Red Hat Enterprise Linux 9

Configuring InfiniBand and RDMA networks

A guide to configuring InfiniBand and RDMA networks on Red Hat Enterprise Linux 9
Abstract

This document describes what InfiniBand and remote direct memory access (RDMA) are and how to configure InfiniBand hardware. Additionally, this documentation explains how to configure InfiniBand-related services.
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Red Hat is committed to replacing problematic language in our code, documentation, and web properties. We are beginning with these four terms: master, slave, blacklist, and whitelist. Because of the enormity of this endeavor, these changes will be implemented gradually over several upcoming releases. For more details, see our CTO Chris Wright’s message.
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CHAPTER 1. UNDERSTANDING INFINIBAND AND RDMA

InfiniBand refers to two distinct things:

- The physical link-layer protocol for InfiniBand networks
- The InfiniBand Verbs API, an implementation of the remote direct memory access (RDMA) technology

RDMA provides access between the main memory of two computers without involving an operating system, cache, or storage. Using RDMA, data transfers with high-throughput, low-latency, and low CPU utilization.

In a typical IP data transfer, when an application on one machine sends data to an application on another machine, the following actions happen on the receiving end:

1. The kernel must receive the data.
2. The kernel must determine that the data belongs to the application.
3. The kernel wakes up the application.
4. The kernel waits for the application to perform a system call into the kernel.
5. The application copies the data from the internal memory space of the kernel into the buffer provided by the application.

This process means that most network traffic is copied across the main memory of the system if the host adapter uses direct memory access (DMA) or otherwise at least twice. Additionally, the computer executes some context switches to switch between the kernel and application. These context switches can cause a higher CPU load with high traffic rates while slowing down the other tasks.

Unlike traditional IP communication, RDMA communication bypasses the kernel intervention in the communication process. This reduces the CPU overhead. The RDMA protocol enables the host adapter to decide after a packet enters the network which application should receive it and where to store it in the memory space of that application. Instead of sending the packet for processing to the kernel and copying it into the memory of the user application, the host adapter directly places the packet contents in the application buffer. This process requires a separate API, the InfiniBand Verbs API, and applications need to implement the InfiniBand Verbs API to use RDMA.

Red Hat Enterprise Linux supports both the InfiniBand hardware and the InfiniBand Verbs API. Additionally, it supports the following technologies to use the InfiniBand Verbs API on non-InfiniBand hardware:

- Internet Wide Area RDMA Protocol (iWARP): A network protocol that implements RDMA over IP networks
- RDMA over Converged Ethernet (RoCE), which is also known as InfiniBand over Ethernet (IBoE): A network protocol that implements RDMA over Ethernet networks

Additional resources

- Configuring RoCE
CHAPTER 2. CONFIGURING SOFT-IWARP

This section explains background information about iWARP, Soft-iWARP and configuration of Soft-iWARP.

2.1. OVERVIEW OF IWARP AND SOFT-IWARP

Remote direct memory access (RDMA) uses the Internet Wide-area RDMA Protocol (iWARP) over Ethernet for converged and low latency data transmission over TCP. Using standard Ethernet switches and the TCP/IP stack, iWARP routes traffic across the IP subnets. This provides flexibility to efficiently use the existing infrastructure. In Red Hat Enterprise Linux, multiple providers implement iWARP in their hardware network interface cards. For example, cxgb4, irdma, qedr etc.

Soft-iWARP (siw) is a software-based iWARP kernel driver and user library for Linux. It is a software-based RDMA device that provides a programming interface to RDMA hardware when attached to network interface cards. It provides an easy way to test and validate the RDMA environment.

2.2. CONFIGURING SOFT-IWARP

Soft-iWARP (siw) implements the Internet Wide-area RDMA Protocol (iWARP) Remote direct memory access (RDMA) transport over the Linux TCP/IP network stack. It enables a system with a standard Ethernet adapter to interoperate with an iWARP adapter or with another system running the Soft-iWARP driver or a host with the hardware that supports iWARP.

IMPORTANT

The Soft-iWARP feature is provided as a Technology Preview only. Technology Preview features are not supported with Red Hat production Service Level Agreements (SLAs), might not be functionally complete, and Red Hat does not recommend using them for production. These previews provide early access to upcoming product features, enabling customers to test functionality and provide feedback during the development process.

See Technology Preview Features Support Scope on the Red Hat Customer Portal for information about the support scope for Technology Preview features.

To configure Soft-iWARP, you can use this procedure in a script to run automatically when the system boots.

Prerequisites

- An Ethernet adapter is installed

Procedure

1. Install the iproute, libibverbs, libibverbs-utils, and infiniband-diags packages:

   # dnf install iproute libibverbs libibverbs-utils infiniband-diags

2. Display the RDMA links:

   # rdma link show

3. Load the siw kernel module:
4. Add a new siw device named siw0 that uses the enp0s1 interface:

   # modprobe siw

   # rdma link add siw0 type siw netdev enp0s1

**Verification**

1. View the state of all RDMA links:

   # rdma link show

   link siw0/1 state ACTIVE physical_state LINK_UP netdev enp0s1

2. List the available RDMA devices:

   # ibv_devices

<table>
<thead>
<tr>
<th>device</th>
<th>node GUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>------</td>
<td>---------------</td>
</tr>
<tr>
<td>siw0</td>
<td>0250b6ffea19d61</td>
</tr>
</tbody>
</table>

3. You can use the ibv_devinfo utility to display a detailed status:

   # ibv_devinfo siw0

   **hca_id:** siw0  
   **transport:** iWARP (1)  
   **fw_ver:** 0.0.0  
   **node_guid:** 0250:b6ff:ea1:9d61  
   **sys_image_guid:** 0250:b6ff:ea1:9d61  
   **vendor_id:** 0x626d74  
   **vendor_part_id:** 1  
   **hw_ver:** 0x0  
   **phys_port_cnt:** 1  
   **port:** 1  
   **state:** PORT_ACTIVE (4)  
   **max_mtu:** 1024 (3)  
   **active_mtu:** 1024 (3)  
   **sm_lid:** 0  
   **port_lid:** 0  
   **port_lmc:** 0x00  
   **link_layer:** Ethernet
CHAPTER 3. CONFIGURING ROCE

This section explains background information about RDMA over Converged Ethernet (RoCE), as well as how to change the default RoCE version.

Note that there are different vendors, such as Mellanox, Broadcom, and QLogic, who provide RoCE hardware.

3.1. OVERVIEW OF ROCE PROTOCOL VERSIONS

RoCE is a network protocol that enables remote direct memory access (RDMA) over Ethernet.

The following are the different RoCE versions:

RoCE v1
The RoCE version 1 protocol is an Ethernet link layer protocol with ethertype 0x8915 that enables the communication between any two hosts in the same Ethernet broadcast domain.

RoCE v2
The RoCE version 2 protocol exists on the top of either the UDP over IPv4 or the UDP over IPv6 protocol. For RoCE v2, the UDP destination port number is 4791.

The RDMA_CM sets up a reliable connection between a client and a server for transferring data. RDMA_CM provides an RDMA transport-neutral interface for establishing connections. The communication uses a specific RDMA device and message-based data transfers.

IMPORTANT
Using different versions like RoCE v2 on the client and RoCE v1 on the server is not supported. In such a case, configure both the server and client to communicate over RoCE v1.

RoCE v1 works at the Data Link layer (Layer 2) and only supports the communication of two machines in the same network. By default, RoCE v2 is available. It works at the Network Layer (Layer 3). RoCE v2 supports packets routing that provides a connection with multiple Ethernet.

Additional resources

- Temporarily changing the default RoCE version

3.2. TEMPORARILY CHANGING THE DEFAULT ROCE VERSION

Using the RoCE v2 protocol on the client and RoCE v1 on the server is not supported. If the hardware in your server only supports RoCE v1, configure your clients to communicate with the server using RoCE v1. This section describes how to enforce RoCE v1 on the client that uses the mlx5_0 driver for the Mellanox ConnectX-5 Infiniband device.

Note that the changes described in this section are only temporary until you reboot the host.

Prerequisites

- The client uses an InfiniBand device with RoCE v2 protocol
- The server uses an InfiniBand device that only supports RoCE v1
Procedure

1. Create the `/sys/kernel/config/rdma_cm/mlx5_0` directory:
   ```
   # mkdir /sys/kernel/config/rdma_cm/mlx5_0/
   ```

2. Display the default RoCE mode:
   ```
   # cat /sys/kernel/config/rdma_cm/mlx5_0/ports/1/default_roce_mode
   RoCE v2
   ```

3. Change the default RoCE mode to version 1:
   ```
   # echo "IB/RoCE v1" > /sys/kernel/config/rdma_cm/mlx5_0/ports/1/default_roce_mode
   ```
CHAPTER 4. CONFIGURING THE CORE RDMA SUBSYSTEM

This section describes how to configure the rdma service and increase the amount of memory that users are allowed to pin in the system.

4.1. RENAMING IPOIB DEVICES USING SYSTEMD LINK FILE

By default, the kernel names Internet Protocol over InfiniBand (IPoIB) devices, for example, ib0, ib1, and so on. To avoid conflicts, create a systemd link file to create persistent and meaningful names such as mlx4_ib0.

Prerequisites

- An InfiniBand device is installed

Procedure

1. Display the hardware address of the device ib0:

   ```
   # ip addr show ib0
   
   7: ib0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 65520 qdisc fq_codel state UP
   group default qlen 256
   link/infiniband 80:00:0a:28:fe:80:00:00:00:00:00:00:00:00:00:7b:e1:b1 brd
   00:ff:ff:ff:ff:ff:ff:ff:ff:ff:ff:ff:ff:ff:ff:ff
   altname ibp7s0
   altname ibs2
   inet 172.31.0.181/24 brd 172.31.0.255 scope global dynamic noprefixroute ib0
   valid_lft 2899sec preferred_lft 2899sec
   inet6 fe80::f652:1403:7b:e1b1/64 scope link noprefixroute
   valid_lft forever preferred_lft forever
   ```

2. For naming the interface with MAC address 80:00:0a:28:fe:80:00:00:00:00:00:00:00:00:7b:e1:b1 to mlx4_ib0, create the /etc/systemd/network/70-custom-ifnames.link file with following contents:

   ```
   [Match]
   MACAddress=80:00:0a:28:fe:80:00:00:00:00:00:00:00:00:7b:e1:b1
   
   [Link]
   Name=mlx4_ib0
   ```

   This link file matches a MAC address and renames the network interface to the name set in the Name parameter.

Verification

1. Reboot the host:

   ```
   # reboot
   ```

2. Verify that the device with the MAC address you specified in the link file has been assigned to mlx4_ib0:

   ```
   ```
### 4.2. Increasing the Amount of Memory that Users Are Allowed to Pin in the System

Remote direct memory access (RDMA) operations require the pinning of physical memory. As a consequence, the kernel is not allowed to write memory into the swap space. If a user pins too much memory, the system can run out of memory, and the kernel terminates processes to free up more memory. Hence, memory pinning is a privileged operation.

If non-root users run large RDMA applications, it is necessary to increase the amount of memory these users can pin in the system. This section describes how to configure an unlimited amount of memory for the `rdma` group.

**Procedure**

- As the root user, create the file `/etc/security/limits.conf` with following contents:
  ```
  @rdma soft memlock unlimited
  @rdma hard memlock unlimited
  ```

**Verification**

1. Log in as a member of the `rdma` group after editing the `/etc/security/limits.conf` file.
   Note that Red Hat Enterprise Linux applies updated `ulimit` settings when the user logs in.

2. Use the `ulimit -l` command to display the limit:
   ```
   $ ulimit -l
   unlimited
   ```
   If the command returns `unlimited`, the user can pin an unlimited amount of memory.

**Additional resources**

- [systemd.link(5)](man) man page
- [limits.conf(5)](man) man page
4.3. ENABLING NFS OVER RDMA (NFSORDMA)

Remote direct memory access (RDMA) service works automatically on RDMA-capable hardware in Red Hat Enterprise Linux 9.

Procedure

1. Install the `rdma-core` package:

   ```sh
   # dnf install rdma-core
   ```

2. Verify the lines with `xprtdma` and `svcrdma` are commented out in the `/etc/rdma/modules/rdma.conf` file:

   ```
   # NFS over RDMA client support
   xprtdma
   # NFS over RDMA server support
   svcrdma
   ```

3. On the NFS server, create directory `/mnt/nfsordma` and export it to `/etc/exports`:

   ```sh
   # mkdir /mnt/nfsordma
   # echo "'/mnt/nfsordma *(fsid=0,rw,async,insecure,no_root_squash)" >> /etc/exports
   ```

4. On the NFS client, mount the nfs-share with server IP address, for example, `172.31.0.186`:

   ```sh
   # mount -o rdma,port=20049 172.31.0.186:/mnt/nfs-share /mnt/nfs
   ```

5. Restart the `nfs-server` service:

   ```sh
   # systemctl restart nfs-server
   ```

Additional resources

- The RFC 5667 standard
CHAPTER 5. CONFIGURING AN INFINIBAND SUBNET MANAGER

All InfiniBand networks must have a subnet manager running for the network to function. This is true even if two machines are connected directly with no switch involved.

It is possible to have more than one subnet manager. In that case, one acts as a master and another subnet manager acts as a slave that will take over in case the master subnet manager fails.

Most InfiniBand switches contain an embedded subnet manager. However, if you need a more up-to-date subnet manager or if you require more control, use the OpenSM subnet manager provided by Red Hat Enterprise Linux.

For details, see Installing the OpenSM subnet manager
CHAPTER 6. CONFIGURING IPOIB

By default, InfiniBand does not use the internet protocol (IP) for communication. However, IP over InfiniBand (IPoIB) provides an IP network emulation layer on top of InfiniBand remote direct memory access (RDMA) networks. This allows existing unmodified applications to transmit data over InfiniBand networks, but the performance is lower than if the application would use RDMA natively.

NOTE

The Mellanox devices, starting from ConnectX-4 and above, on RHEL 8 and later use Enhanced IPoIB mode by default (datagram only). Connected mode is not supported on these devices.

6.1. THE IPOIB COMMUNICATION MODES

An IPoIB device is configurable in either Datagram or Connected mode. The difference is the type of queue pair the IPoIB layer attempts to open with the machine at the other end of the communication:

- In the Datagram mode, the system opens an unreliable, disconnected queue pair. This mode does not support packages larger than Maximum Transmission Unit (MTU) of the InfiniBand link layer. During transmission of data, the IPoIB layer adds a 4-byte IPoIB header on top of the IP packet. As a result, the IPoIB MTU is 4 bytes less than the InfiniBand link-layer MTU. As 2048 is a common InfiniBand link-layer MTU, the common IPoIB device MTU in Datagram mode is 2044.

- In the Connected mode, the system opens a reliable, connected queue pair. This mode allows messages larger than the InfiniBand link-layer MTU. The host adapter handles packet segmentation and reassembly. As a result, in the Connected mode, the messages sent from InfiniBand adapters have no size limits. However, there are limited IP packets due to the data field and TCP/IP header field. For this reason, the IPoIB MTU in the Connected mode is 65520 bytes.

The Connected mode has a higher performance but consumes more kernel memory.

Though a system is configured to use the Connected mode, a system still sends multicast traffic using the Datagram mode because InfiniBand switches and fabric cannot pass multicast traffic in the Connected mode. Also, when the host is not configured to use the Connected mode, the system falls back to the Datagram mode.

While running an application that sends multicast data up to MTU on the interface, configures the interface in Datagram mode or configure the application to cap the send size of a packet that will fit in datagram-sized packets.

6.2. UNDERSTANDING IPOIB HARDWARE ADDRESSES

IPoIB devices have a 20 byte hardware address that consists of the following parts:

- The first 4 bytes are flags and queue pair numbers
- The next 8 bytes are the subnet prefix
  The default subnet prefix is Oxfe:80:00:00:00:00:00:00. After the device connects to the subnet manager, the device changes this prefix to match with the configured subnet manager.
- The last 8 bytes are the Globally Unique Identifier (GUID) of the InfiniBand port that attaches to the IPoIB device
NOTE
As the first 12 bytes can change, don’t use them in the `udev` device manager rules.

6.3. CONFIGURING AN IPOIB CONNECTION USING NMCLI COMMANDS

The `nmcli` command-line utility controls the NetworkManager and reports network status using CLI.

Prerequisites

- An InfiniBand device is installed on the server
- The corresponding kernel module is loaded

Procedure

1. Create the InfiniBand connection to use the `mlx4_ib0` interface in the `Connected` transport mode and the maximum MTU of 65520 bytes:

   ```bash
   # nmcli connection add type infiniband con-name mlx4_ib0 ifname mlx4_ib0 transport-mode Connected mtu 65520
   ```

2. You can also set 0x8002 as a P_Key interface of the `mlx4_ib0` connection:

   ```bash
   # nmcli connection modify mlx4_ib0 infiniband.p-key 0x8002
   ```

3. To configure the IPv4 settings set a static IPv4 address, network mask, default gateway, and DNS server of the `mlx4_ib0` connection:

   ```bash
   # nmcli connection modify mlx4_ib0 ipv4.addresses 192.0.2.1/24
   # nmcli connection modify mlx4_ib0 ipv4.gateway 192.0.2.254
   # nmcli connection modify mlx4_ib0 ipv4.dns 192.0.2.253
   # nmcli connection modify mlx4_ib0 ipv4.method manual
   ```

4. To configure the IPv6 settings set a static IPv6 address, network mask, default gateway, and DNS server of the `mlx4_ib0` connection:

   ```bash
   # nmcli connection modify mlx4_ib0 ipv6.addresses 2001:db8:1::1/32
   # nmcli connection modify mlx4_ib0 ipv6.gateway 2001:db8:1::ffe
   # nmcli connection modify mlx4_ib0 ipv6.dns 2001:db8:1::fff
   # nmcli connection modify mlx4_ib0 ipv6.method manual
   ```

5. To activate the `mlx4_ib0` connection:

   ```bash
   # nmcli connection up mlx4_ib0
   ```

6.4. CONFIGURING AN IPOIB CONNECTION USING NM-CONNECTION-EDITOR

The `nmcli-connection-editor` application configures and manages network connections stored by NetworkManager using GUI.
Prerequisites

- An InfiniBand device is installed on the server
- Corresponding kernel module is loaded
- The `nm-connection-editor` package is installed

Procedure

1. Enter the command:
   
   ```
   $ nm-connection-editor
   ```

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

3. Select the **InfiniBand** connection type and click **Create**.

4. On the **InfiniBand** tab:
   
   a. Change the connection name if you want to.
   
   b. Select the transport mode.
   
   c. Select the device.
   
   d. Set an MTU if needed.

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

   ![IPv4 Settings configuration](image)

   - Connection name: `mlx4_ib0`
   - Addresses:
     
     | Address    | Netmask | Gateway      |
     |------------|---------|-------------|
     | 192.0.2.1  | 24      | 192.0.2.254 |
   
   - DNS servers: `192.0.2.253`
6. On the **IPv6 Settings** tab, configure the IPv6 settings. For example, set a static IPv6 address, network mask, default gateway, and DNS server:

   ![IPv6 Settings Configuration](image)

   ![Connection Name: mlx4_ib0](image)

   ![General Settings](image)

   ![InfiniBand Settings](image)

   ![Proxy Settings](image)

   ![IPv4 Settings](image)

   ![IPv6 Settings](image)

   ![Addresses](image)

   ![DNS servers](image)

7. Click **Save** to save the team connection.

8. Close **nm-connection-editor**.

9. You can set a **P_Key** interface. As this setting is not available in **nm-connection-editor**, you must set this parameter on the command line.

   For example, to set **0x8002** as **P_Key** interface of the **mlx4_ib0** connection:

   ```
   # nmcli connection modify mlx4_ib0 infiniband.p-key 0x8002
   ```
CHAPTER 7. TESTING INFINIBAND NETWORKS

This section provides procedures how to test InfiniBand networks.

7.1. TESTING EARLY INFINIBAND RDMA OPERATIONS

This section describes how to test InfiniBand remote direct memory access (RDMA) operations.

NOTE

This section applies only to InfiniBand devices. If you use IP-based devices such as Internet Wide-area Remote Protocol (iWARP) or RDMA over Converged Ethernet (RoCE) or InfiniBand over Ethernet (IBoE) devices, see:

- Testing an IPoIB using the ping utility
- Testing an RDMA network using iperf3 after IPoIB is configured

Prerequisites

- The rdma service is configured
- The libibverbs-utils and infiniband-diags packages are installed

Procedure

1. List the available InfiniBand devices:

```bash
# ibv_devices

<table>
<thead>
<tr>
<th>device</th>
<th>node GUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>mlx4_0</td>
<td>0002c903003178f0</td>
</tr>
<tr>
<td>mlx4_1</td>
<td>f4521403007bbc0a0</td>
</tr>
</tbody>
</table>
```

2. To display the information of the mlx4_1 device:

```bash
# ibv_devinfo -d mlx4_1

hca_id: mlx4_1

transport: InfiniBand (0)
fw_ver: 2.30.8000
node_guid: f452:1403:007b:cb0
sys_image_guid: f452:1403:007b:cb0
vendor_id: 0x02c9
vendor_part_id: 4099
hw_ver: 0x0
board_id: MT_1090120019
phys_port_cnt: 2
port: 1

state: PORT_ACTIVE (4)
max_mtu: 4096 (5)
active_mtu: 2048 (4)
sm_lid: 2
```
3. To display the status of the mlx4_1 device:

```bash
# ibstat mlx4_1

CA 'mlx4_1'
  CA type: MT4099
  Number of ports: 2
  Firmware version: 2.30.8000
  Hardware version: 0
  Node GUID: 0xf4521403007bcba0
  System image GUID: 0xf4521403007bcba3
Port 1:
  State: Active
  Physical state: LinkUp
  Rate: 56
  Base lid: 2
  LMC: 1
  SM lid: 2
  Capability mask: 0x0251486a
  Port GUID: 0xf4521403007bcba1
  Link layer: InfiniBand
Port 2:
  State: Active
  Physical state: LinkUp
  Rate: 40
  Base lid: 0
  LMC: 0
  SM lid: 0
  Capability mask: 0x04010000
  Port GUID: 0xf65214fffe7bcba2
  Link layer: Ethernet
```

4. The `ibping` utility pings an InfiniBand address and runs as a client/server by configuring the parameters.

   a. To start server mode `-S` on port number `-P` with `-C` InfiniBand certificate authority (CA) name on the host:

   ```bash
   # ibping -S -C mlx4_1 -P 1
   ```

   b. To start client mode, send some packets `-c` on port number `-P` using `-C` InfiniBand certificate authority (CA) name with `-L` Local Identifier (LID) on the host:
# ibping -c 50 -C mlx4_0 -P 1 -L 2

Additional resources
- ibping(8) man page

7.2. TESTING AN IPOIB USING THE PING UTILITY

After you configured IP over InfiniBand (IPoIB), use the ping utility to send ICMP packets to test the IPoIB connection.

Prerequisites
- The two RDMA hosts are connected in the same InfiniBand fabric with RDMA ports
- The IPoIB interfaces in both hosts are configured with IP addresses within the same subnet

Procedure
- Use the ping utility to send five ICMP packets to the remote host’s InfiniBand adapter:
  # ping -c5 192.0.2.1

7.3. TESTING AN RDMA NETWORK USING IPERF3 AFTER IPOIB IS CONFIGURED

In the following example, the large buffer size is used to perform a 60 seconds test to measure maximum throughput and fully utilize the bandwidth and latency between two hosts using the iperf3 utility.

Prerequisites
- IPoIB is configured on both hosts

Procedure
1. To run iperf3 as a server on a system, define a time interval to provide periodic bandwidth updates -i to listen as a server -s that waits for the response of the client connection:
   # iperf3 -i 5 -s

2. To run iperf3 as a client on another system, define a time interval to provide periodic bandwidth updates -i to connect to the listening server -c of IP address 192.168.2.2 with -t time in seconds:
   # iperf3 -i 5 -t 60 -c 192.168.2.2

3. Use the following commands:
   a. Display test results on the system that acts as a server:
      # iperf3 -i 10 -s
Server listening on 5201

Accepted connection from 192.168.2.3, port 22216

[5] local 192.168.2.2 port 5201 connected to 192.168.2.3 port 22218

[5] Interval     Transfer    Bandwidth

[5] 0.00-10.00 sec 17.5 GBytes 15.0 Gbits/sec
[5] 10.00-20.00 sec 17.6 GBytes 15.2 Gbits/sec
[5] 20.00-30.00 sec 18.4 GBytes 15.8 Gbits/sec
[5] 30.00-40.00 sec 18.0 GBytes 15.5 Gbits/sec
[5] 40.00-50.00 sec 17.5 GBytes 15.1 Gbits/sec
[5] 50.00-60.00 sec 18.1 GBytes 15.5 Gbits/sec
[5] 60.00-60.04 sec 82.2 MBytes 17.3 Gbits/sec

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[5] Interval     Transfer    Bandwidth

[5] 0.00-60.04 sec 0.00 Bytes 0.00 bits/sec sender
[5] 0.00-60.04 sec 107 GBytes 15.3 Gbits/sec receiver

b. Display test results on the system that acts as a client:

```
# iperf3 -i 1 -t 60 -c 192.168.2.2
```

Connecting to host 192.168.2.2, port 5201

[4] local 192.168.2.3 port 22218 connected to 192.168.2.2 port 5201

[4] Interval     Transfer    Bandwidth Retr  Cwnd

[4] 0.00-10.00 sec 17.6 GBytes 15.1 Gbits/sec 0 6.01 MBytes
[4] 10.00-20.00 sec 17.6 GBytes 15.1 Gbits/sec 0 6.01 MBytes
[4] 20.00-30.00 sec 18.4 GBytes 15.8 Gbits/sec 0 6.01 MBytes
[4] 30.00-40.00 sec 18.0 GBytes 15.5 Gbits/sec 0 6.01 MBytes
[4] 40.00-50.00 sec 17.5 GBytes 15.1 Gbits/sec 0 6.01 MBytes
[4] 50.00-60.00 sec 18.1 GBytes 15.5 Gbits/sec 0 6.01 MBytes

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[4] Interval     Transfer    Bandwidth Retr

[4] 0.00-60.00 sec 107 GBytes 15.4 Gbits/sec 0 sender
[4] 0.00-60.00 sec 107 GBytes 15.4 Gbits/sec receiver

Additional resources

- iperf3 man page