RDMA over Converged Ethernet (RoCE)

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Remote Direct Memory Access (RDMA) is the remote memory management capability that allows server-to-server data movement directly between application memory without any CPU involvement. RDMA over Converged Ethernet (RoCE) is a mechanism to provide this efficient data transfer with very low latencies on lossless Ethernet networks. With advances in data center convergence over reliable Ethernet, ConnectX® Ethernet adapter cards family with RoCE uses the proven and efficient RDMA transport to provide the platform for deploying RDMA technology in mainstream data center application at 10GigE and 40GigE link-speed. ConnectX® Ethernet adapter cards family with its hardware offload support takes advantage of this efficient RDMA transport (InfiniBand) services over Ethernet to deliver ultra-low latency for performance-critical and transaction-intensive applications such as financial, database, storage, and content delivery networks.
When working with RDMA applications over Ethernet link layer the following points should be noted:

- The presence of a Subnet Manager (SM) is not required in the fabric. Thus, operations that require communication with the SM are managed in a different way in RoCE. This does not affect the API but only the actions such as joining the multicast group, that need to be taken when using the API

- Since LID is a layer 2 attribute of the InfiniBand protocol stack, it is not set for a port and is displayed as zero when querying the port

- With RoCE, the alternate path is not set for RC QP. Therefore, APM (another type of High Availability and part of the InfiniBand protocol) is not supported

- Since the SM is not present, querying a path is impossible. Therefore, the path record structure must be filled with relevant values before establishing a connection. Hence, it is recommended working with RDMA-CM to establish a connection as it takes care of filling the path record structure

- VLAN tagged Ethernet frames carry a 3-bit priority field. The value of this field is derived from the IB SL field by taking the 3 least significant bits of the SL field

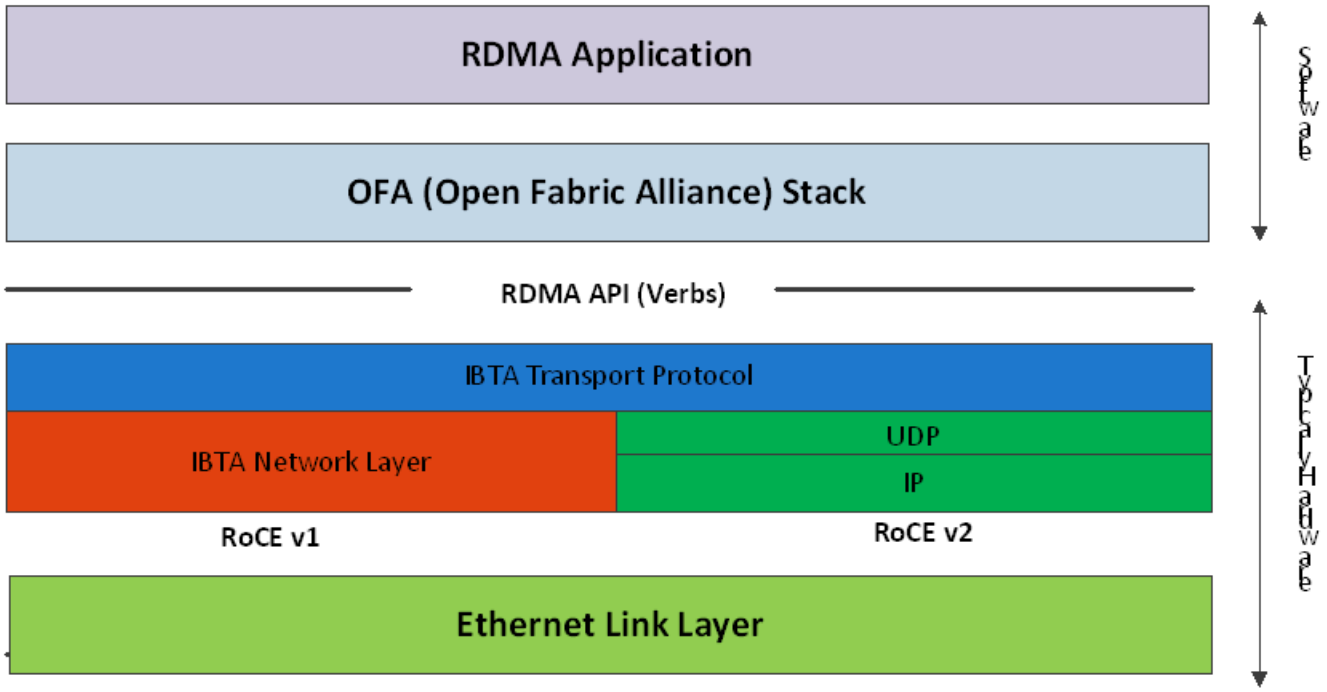
- RoCE traffic is not shown in the associated Ethernet device's counters since it is offloaded by the hardware and does not go through Ethernet network driver. RoCE traffic is counted in the same place where InfiniBand traffic is counted; /sys/class/infiniband/<device>/ports/<port number>/counters/

RoCE Modes

RoCE encapsulates IB transport in one of the following Ethernet packets:

- **RoCEv1** - dedicated ether type (0x8915)
- **RoCEv2** - UDP and dedicated UDP port (4791)

RoCEv1 and RoCEv2 Protocol Stack



RoCEv1

RoCE v1 protocol is defined as RDMA over Ethernet header (as shown in the figure above). It uses ethertype 0x8915 and can be used with or without the VLAN tag. The regular Ethernet MTU applies on the RoCE frame.

RoCEv2

A straightforward extension of the RoCE protocol enables traffic to operate in IP layer 3 environments. This capability is obtained via a simple modification of the RoCE packet format. Instead of the GRH used in RoCE, IP routable RoCE packets carry an IP header which allows traversal of IP L3 Routers and a UDP header (RoCEv2 only) that serves as a stateless encapsulation layer for the RDMA Transport Protocol Packets over IP.

The proposed RoCEv2 packets use a well-known UDP destination port value that unequivocally distinguishes the datagram. Similar to other protocols that use UDP encapsulation, the UDP source port field is used to carry an opaque flow-identifier that allows network devices to implement packet forwarding optimizations (e.g. ECMP) while staying agnostic to the specifics of the protocol header format.
Furthermore, since this change exclusively affects the packet format on the wire, and due to the fact that with RDMA semantics packets are generated and consumed below the AP, applications can seamlessly operate over any form of RDMA service, in a completely transparent way.

> **Note**
>
> Both RoCEv1 and RoCEv2 are supported by default; the driver associates all GID indexes to RoCEv1 and RoCEv2, thus, a single entry for each RoCE version.
>
> For further information, please refer to Recommended Network Configuration Examples For RoCE Deployment Community post.

GID Table Population

GID table entries are created whenever an IP address is configured on one of the Ethernet devices of the NIC's ports. Each entry in the GID table for RoCE ports has the following fields:

- GID value
- GID type
- Network device

The GID table is occupied with two GIDs, both with the same GID value but with different types. The network device in an entry is the Ethernet device with the IP address that GID

is associated with. The GID format can be of 2 types; IPv4 and IPv6. IPv4 GID is an IPv4-mapped IPv6 address, while IPv6 GID is the IPv6 address itself. Layer 3 header for packets associated with IPv4 GIDs will be IPv4 (for RoCEv2) and IPv6/GRH for packets associated with IPv6 GIDs and IPv4 GIDs for RoCEv1.

GID Table in sysfs

GID table is exposed to userspace via sysfs

- GID values can be read from:

```
/sys/class/infiniband/{device}/ports/{port}/gids/{index}
```

- GID type can be read from:

```
/sys/class/infiniband/{device}/ports/{port}/gid_attrs/types/{index}
```

- GID net_device can be read from:

```
/sys/class/infiniband/{device}/ports/{port}/gid_attrs/ndevs/{index}
```

Setting the RoCE Mode for a Queue Pair (QP)

Setting RoCE mode for devices that support two RoCE modes is different for RC/UC QPs (connected QP types) and UD QP.

To modify an RC/UC QP (connected QP) from INIT to RTR, an Address Vector (AV) must be given. The AV, among other attributes, should specify the index of the port's GID table for the source GID of the QP. The GID type in that index will be used to set the RoCE type of the QP.

Setting RoCE Mode of RDMA_CM Applications

RDMA_CM interface requires only the active side of the peer to pass the IP address of the passive side. The RDMA_CM decides upon the source GID to be used and obtains it from the GID table. Since more than one instance of the GID value is possible, the lookup

should be also according to the GID type. The type to use for the lookup is defined as a global value of the RDMA_CM module. Changing the value of the GID type for the GID table lookups is done using the cma_roce_mode script.

- ***To print the current RoCE mode for a device port:***

```
cma_roce_mode -d <dev> -p <port>
```

- ***To set the RoCE mode for a device port:***

```
cma_roce_mode -d <dev> -p <port> -m <1|2>
```

GID Table Example

The following is an example of the GID table.

DEV	PORT	INDEX	GID	IPv4	Type	Netdev
mlx5_0	1	0	fe80:0000:0000:0000:ba59:9fff:fe1a:e3ea		v1	p4p1
mlx5_0	1	1	fe80:0000:0000:0000:ba59:9fff:fe1a:e3ea		v2	p4p1
mlx5_0	1	2	0000:0000:0000:0000:0000:ffff:0a0a:0a01	10.10.10.1	v1	p4p1
mlx5_0	1	3	0000:0000:0000:0000:0000:ffff:0a0a:0a01	10.10.10.1	v2	p4p1
mlx5_1	1	0	fe80:0000:0000:0000:ba59:9fff:fe1a:e3eb		v1	p4p2
mlx5_1	1	1	fe80:0000:0000:0000:ba59:9fff:fe1a:e3eb		v2	p4p2

where:

- Entries on port 1 index 0/1 are the default GIDs, one for each supported RoCE type

- Entries on port 1 index 2/3 belong to IP address 192.168.1.70 on eth1
- Entries on port 1 index 4/5 belong to IP address 193.168.1.70 on eth1.100
- Packets from a QP that is associated with these GID indexes will have a VLAN header (VID=100)
- Entries on port 1 index 6/7 are IPv6 GID. Packets from a QP that is associated with these GID indexes will have an IPv6 header

RoCE Lossless Ethernet Configuration

In order to function reliably, RoCE requires a form of flow control. While it is possible to use global flow control, this is normally undesirable, for performance reasons.
The normal and optimal way to use RoCE is to use Priority Flow Control (PFC). To use PFC, it must be enabled on all endpoints and switches in the flow path.

Configuring SwitchX® Based Switch System

To enable RoCE, the SwitchX should be configured as follows:

- Ports facing the host should be configured as access ports, and either use global pause or Port Control Protocol (PCP) for priority flow control
- Ports facing the network should be configured as trunk ports, and use Port Control Protocol (PCP) for priority flow control
- For further information on how to configure SwitchX, please refer to SwitchX User Manual

Installing and Loading the Driver

To install and load the driver:

1. Install MLNX_OFED (See Installation section for further details).
   RoCE is installed as part of mlx5 and other modules upon driver's installation.

> **Note**
>
> The list of the modules that will be loaded automatically upon boot can be found in the configuration file /etc/infiniband/openib.conf.

2. Query for the device's information. Example:

```
ibv_devinfo MLNX_OFED_LINUX-5.0-2.1.8.0:
```

3. Display the existing MLNX_OFED version.

```
ofed_info -s
hca_id: mlx5_0
transport: InfiniBand (0)
fw_ver: 16.28.0578
node_guid: ec0d:9a03:0044:3764
sys_image_guid: ec0d:9a03:0044:3764
vendor_id: 0x02c9
vendor_part_id: 4121
hw_ver: 0x0
board_id: MT_0000000009
phys_port_cnt: 1
port: 1
state: PORT_ACTIVE (4)
max_mtu: 4096 (5)
active_mtu: 1024 (3)
sm_lid: 0
port_lid: 0
port_lmc: 0x00
link_layer: Ethernet
```

Output Notes:

The port's state is: Ethernet is in PORT_ACTIVE state	The port state can also be obtained by running the following command: # cat /sys/class/infiniband/mlx5_0/ports/1/state 4: ACTIVE
link_layer parameter shows that port 1 is Ethernet	The link_layer can also be obtained by running the following command: # cat /sys/class/infiniband/mlx5_0/ports/1/link_layer Ethernet
The fw_ver parameter shows that the firmware version is 16.28.0578.	The firmware version can also be obtained by running the following command: # cat /sys/class/infiniband/mlx5_0/fw_ver 16.28.0578

Associating InfiniBand Ports to Ethernet Ports

The mlx5_ib driver holds a reference to the net device for getting notifications about the state of the port, as well as using the mlx5_core driver to resolve IP addresses to MAC that are required for address vector creation. However, RoCE traffic does not go through the mlx5_core driver; it is completely offloaded by the hardware.

```
# ibdev2netdev
mlx5_0 port 1 <===> eth2
#
```

Configuring an IP Address to the netdev Interface

To configure an IP address to the netdev interface:

1. Configure an IP address to the netdev interface on both sides of the link.

```
# ifconfig eth2 20.4.3.220
```

```
# ifconfig eth2
eth2 Link encap:Ethernet HWaddr 00:02:C9:08:E8:11
inet addr:20.4.3.220 Bcast:20.255.255.255 Mask:255.0.0.0
UP BROADCAST MULTICAST MTU:1500 Metric:1
RX packets:0 errors:0 dropped:0 overruns:0 frame:0
TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
collisions:0 txqueuelen:1000
RX bytes:0 (0.0 b) TX bytes:0 (0.0 b)
```

2. Make sure that ping is working.

```
ping 20.4.3.219
PING 20.4.3.219 (20.4.3.219) 56(84) bytes of data.
64 bytes from 20.4.3.219: icmp_seq=1 ttl=64 time=0.873 ms
64 bytes from 20.4.3.219: icmp_seq=2 ttl=64 time=0.198 ms
64 bytes from 20.4.3.219: icmp_seq=3 ttl=64 time=0.167 ms
20.4.3.219 ping statistics —
3 packets transmitted, 3 received, 0% packet loss, time 2000ms rtt
min/avg/max/mdev = 0.167/0.412/0.873/0.326 ms
```

Adding VLANs

To add VLANs:

1. Make sure that the 8021.q module is loaded.

```
modprobe 8021q
```

2. Add VLAN.

```
# vconfig add eth2 7
Added VLAN with VID == 7 to IF -:eth2:-
#
```

3. Configure an IP address.

```
ifconfig eth2.7 7.4.3.220
```

Defining Ethernet Priority (PCP in 802.1q Headers)

1. Define Ethernet priority on the server.

```
# ibv_rc_pingpong -g 1 -i 2 -l 4
local address: LID 0x0000, QPN 0x1c004f, PSN 0x9daf6c, GID
fe80::202:c900:708:e799
remote address: LID 0x0000, QPN 0x1c004f, PSN 0xb0a49b, GID
fe80::202:c900:708:e811
8192000 bytes in 0.01 seconds = 4840.89 Mbit/sec
1000 iters in 0.01 seconds = 13.54 usec/iter
```

2. Define Ethernet priority on the client.

```
# ibv_rc_pingpong -g 1 -i 2 -l 4 sw419
local address: LID 0x0000, QPN 0x1c004f, PSN 0xb0a49b, GID
fe80::202:c900:708:e811
remote address: LID 0x0000, QPN 0x1c004f, PSN 0x9daf6c, GID
fe80::202:c900:708:e799
8192000 bytes in 0.01 seconds = 4855.96 Mbit/sec
1000 iters in 0.01 seconds = 13.50 usec/iter
```

Using rdma_cm Tests

1. Use rdma_cm test on the server.

```
# ucmatose
```

```
cmatose: starting server
initiating data transfers
completing sends
receiving data transfers
data transfers complete
cmatose: disconnecting
disconnected
test complete
return status 0
#
```

2. Use rdma_cm test on the client.

```
# ucmatose -s 20.4.3.219
cmatose: starting client
cmatose: connecting
receiving data transfers
sending replies
data transfers complete
test complete
return status 0
#
```

This server-client run is without PCP or VLAN because the IP address used does not belong to a VLAN interface. If you specify a VLAN IP address, then the traffic should go over VLAN.

Type Of Service (ToS)

Overview

The TOS field for rdma_cm sockets can be set using the rdma_set_option() API, just as it is set for regular sockets. If a TOS is not set, the default value (0) is used. Within the

rdma_cm kernel driver, the TOS field is converted into an SL field. The conversion formula is as follows:

- SL = TOS >> 5 (e.g., take the 3 most significant bits of the TOS field)

In the hardware driver, the SL field is converted into PCP by the following formula:

- PCP = SL & 7 (take the 3 least significant bits of the TOS field)

> **Note**
>
> SL affects the PCP only when the traffic goes over tagged VLAN frames.

DSCP

A new entry has been added to the RDMA-CM configfs that allows users to select default TOS for RDMA-CM QPs. This is useful for users that want to control the TOS field without changing their code. Other applications that set the TOS explicitly using the rdma_set_option API will continue to work as expected to override the configfs value. For further information about DSCP marking, refer to HowTo Set Egress ToS/DSCP on RDMA CM QPs Community post.

RoCE LAG

RoCE LAG is a feature meant for mimicking Ethernet bonding for IB devices and is available for dual port cards only.
This feature is supported on kernel versions 4.9 and above.

RoCE LAG mode is entered when both Ethernet interfaces are configured as a bond in one of the following modes:

- active-backup (mode 1)
- balance-xor (mode 2)
- 802.3ad (LACP) (mode 4)

Any change of bonding configuration that negates one of the above rules (i.e, bonding mode is not 1, 2 or 4, or both Ethernet interfaces that belong to the same card are not the only slaves
of the bond interface), will result in exiting RoCE LAG mode and the return to normal IB device per port configuration.
Once RoCE LAG is enabled, instead of having two IB devices; mlx5_0 and mlx5_1, there will be one device named mlx5_bond_0.
For information on how to configure RoCE LAG, refer to HowTo Configure RoCE over LAG (ConnectX-4/ConnectX-5/ConnectX-6) Community post.

Disabling RoCE

By default, RoCE is enabled on all mlx5 devices. When RoCE is enabled, all traffic to UDP port 4791 is treated as RoCE traffic by the device.

In case you are only interested in Ethernet (no RDMA) and wish to enable forwarding of traffic to this port, you can disable RoCE through sysfs:

```
echo <0|1> > /sys/devices/{pci-bus-address}/roce_enable
```

Note

Once RoCE is disabled, only Ethernet traffic will be supported.
Therefore, there will be no GID tables and only Raw Ethernet QPs will be supported.

The current RoCE state can be queried by sysfs:

```
cat /sys/devices/{pci-bus-address}/roce_enable
```

Enabling/Disabling RoCE on VMs via VFs

By default, when configuring VFs on the hypervisor, all VFs will be enabled with RoCE. This means they require more OS memory (from the VM). In case you are only interested in Ethernet (no RDMA) on the VM, and you wish to save the VM memory, you can disable RoCE on the VF from the hypervisor. In addition, by disabling RoCE, a VM can have the capability of utilizing the RoCE UDP port (4791) for standard UDP traffic.

For details on how to enable/disable RoCE on a VF, refer to HowTo Enable/Disable RoCE on VMs via VFs Community post.

Force DSCP

This feature enables setting a global traffic_class value for all RC QPs, or setting a specific traffic class based on several matching criteria.

Usage

- To set a single global traffic class to be applied to all QPs, write the desired global traffic_class value to /sys/class/infiniband/<dev>/tc/<port>/traffic_class.
  Note the following:
  - Negative values indicate that the feature is disabled. traffic_class value can be set using ibv_modify_qp()
  - Valid values range between 0 - 255

> **Note**
>
> The ToS field is 8 bits, while the DSCP field is 6 bits. To set a DSCP value of X, you need to multiply this value by 4 (SHIFT 2). For example, to set DSCP value of 24, set the ToS bit to 96 (24x4=96).

- To set multiple traffic class values based on source and/or destination IPs, write the desired rule to /sys/class/infiniband/<dev>/tc/<port>/traffic_class. For example:

```
echo "tclass=16,src_ip=1.1.1.2,dst_ip=1.1.1.0/24" >
/sys/class/infiniband/mlx5_0/tc/1/traffic_class
```

Note: Adding "tclass" prefix to tclass value is optional.

In the example above, traffic class 16 will be set to any QP with source IP 1.1.1.2 and destination IP 1.1.1.0/24.
Note that when setting a specific traffic class, the following rule precedence will apply:

- If a global traffic class value is set, it will be applied to all QPs
- If no global traffic class value is set, and there is a rule with matching source and destination IPs applicable to at least one QP, it will be applied
- Rules only with matching source and/or destination IPs have no defined precedence over other rules with matching source and/or destination IPs

Notes:

- A mask can be provided when using destination IPv4 addresses
- The rule precedence is not affected by the order in which rules are inserted
- Overlapping rules are entirely up to the administrator.
- "tclass=-1" will remove the rule from the database

Force Time to Live (TTL)

This feature enables setting a global TTL value for all RC QPs.
Write the desired TTL value to /sys/class/infiniband/<dev>/tc/<port>/ttl. Valid values range between 0 - 255