: 0
timestamp: 1609182929151
sync_response: false
  key: __timestamp__
  uint_value: 1609182929152
  key: __junos_re_stream_creation_timestamp__
  uint_value: 1609182929140
  key: __junos_re_payload_get_timestamp__
  uint_value: 1609182929140
  key: __prefix__
  str_value: /network-instances/network-instance[name='master']/
  key: protocols/protocol/bgp/global/state/as
  uint_value: 100
  key: protocols/protocol/bgp/global/state/router-id
  str_value: 53.1.1.2
```

There you go! Figure 4.2 shows the final output. In the Dashboard you can visualize the host/server:

- Uptime for the server or host
- Memory utilization and availability for the server/host
- Network/ CPU utilization for the host

And for cRPD containers, crpdbaseline and crpdtest:

- Sent and received network traffic
- Memory and CPU usage
- Number of BGP routes in



	max	avg
crpdbaseline	171.0 kBs	20.4 kBs
crpdtest	158.9 kBs	19.1 kBs

	max	avg	current
Working Memory crpdtest	1.104 GiB	137 MiB	0 B
Working Memory crpdbaseline	1.418 GiB	190 MiB	0 B

	max	avg
crpdbaseline	12.59 kBs	625 Bs
crpdtest	14.64 kBs	839 Bs

	max	avg
crpdbaseline	17.29%	2.12%
crpdtest	17.98%	2.12%

Figure 4.2 Grafana Dashboard

Chapter 5

Troubleshooting

Troubleshooting determines why something does not work as expected and how to resolve the problem. You can troubleshoot issues at the CLI, container, Docker, rpd crashes, core files, and by using log messages stored at /var/log/messages.

Unable to Install Linux Packages/utilities

As a part of learning or troubleshooting you might often find it useful to install additional software packages. Since cRPD is built on Ubuntu distribution, you should be able to install packages from Ubuntu repositories.

If you are unable to reach the Ubuntu repositories, start checking your network reachability.

As a first step, verify that the host network is set up correctly to reach the internet. Tools like `ping`, `ip`, and `traceroute` will be useful.

As a next step, check if the default route is present in the cRPD Linux shell to reach public repositories:

```
root@node-2:~# ip route show
default via 192.168.122.1 dev ens3 proto static
```

Docker creates an interface "eth0" in each container by default in bridge mode, and adds it to the Docker bridge. The Docker bridge is connected to the host network. All traffic in and out of the Docker bridge towards the host network is NAT'd, so basically the host where the cRPD is running does SNAT for the traffic going towards the Internet from cRPD. Similarly, it does DNAT for return traffic reaching the cRPD Docker container. It is very important to check internet reachability from the host itself.

One may also need to run "`apt-get update`" prior to running any "`apt install`" command.

Also, please check "/etc/resolv.conf" to make sure DNS is properly configured both at the cRPD Linux shell and at the host, so that domain names are properly resolved.

Where Are My Crashed Files?

When a process inside cRPD dumps core, corefile is collected and stored on the host filesystem. It should be noted that the corefiles are not stored within the container volume itself.

Crash files can be found under /var/crash on the host or to a location defined by the sysctl kernel.core_pattern. Please note that you may need to manually create this directory under the host if it is not available in order to have crash files to be saved under them.

NOTE Unlike Junos, corefiles generated by cRPD don't include config files and other data and should be collected separately.

How to Enable MPLS Routing?

To enable MPLS routing:

```
root@kubernetes-master:~# uname -a
Linux kubernetes-
master 4.15.0-130-generic #134-Ubuntu SMP Tue Jan 5 20:46:26 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
root@kubernetes-master:~#

root@kubernetes-master:~# lsmod | grep mpls

root@kubernetes-master:~# sudo apt-get install linux-modules-extra-4.15.0-130-generic
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following package was automatically installed and is no longer required:

root@kubernetes-master:~# modprobe mpls_router
root@kubernetes-master:~# modprobe mpls_iptunnel
root@kubernetes-master:~# cat /proc/sys/net/mpls/platform_labels
0
root@kubernetes-master:~# echo 1048575 > /proc/sys/net/mpls/platform_labels

root@kubernetes-master:~# cat /proc/sys/net/mpls/conf/ens5/input
0
root@kubernetes-master:~# echo 1 > /proc/sys/net/mpls/conf/ens5/input
```

Whereas ens5 is the core facing interface in the Linux host.

BGP Session Does Not Come Up

Sometimes BGP sessions may not come up over a link connected to OVS switch, specially towards a traffic generator like Spirent. You need to turn off TCP offloading for the link using the following command:

```
ethtool -K 0db078bba91d4_l tx off
```

My ISIS Adjacency Doesn’t Come Up With cRPD?

The most common problem with ISIS not coming up is that lo0 is not configured in a Junos configuration in addition to the Linux shell. You need to configure Junos for loopback interface:

```
root@crpd> show configuration interfaces
lo0 {
          unit 0 {
          family iso {
          address 49.0001.0001.0001.00;
          }
          }
}

root@crpd> show configuration protocols isis
iinterface lo.0 {
          passive;
}
interface lo0.0 {
          passive;
}
```

MPLS Forwarding Not Happening for VRF?

Check if MPLS kernel modules are present:

```
Lsmod | grep mpls
```

Check if a VRF device got created in the kennel corresponding to the routing-instance configured:

```
root@crpd> show configuration routing-instances
VRF1 {
          instance-type vrf;
          interface veth91c08573;
          route-distinguisher 100.1.1.3:64512;
          vrf-target target:1:1;
          vrf-table-label;
}
root@crpd>

root@crpd:/# ip link | grep -B2 VRF
```

```
19: __crpd-vrf1: <MASTER,UP,LOWER_
UP> mtu 65536 qdisc noqueue state UP mode DEFAULT group default qlen 1000
          link/ether b2:e0:06:71:ab:b9 brd ff:ff:ff:ff:ff:ff
          alias VRF1
root@crpd:/#
```

Where Are cRPD Links Connected?

The best option is to run LLDP. LLDP is not available under the Junos configuration in cRPD, but you can install LLDP in the cRPD Linux shell:

```
root@crpd:/# apt-get install lldpd
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following additional packages will be installed:
  libevent-2.1-6 libgdbm-compat4 libgdbm5 libicu60 libpci3 libperl5.26 libsensors4 libsnmp-
base libsnmp30 libwrap0 libxml2 netbase perl perl-base
  perl-modules-5.26
Suggested packages:
  gdbm-l10n lm-sensors snmp-mibs-downloader snmpd perl-doc libterm-readline-gnu-perl | libterm-
readline-perl-perl make
The following NEW packages will be installed:
  libevent-2.1-6 libgdbm-compat4 libgdbm5 libicu60 libpci3 libperl5.26 libsensors4 libsnmp-
base libsnmp30 libwrap0 libxml2 lldpd netbase perl
  perl-modules-5.26
The following packages will be upgraded:
  perl-base
1 upgraded, 15 newly installed, 0 to remove and 31 not upgraded.
Need to get 18.2 MB of archives.
After this operation, 80.8 MB of additional disk space will be used.


root@crpd:/# lldpcli
[lldpcli] $ show
-- Show running system information
          neighbors  Show neighbors data
          interfaces  Show interfaces data
          chassis  Show local chassis data
          statistics  Show statistics
          configuration  Show running configuration
running-configuration  Show running configuration
[lldpcli] $ show neighbors
```

Not Able to Reach the Internet From cRPD

Can't reach the internet from cRPD after fetching the internet routing table from the lab server? This can happen when the cRPD is peering with a lab server for the internet feed. The internet routes get installed in the kernel and when you try to reach a public destination it gets resolved over the internet routes received from the lab server, which gets dropped there.

How Can I Get Internet Feed to cRPD?

Juniper has an internet feed lab server that is reachable from the Juniper lab accepting all incoming BGP connections. Once a BGP session is brought up with that server, the internet feed can be established. The configuration on cRPD side goes like this:

```
root@internet# show protocols bgp group tointernetfeed
multihop;
local-address <lab_route_server_ip>;
receive-buffer 256k;
peer-as 10458;
local-as 69;
neighbor 192.168.69.71;

[edit]
root@internet#
```

Seeking Technical Support

When you run out of options to troubleshoot the issue and need to reach out to Juniper technical support, the following command will be useful to gather the information needed by the support team.

```
cli> request support information
```