URDMA: RDMA VERBS OVER DPDK

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EXISTING SOFTWARE RDMA DRIVERS

- **softiwp and rxe**
  - Implement iWARP over TCP and RoCEv2, respectively
  - Data transfer in kernel space
  - Run unmodified verbs applications
  - Designed with performance in mind

- **libfabric sockets provider**
  - Implements private protocol
  - Userspace implementation using TCP/IP sockets
  - Cannot run verbs applications
  - High performance explicitly not a goal
SOFTWARE VERBS DRIVERS: KERNEL VS. USER SPACE

Why not implement a verbs driver using sockets API from userspace?

- **Userspace verbs API design choices**
  - Verbs will not load a userspace driver without a corresponding uverbs device exposed by the kernel
  - Connection management deferred to kernel by librdmacm
  - CQ events delivered from kernel

- **Using userspace sockets API requires both userspace and kernel involvement**

- **Using kernel sockets API**
  - Incoming RDMA READ and RDMA WRITE can be handled entirely in kernel without waking user thread
  - Can use tricks like sendpage() to send TCP segments with zero-copy

- **Path of least resistance has been implementation using sockets API in kernel**
Goals
• Prototype software RDMA driver with data transfer entirely in userspace
• Run unmodified verbs applications
• High performance

Why a userspace implementation?
• Ease of development, makes it easy to use as a development vehicle for new RDMA features
• Avoid context switches between kernel and userspace (especially for small SENDs)

Implementation uses DPDK (Data Plane Development Kit)
**BACKGROUND: DPDK (DATA PLANE DEVELOPMENT KIT)**

- DPDK leverages Linux UIO/VFIO to map Ethernet NICs into userspace

- **Features:**
  - Bulk packet transmit/receive to/from hardware NIC queues
  - NUMA-aware memory buffer pool allocation using hugepages
  - High performance multi-core data structures
  - Hardware packet filtering
  - TCP/UDP offloads, including checksum calculation

- **Does not provide:**
  - RDMA functionality
  - Network-layer or transport-layer protocol logic

- **Using DPDK for userspace RDMA verbs eliminates kernel from data transfer path**
RDMA SEND/RECV MESSAGE TRANSFER

Sender Virtual Address Space

- Send WR
- Memory Region
- Send WQE
- Sender HCA
- iWARP Headers
- Data
- ibv_post_send() arrow

Receiver Virtual Address Space

- Receive WR
- Memory Region
- Receive WQE
- Receiver HCA
- Receiver HCA
- Data
- ibv_post_recv() arrow
DPDK PACKET TRANSFER

Sender Virtual Address Space

Packet Buffer
Eth/TCP/IP Hdrs
Data

rte_eth_tx_burst()

Send Descriptor

Sender NIC

Receiver Virtual Address Space

Packet Buffer
Eth/TCP/IP Hdrs
Data

rte_eth_rx_burst()

Receive Descriptor

Receiver NIC

Eth/TCP/IP Hdrs
Data
BACKGROUND: DPDK THREAD MODEL

DPDK process consists of threads called “logical cores” or “lcores”

- DPDK creates 1 “lcore” thread per CPU core by default
- Thread which initializes DPDK is “master” lcore
- CPU affinity of each thread, including master, is set to run on a specific CPU core
- API allows launching tasks on other logical cores
- DPDK API expected to be called from lcores, in particular ring queues and memory pools rely on this
- We tell DPDK *not* to create lcores other than the master lcore
**BACKGROUND: DPDK THREADS AND LIBRARIES**

DPDK is more of an application framework than a library

- **DPDK initialization function**
  - Takes command-line arguments
  - Consumes all available hugepages by default
  - Changes CPU affinity of calling thread

- **To use DPDK from library, we create a thread and call DPDK initialization from there**
  - Pass parameter to not create further lcores
  - Separate DPDK thread from user threads
  - We do not affect CPU affinity of user threads

```c
main()
pthread_create()
```

Master Icore
**BACKGROUND: DPDK KNI**

- **KNI (Kernel Network Interface)**
  - Creates a virtual network interface in the kernel
  - Loosely associated with a DPDK Ethernet hardware NIC
  - Can exchange packets between kernel and userspace
  - Useful for small interactions between kernel service and DPDK application
URDMA: DESIGN

- Implements iWARP DDP and RDMAP protocols
- Runs over UDP transport protocol
  - TRP (Trivial Reliability Protocol) provides a thin shim for reliability
  - Simplifies implementation considerably
- Small kernel component
  - Required for libibverbs initialization, RDMA CM, and CQ events
  - Performs connection establishment before ceding control of UDP “connection” to liburdma
  - Uses KNI to send/receive packets to/from userspace
- Packet processing done in background thread
  - Ensure quick response to RDMA packets and KNI events
- Hardware receive filter used to assign queue pairs to NIC receive queues
URDMA: MULTI-PROCESS SUPPORT

- DPDK maps Ethernet NIC hardware into userspace → owned by that process
  - Can delegate to secondary processes that explicitly cooperate
  - DPDK considers primary + secondary processes as one combined application
  - DPDK threads in combined application cannot share the same lcore identifier

- In urdma, primary process is a user daemon urdmad
  - Initializes DPDK
  - Registers secondary processes with separate core mask
  - Assigns Ethernet NIC hardware RX/TX queues to urdma processes
  - Sets up Ethernet NIC hardware filtering rules

- liburdma verbs provider
  - Sets up process as secondary DPDK process
  - DPDK “master” lcore acts as background progress thread

- Each liburdma process has direct access to its Ethernet NIC hardware queues
URDMA: COMPONENTS

Legend:
- urdma
  Verbs-related
- DPDK-related

App
- librdmacm
- libibverbs
- liburdma
- uverbs
- urdma
- KNI
- DPDK
- VFIO
- Userspace
- Kernel space
URDMA CONNECTION ESTABLISHMENT

- Connection establishment done in kernel space
- In userspace:
  - Each queue pair must be assigned a Ethernet NIC hardware send and receive queue
  - Hardware receive filtering rules must be assigned before first packet arrives
  - Private character device used to communicate connection establishment

```
app
Create QP

liburmdma
Assign TX/RX queue
ibv_cmd_create_qp()

urmdad
QP connected
QP Ready to recv

RDMA CM Established Event

kernel
rdma_cm
uverbs
urmda

RDMA Connect/Accept
```
URDMA DATA TRANSFER

Send WR

ibv_post_send()

ring enqueue

Send WQE

ring dequeue

Work

ring enqueue

Send CQE

ring dequeue

Send WC

User thread

URDMA Progress Thread
(DPDK master lcore)

User thread

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PERFORMANCE
**PERFORMANCE: OVERVIEW**

- **Two identical systems:**
  - Supermicro SYS-6028R-T
  - 2 Intel Xeon ES-2630 v4 CPU @ 2.20GHz
  - 64 GB DDR4 RAM
  - PCIe generation 3
  - Ubuntu 16.10 with inbox 4.8 kernel
  - Intel XL710 40GbE NIC
  - Verbs and RDMA CM as supplied with Ubuntu 16.10

- **Applications used**
  - perftest version 3.0+0.18.gb464d59-1
  - UNH EXS (Extended Sockets) 1.4.1 ([https://www.iol.unh.edu/expertise/unh-exs](https://www.iol.unh.edu/expertise/unh-exs))
RAW VERBS: LATENCY

urdma

softiwarp
RAW VERBS: THROUGHPUT

urdma

softiwp
UNH EXS: THROUGHPUT

urdma

softiwar
CONCLUSION
ERDMA SUMMARY

- Existing software RDMA implementations done in kernel space
- DPDK allows us to implement RDMA verbs data transfer in userspace
  - Eliminates all kernel involvement in data transfer path
  - Small kernel module for connection management
- Runs unmodified verbs applications
- Designed with performance in mind
  - Good small message latency
  - Needs tuning for throughput
- Future work
  - Investigate zero-copy transmit support
  - libfabric provider implementation
  - Reliable datagram support
URDMA DOWNLOAD AND STATUS

- urdma development done on GitHub
  - [https://github.com/zrlio/urdma](https://github.com/zrlio/urdma)
- No formal release as of yet
- Not integrated into rdma-core
- Tested on Ubuntu 16.10 and DPDK 16.07
THANK YOU

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BACKUP
RAW VERBS: THROUGHPUT VS. HARDWARE RNIC

urdma on Intel XL710

Chelsio T580-LP-CR iWARP

Throughput (Mbps)

Message size

Throughput (Mbps)

Message size
RAW VERBS: LATENCY VS. HARDWARE RNIC

urdma on Intel XL710

Chelsio T580-LP-CR iWARP