Mellanox ScalableSHMEM User Manual

Rev 2.1

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Mellanox Technologies
350 Oakmead Parkway Suite 100
Sunnyvale, CA 94085
U.S.A.
www.mellanox.com
Tel: (408) 970-3400
Fax: (408) 970-3403

Mellanox Technologies, Ltd.
Beit Mellanox
PO Box 586
Yokneam 20692
Israel
Tel: +972-4-909-7200 /
+972-74-723-7200
Fax: +972-4-959-3245

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1 Shared Memory Access Overview

The Shared Memory Access (SHMEM) routines provide low-latency, high-bandwidth communication for use in highly parallel scalable programs. The routines in the SHMEM Application Programming Interface (API) provide a programming model for exchanging data between cooperating parallel processes. The SHMEM API can be used either alone or in combination with MPI routines in the same parallel program.

The SHMEM parallel programming library is an easy-to-use programming model which uses highly efficient one-sided communication APIs to provide an intuitive global-view interface to shared or distributed memory systems. SHMEM's capabilities provide an excellent low level interface for PGAS applications.

A SHMEM program is of a single program, multiple data (SPMD) style. All the SHMEM processes, referred as processing elements (PEs), start simultaneously and run the same program. Commonly, the PEs perform computation on their own sub-domains of the larger problem, and periodically communicate with other PEs to exchange information on which the next communication phase depends.

The SHMEM routines minimize the overhead associated with data transfer requests, maximize bandwidth, and minimize data latency (the period of time that starts when a PE initiates a transfer of data and ends when a PE can use the data).

SHMEM routines support remote data transfer through:

- "put" operations - data transfer to a different PE
- "get" operations - data transfer from a different PE, and remote pointers, allowing direct references to data objects owned by another PE

Additional supported operations are collective broadcast and reduction, barrier synchronization, and atomic memory operations. An atomic memory operation is an atomic read-and-update operation, such as a fetch-and-increment, on a remote or local data object.

SHMEM libraries implement active messaging. The sending of data involves only one CPU where the source processor puts the data into the memory of the destination processor. Likewise, a processor can read data from another processor's memory without interrupting the remote CPU. The remote processor is unaware that its memory has been read or written unless the programmer implements a mechanism to accomplish this.

1.1 Mellanox ScalableSHMEM

The ScalableSHMEM programming library is a one-side communications library that supports a unique set of parallel programming features including point-to-point and collective routines, synchronizations, atomic operations, and a shared memory paradigm used between the processes of a parallel programming application.

Mellanox ScalableSHMEM is based on the API defined by the OpenSHMEM.org consortium. The library works with the OpenFabrics RDMA for Linux stack (OFED), and also has the ability to uti-

lize MellanoX Messaging libraries (MXM) as well as Mellanox Fabric Collective Accelerations (FCA), providing an unprecedented level of scalability for SHMEM programs running over InfiniBand.

The latest ScalableSHMEM software can be downloaded from the Mellanox website.

1.2 ScalableSHMEM Supported Platforms and Operating Systems

- Platforms:
  - x86_64
- Operating Systems:
  - RHEL 5.5; 5.6; 5.7; 6.0; 6.1; 6.2
  - SLES10 SP4; SLES11 SP1
- OFED:
  - MLNX_OFED 1.5.3-3.0.0 or higher

The following packages must me installed separately on all cluster nodes when using MLNX_OFED 1.5.3-3.0.0:

- Mellanox MXM
- Mellanox FCA
- KNEM

  KMEM is a Linux module enabling high-performance intra-node SHMEM communication for large messages. KNEM is not started automatically after the installation process. To start it manually, run as root "`modprobe knem`".

  For information on how to starts KNEM automatically after system boot, please refer to KNEM documentation.

Mellanox OFED 1.8 includes all the packages above, which are installed under:
- MXM: /opt/mellanox/mxm
- FCA: /opt/mellanox/fca
- KNEM: /opt/knem-0.9.7mlnx1

If you have installed OFED 1.8, you do *not* need to download and install them.

2 Installing and Configuring ScalableSHMEM

2.1 Installing ScalableSHMEM

MLNX_OFED v1.8 includes ScalableSHMEM 2.1 which is installed under: `/opt/mellanox/openshmem/2.1.`
If you have installed OFED 1.8, you do *not* need to download and install ScalableSHMEM.

The ScalableSHMEM package is an .rpm file and should be installed on all cluster nodes. It is built to support the SLURM job scheduler by utilizing a PMI API.

The procedure below is required only if you have installed MLNX_OFED 1.5.3.-3.0.0.
If you have installed OFED 1.8, you do *not* need to download and install ScalableSHMEM.

» ***To install ScalableSHMEM, perform the following steps:***

1. Login as root. Run:

```
# rpm -ihv openshmem-2.1-20624.x86_64.rpm --nodeps
```

2. Update the OPENIB kernel parameter in the `/etc/modprobe.conf` file on all cluster nodes.

```
# echo "options mlx4_core log_num_mtt=24" >> /etc/modprobe.conf
```

3. Restart the openibd driver.

```
# /etc/init.d/openibd restart
```

2.2 Compiling ScalableSHMEM Application

The ScalableSHMEM package contains a `shmemcc` utility which is used as a compiler command.

» ***To compile ScalableSHMEM application:***

1. Save the code example below as a file called "`example.c`".

```
#include <stdio.h>
#include <stdlib.h>
#include <shmem.h>

int main(int argc, char **argv)
{

    int my_pe, num_pe;
    shmem_init();

    my_pe = my_pe();
    num_pe = num_pes();

    printf("Hello World from process %d of %d\n", my_pe, num_pes);
    exit(0);
}
```

2. Compile the example with the SHMEM C wrapper compiler.

```
% /opt/mellanox/openshmem/2.1/bin/shmemcc -o example.exe example.c
```

2.3 Running ScalableSHMEM Application

The ScalableSHMEM framework contains the `shmemrun` utility which launches the executable from a service node to compute nodes. This utility accepts the same command line parameters as `mpirun` from the OpenMPI package.

For further information, please refer to OpenMPI MCA parameters documentation at:

http://www.open-mpi.org/faq/?category=running.

Run "`shmemrun --help`" to obtain ScalableSHMEM job launcher runtime parameters.

ScalableSHMEM contains support for environment module system (http://modules.sf.net/). The modules configuration file can be found at: `/opt/mellanox/openshmem/2.1/etc/shmem_modulefile`

2.3.1 Basic ScalableSHMEM Job Run Example

» ***To launch ScalableSHMEM application, run:***

```
% /opt/mellanox/openshmem/2.1/bin/shmemrun -np 2 -mca mpi_paffinity_alone 1 -bynode -display-
map -hostfile myhostfile /opt/mellanox/openshmem/2.1/bin/shmem_osu_latency
```

The example above shows how to run 2 copies of `shmem_osu_latency` program on hosts specified in the '`myhostfile`' file.

ScalableSHMEM package is compiled with SLURM support. However, if you do not use SLURM job scheduler on your system, you can disable it for SHMEM job as following:

```
% /opt/mellanox/openshmem/2.1/bin/shmemrun -np 2 -mca grpcomm ^pmi -mca pubsub ^pmi -mca ess
^pmi /opt/mellanox/openshmem/2.1/bin/shmem_osu_latency
```

2.4 ScalableSHMEM Tunable Parameters

ScalableSHMEM uses Modular Component Architecture (MCA) parameters to provide a way to tune your runtime environment. Each parameter corresponds to a specific function. The following are parameters that you can change their values to change the application's the function:

- memheap - controls memory allocation policy and thresholds
- scoll - controls ScalableSHMEM collective API threshold and algorithms
- spml - controls ScalableSHMEM point-to-point transport logic and thresholds
- atomic - controls ScalableSHMEM atomic operations logic and thresholds
- shmem - controls general ScalableSHMEM API behavior

» To display ScalableSHMEM parameters:

1. Print all available parameters.Run:

```
/opt/mellanox/openshmem/2.1/bin/shmem_info -a
```

2. Print ScalableSHMEM specific parameters. Run:

```
/opt/mellanox/openshmem/2.1/bin/shmem_info --param shmem all
/opt/mellanox/openshmem/2.1/bin/shmem_info --param memheap all
/opt/mellanox/openshmem/2.1/bin/shmem_info --param scoll all
/opt/mellanox/openshmem/2.1/bin/shmem_info --param spml all
/opt/mellanox/openshmem/2.1/bin/shmem_info --param atomic all
```

2.5 Running ScalableSHMEM with MXM

MellanoX Messaging (MXM) library provides enhancements to parallel communication libraries by fully utilizing the underlying networking infrastructure provided by Mellanox HCA/switch hardware. This includes a variety of enhancements that take advantage of Mellanox networking hardware including:

- Multiple transport support including RC, XRC and UD
- Proper management of HCA resources and memory structures
- Efficient memory registration
- One-sided communication semantics
- Connection management
- Receive side tag matching
- Intra-node shared memory communication

These enhancements significantly increase the scalability and performance of message communications in the network, alleviating bottlenecks within the parallel communication libraries

2.5.1 Enabling MXM for ScalableSHMEM Jobs

MXM is activated automatically in ScalabeSHMEM for jobs with Number of Elements (PE) higher or equal to 128.

» ***To enable MXM for SHMEM jobs for any PE:***

- Add the following MCA parameter to the `shmemrun` command line:

```
-mca spml_ikrit_np <number>
```

For additional MXM tuning information, please refer to the MellanoX Messaging Library README file found in the Mellanox website.

2.6 Running ScalableSHMEM with FCA

The Mellanox Fabric Collective Accelerator (FCA) is a unique solution for offloading collective operations from the Message Passing Interface (MPI) or ScalableSHMEM process onto Mellanox InfiniBand managed switch CPUs. As a system-wide solution, FCA utilizes intelligence on Mellanox InfiniBand switches, Unified Fabric Manager and MPI nodes without requiring additional hardware. The FCA manager creates a topology based collective tree, and orchestrates an efficient collective operation using the switch-based CPUs on the MPI/ScalableSHMEM nodes.

FCA accelerates MPI/ScalableSHMEM collective operation performance by up to 100 times providing a reduction in the overall job runtime. Implementation is simple and transparent during the job runtime.

FCA is disabled by default and *must* be configured prior to using it from the ScalableSHMEM.

» ***To enable FCA by default in the ScalableSHMEM***

1. Edit the `/opt/mellanox/openshmem/2.1/etc/openmpi-mca-params.conf` file.
2. Set the `scoll_fca_enable` parameter to `1`.

```
scoll_fca_enable=1
```

» ***To enable FCA in the*** `shmemrun` ***command line, add the following***

```
-mca scoll_fca_enable=1
```

» ***To disable FCA:***

```
-mca scoll_fca_enable 0 -mca coll_fca_enable 0
```

For more details on FCA installation and configuration, please refer to the FCA User Manual found in the Mellanox website.

2.7 Configuring ScalableSHMEM with External Profiling Tools (TAU)

ScalableSHMEM supports external Tuning and Profiling tool TAU.

For further information, please refer to http://www.cs.uoregon.edu/Research/tau/home.php

2.7.1 Using TAU with OpenSHMEM

2.7.1.1 Building a PDT Toolkit

1. Download the PDT Toolkit.

```
wget -nc http://tau.uoregon.edu/pdt_releases/pdtoolkit-3.17.tar.gz
tar -xzf pdtoolkit-3.17.tar.gz
```

2. Configure and build the PDT toolkit..

```
cd pdtoolkit-3.17
PDT_INST=$PWD
./configure --prefix=/usr/local
make install
```

2.7.1.2 Building a TAU Toolkit

1. Download the TAU Toolkit..

```
wget -nc http://www.cs.uoregon.edu/research/paracomp/tau/tauprofile/dist/tau_latest.tar.gz
tar -xzf tau_latest.tar.gz
```

2. Configure and build the TAU toolkit..

```
cd tau-latest
TAU_SRC=$PWD
patch -p1 -i /opt/mellanox/openshmem/2.1/share/openshmem/tau_openshmem.patch
OSHMEM_INST=/opt/mellanox/openshmem/2.1
TAU_INST=$TAU_SRC/install
./configure -prefix=$TAU_INST -shmem -tag=oshmem -cc=gcc -pdt=$PDT_INST -PROFILEPARAM -use-
ropt="-I$OSHMEM_INST/include/mpp" -shmemlib=$OSHMEM_INST/lib -shmemlibrary="-lshmem -lpmi"
make install
```

The patch is required to define a profiling API that is not part of an official openshmem.org standard.

Appendix A: Performance Optimization

A.1 Configuring Hugepages

Hugepages is a feature applicable to users using MLNX_OFED v1.5.3-3.0.0.

Hugepages can be allocated using the `/proc/sys/vm/nr_hugepages` entry, or by using the sysctl command.

» ***To view the current setting using the /proc entry:***

```
cat /proc/sys/vm/nr_hugepages
0
```

» ***To view the current setting using the sysctl command:***

```
sysctl vm.nr_hugepages
vm.nr_hugepages = 0
```

» ***To set the number of huge pages using /proc entry:***

```
echo 1024 > /proc/sys/vm/nr_hugepages
```

» ***To set the number of hugepages using sysctl :man***

```
sysctl -w vm.nr_hugepages=1024
vm.nr_hugepages = 1024
```

To allocate all the hugepages needed, you might need to reboot your system since the hugepages requires large areas of contiguous physical memory.

In time, physical memory may be mapped and allocated to pages, thus the physical memory can become fragmented. If the hugepages are allocated early in the boot process, fragmentation is unlikely to have occurred.

It is recommended that the `/etc/sysctl.conf` file be used to allocate hugepages at boot time.

For example, to allocate 1024 hugepages at boot time, add the line below to the sysctl.conf file:

```
vm.nr_hugepages = 1024
```

A.2 Tuning MTU Size to the Recommended Value

The procedures described below apply to user using MLNX_OFED 1.5.3.-3.0.0 only.

When using MLNX_OFED 1.5.3-3.0.0, it is recommended to change the MTU to 4k. Whereas in MLNX_OFED 1.8 the MTU is already set by default to 4k.

» ***To check the current MTU support of an InfiniBand port, use the smpquery tool:***

```
# smpquery -D PortInfo 0 1 | grep -i mtu
```

If the MtuCap value is lower than 4K, enable it to 4K.

Assuming the firmware is configured to support 4K MTU, the actual MTU capability is further limited by the mlx4 driver parameter.

» ***To further tune it:***

1. Set the `set_4k_mtu` mlx4 driver parameter to 1 on all the cluster machines. For instance:

```
# echo "options mlx4_core set_4k_mtu=1" >> /etc/modprobe.d/mofed.conf
```

2. Restart openibd by running the following command:

```
# service openibd restart
```

» ***To check whether the parameter was accepted, run:***

```
# cat /sys/module/mlx4_core/parameters/set_4k_mtu
```

To check whether the port was brought up with 4K MTU this time, use the smpquery tool again.

A.3 HPC Applications on Intel Sandy Bridge Machines

This section applies to user using MLNX_OFED 1.8 only.

Intel Sandy Bridge machines have NUMA hardware related limitation which affects performance of HPC jobs utilizing all node sockets. When installing MLNX_OFED 1.8, an automatic work-around is activated upon Sandy Bridge machine detection, and the following message is printed in the job`s standard output device: "`mlx4: Sandy Bridge CPU was detected`"

» ***To disable MOFED 1.8 Sandy Bridge NUMA related workaround:***

- Set the SHELL environment variable before launching HPC application. Run:

```
% export MLX4_STALL_CQ_POLL=0
% shmemrun <...>
```

or

```
shmemrun -x MLX4_STALL_CQ_POLL=0 <other params>
```