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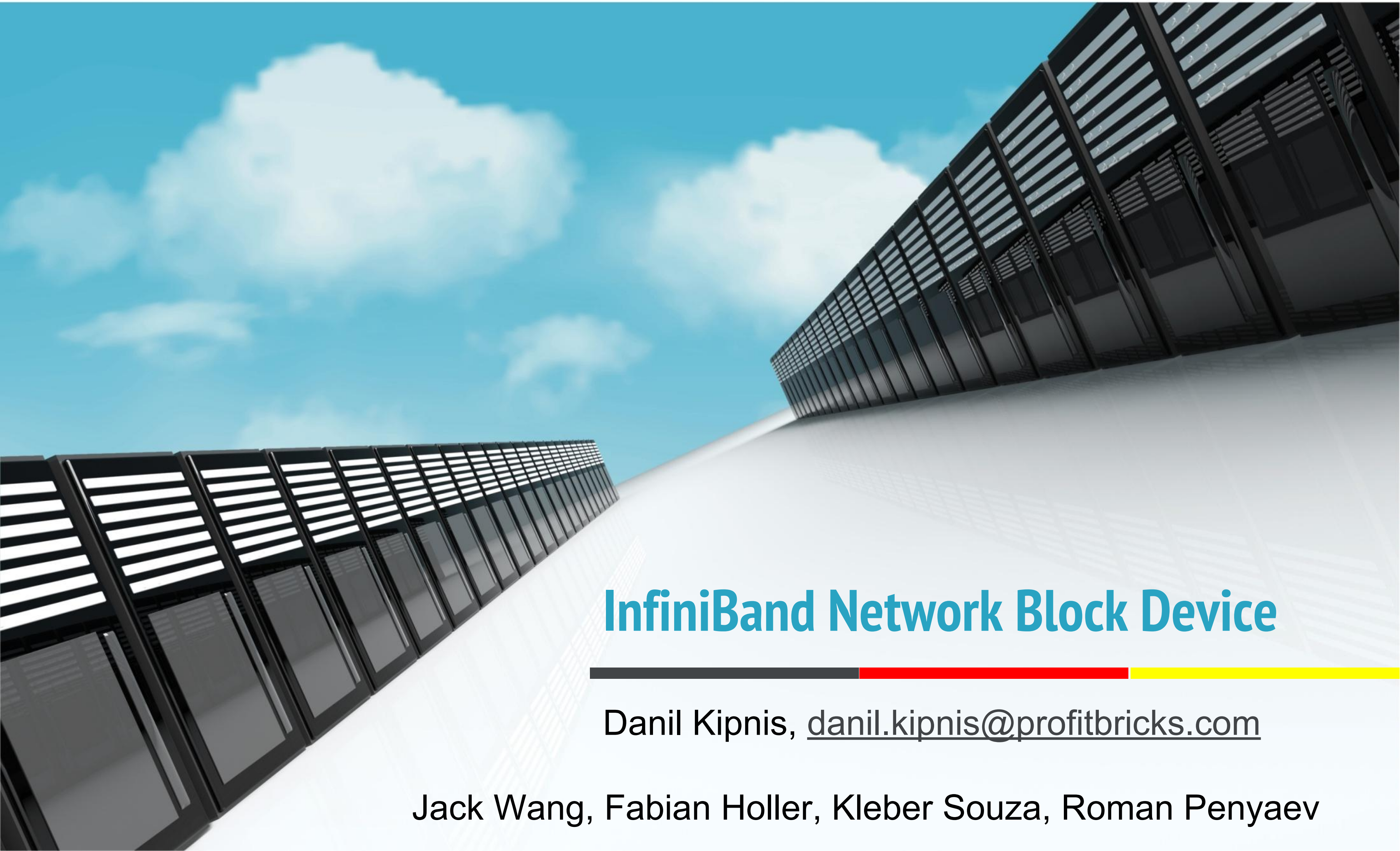


InfiniBand Network Block Device

Danil Kipnis, danil.kipnis@profitbricks.com

Jack Wang, Fabian Holler, Kleber Souza, Roman Penyaev

Overview

- IBNBD: InfiniBand Network Block device
- Transfer block IO using InfiniBand RDMA
- Map a remote block device and access it locally
- Client side
  - registers as a block device, i.e. `/dev/ibnbd0`
  - transfers block requests to the remote side
- Server side
  - Receives RDMA buffers and converts them to BIOs
  - Submit BIOs down to the underlying block device
  - Send IO responses back to the client

Motivation

- ProfitBricks GmbH is an IaaS provider
- Our data centers:
  - compute nodes with customer VMs
  - storage servers with the HDDs/SSDs
  - InfiniBand network
- SRP/SCST for transfer of customer IOs from the VM on a compute node to the physical device on the storage server.
- Problems:
  - SCSI IO Timeouts
  - SCSI Aborts
  - Overhead of intermediate protocol

Goals

- Simplify operation
  - regular tasks (i.e. mapping / unmapping)
  - maintenance (i.e. server crash)
- Thin implementation
  - plain Block IO - no intermediate SCSI layer
  - better maintainability
  - integration into a software defined storage solution
- Performance
  - optimize for io latency

Design objective

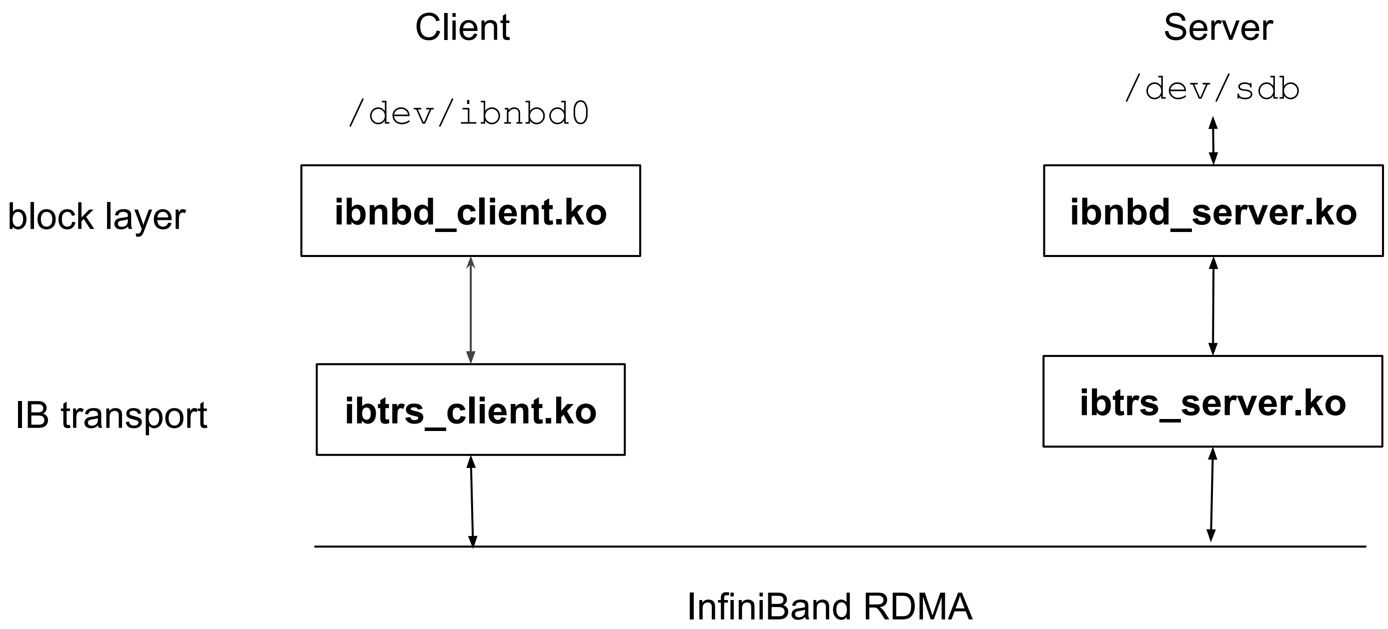
- Eliminate SCSI as intermediate transport layer
- Rely on the IB service to reduce design complexity
  - Minimal error handling: take advantage of the reliable mode of IB, which guarantees an RDMA operation to either succeed or fail.
  - simpler, robust and easier to maintain transport layer
  - No IO timeouts and retransmissions
- Minimize number of RDMA operations per IO to achieve lower latency
- Allow for an IO response to be processed on the CPU the IO was originally submitted on

Operation

- Mapping client side
    - Server address and device path on the server

    -
      ```
      $echo “device=/dev/sdb server=gid:xxxx:xxx:xxxx” >
      /sys/kernel/ibnbd/map_device
      ```
    - `/dev/ibnbd<x>` is created
- Export server side
    - no configuration is required
- Devices listed under /sys/kernel/ibnbd/devices/
- Session listed under /sys/kernel/ibtrs/sessions/
- Mapping options
    - Input mode (client side): Request or Multiqueue
    - IO mode (server side): block IO or file IO

Overall structure



- IBTRS (InfiniBand transport)
  - generic UAL for IB RDMA
  - can be reused by a different block device or any application utilizing request read/write RDMA semantics (i.e. replication solution)

Module functions

IBNBD is responsible for the delivery of block IO requests from client to storage server. Uses **IBTRS** as its IB rdma transport layer

- **Client** on compute node:
  - **ibnbd_client.ko** provides the mapped block devices (/dev/ibnbd<x>) and prepares IO for the transfer.
  - **ibtrs_client.ko** establishes connection to a server and executes rdma operations requested by ibnbd

- **Server** on storage side:
  - **ibtrs_server.ko** accepts connections from client, executes rdma transfers, hands over received data to ibnbd_server.
  - **ibnbd_server.ko** processes incoming IO requests and hands them over down to the underlying block device (i.e. an /dev/sdb device)

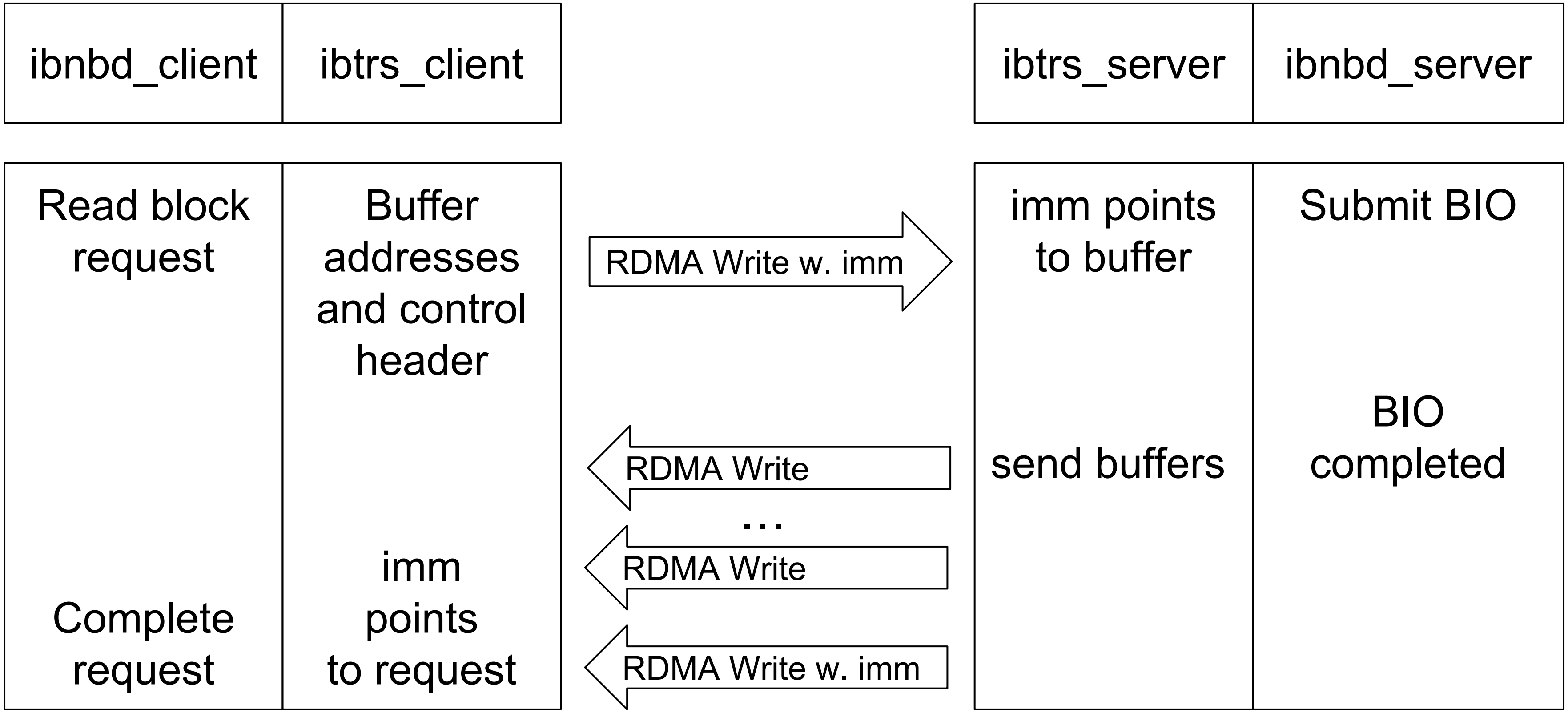
Memory management, immediate field

- Client-side server (DMA) memory management
- Server reserves queue_depth chunks each max_io_size big
- Client is managing this memory
- Allows to reduce number of RDMA operations per IO
- Tradeoff between memory consumption vs. latency
- client uses 32 bit imm field to tell server where transferred data can be found
- server uses imm field to tell client which outstanding IO is completed

Transfer procedure

1. **ibnbd_client**
   - converts incoming block request into an sg list with a header
2. **ibtrs_client**
   - transfers data (write IO) or control (read IO) in a single rdma write
   - uses 32 bit imm field to tell the server where the data can be found
3. **ibtrs_server**
   - notifies ibnbd_server about an incoming IO request
4. **ibnbd_server**
   - generates BIO and submits it to underlying device
   - acknowledges the RDMA operation, when BIO comes back
5. **ibtrs_server** sends confirmation (write IO) or data (read IO) back to client
6. **ibtrs_client** notifies ibnbd_client about a completed RDMA operation
7. **ibnbd_client** completes the original block request

Transfer procedure: read



ibnbd_client

ibtrs_client

ibtrs_server

ibnbd_server

Read block request

Buffer addresses and control header

RDMA Write w. imm

imm points to buffer

Submit BIO

BIO completed

send buffers

RDMA Write

…

RDMA Write

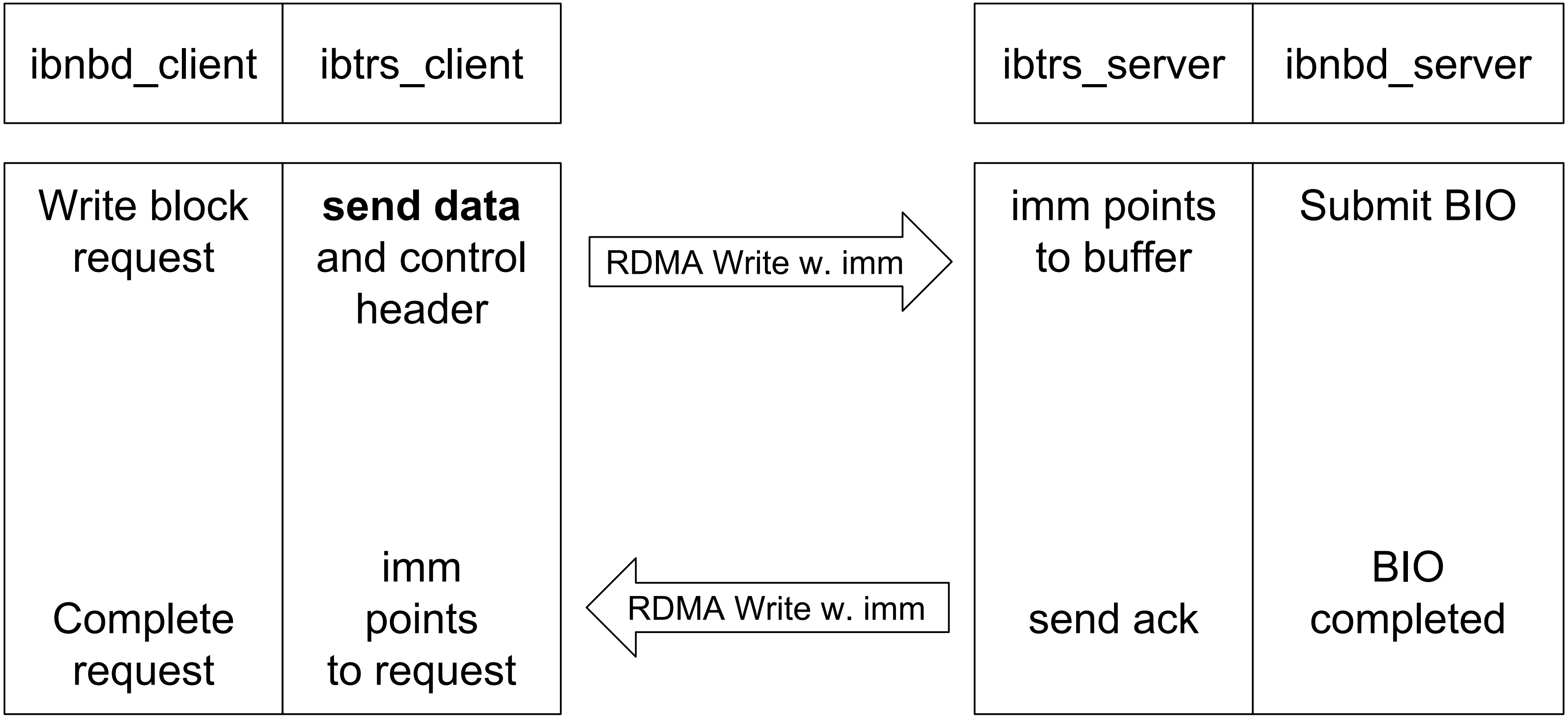
RDMA Write w. imm

imm points to request

Complete request

- Same procedure as used by iSER or SRP: server initiates transfer
- Fast memory registration feature is used to reduce number of transfers

Transfer procedure: write



ibnbd_client

ibtrs_client

ibtrs_server

ibnbd_server

Write block request

send data and control header

RDMA Write w. imm

imm points to buffer

Submit BIO

BIO completed

send ack

RDMA Write w. imm

imm points to request

Complete request

- Different to iSER or SRP: Client initiates the transfer into a server buffer
- Only two RDMA operations

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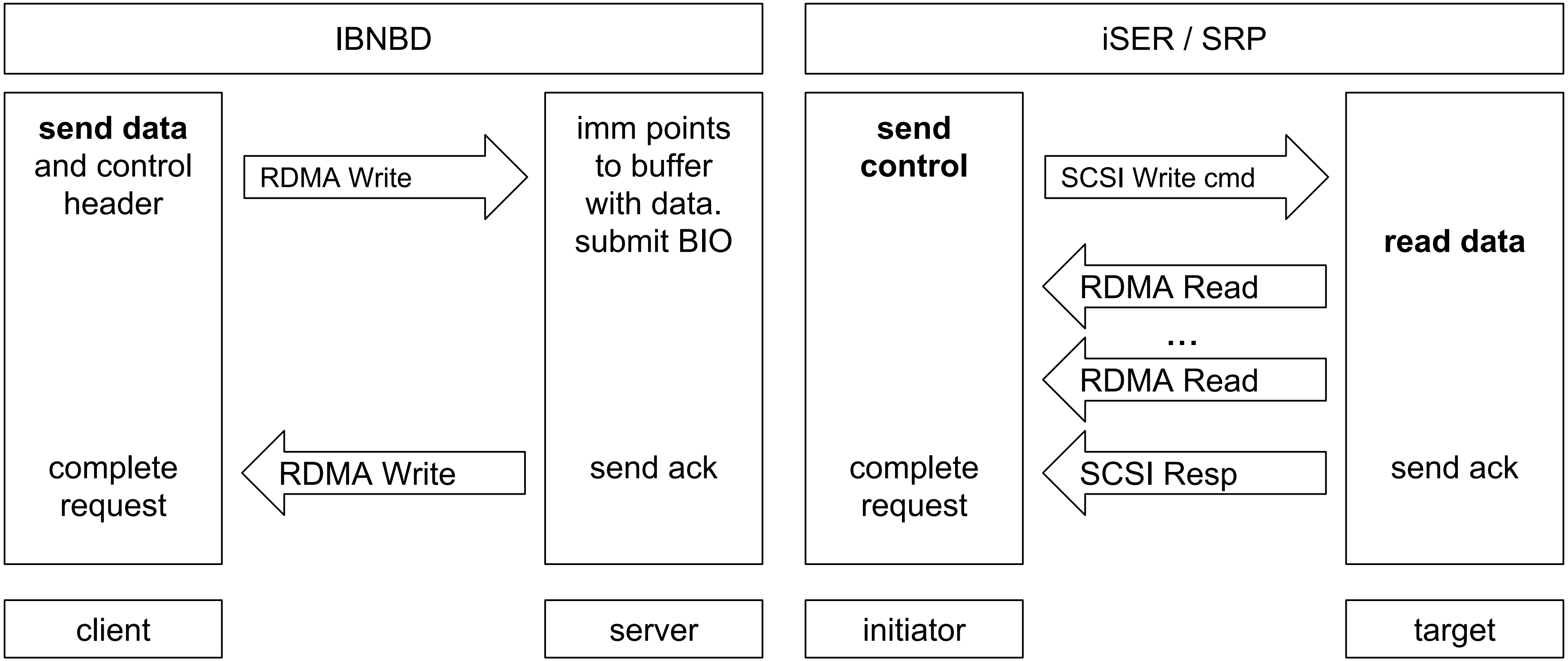
Transfer procedure: write, IBNBD vs iSER/SRP



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Connection management

- “Session” is connecting a client with a server.
- Consists of as many IB connections as CPUs on client.
- Each IB connection: separate cq_vector (and IRQ).
- Affinity of each IRQ is set to a separate CPU.
- Server sends IO response on the same connection he got the request on.
- Interrupt on client is generated on the same cpu where the IO was originally submitted.
- Reduce data access across different NUMA nodes

Queue Depth and MQ support

- Inflight on client side is limited by the number of DMA buffers reserved on the server side
- All the ibnbd devices mapped from the same server share the same remote buffers
- Fair sharing by making use of the shared tags feature
- MQ: As many hardware queues as CPUs - each IB connection belonging to a session does in fact function as a separate hardware queue.

Error handling

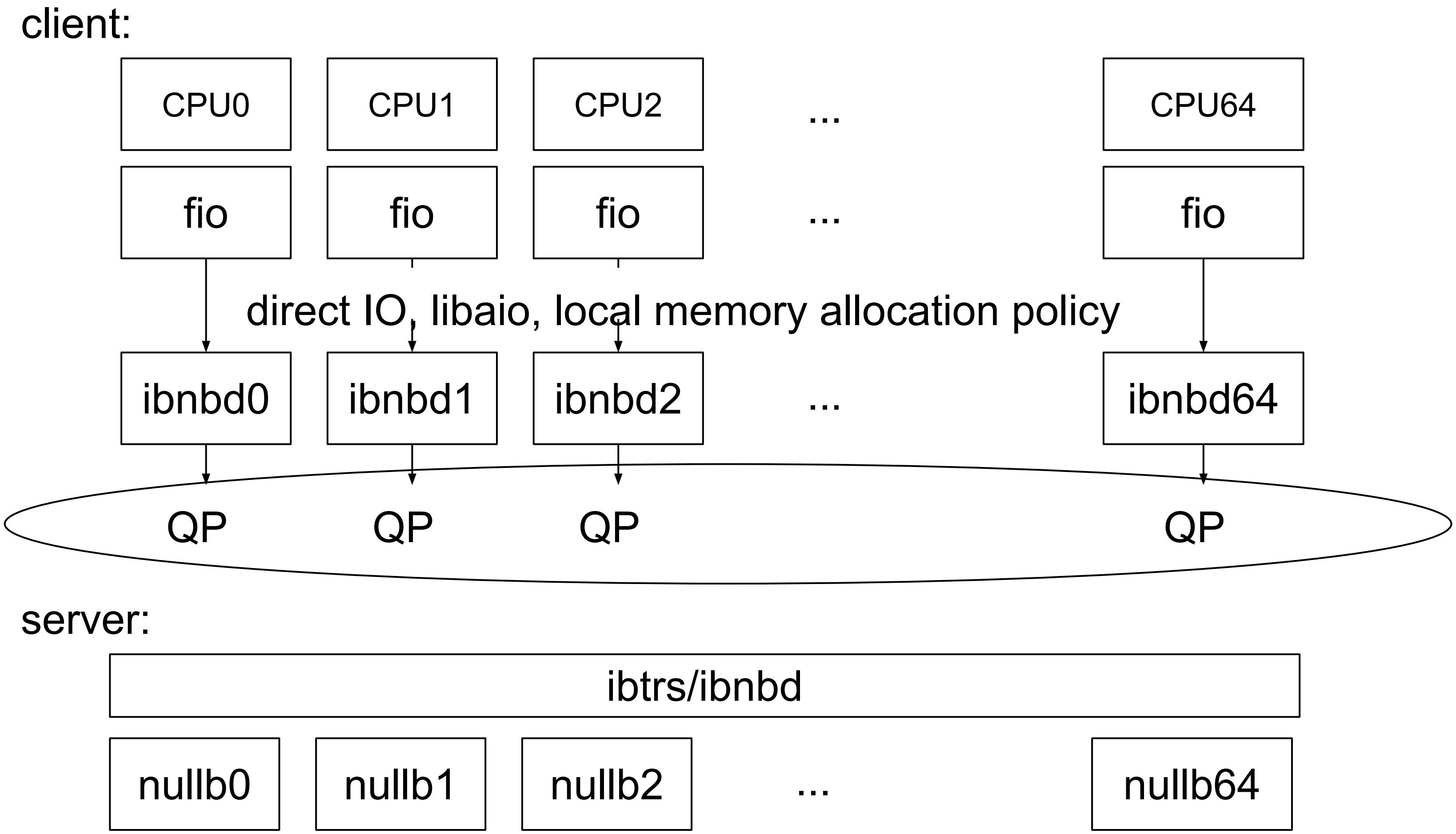
- No IO timeouts and no IO retransmissions
- Heartbeats to detect unresponsive peers (i.e. kernel crash)
  - RDMA might succeed even if CPU on remote is halted
- Reconnecting after an IB error
  - Client keeps the devices and tries to reconnect
  - Server closes all devices and destroys session
- APM Support
  - Server is connected with two IB ports to two different switches
  - transparent failover in case of cable or IB switch failure

Outlook: Reliable Multicast

- Reliable multicast over InfiniBand UD Multicast
- IBTRS API: Join several established sessions into one "multicast" session
- Submit IO once - it will be confirmed after the IO is delivered to all servers in the group
- Useful for replication (i.e. mirror)
- Reduce load on the IB link connecting a compute node with the IB switch

Performance: Measurement setup

Mimic VMs running on different CPUs and accessing their devices.



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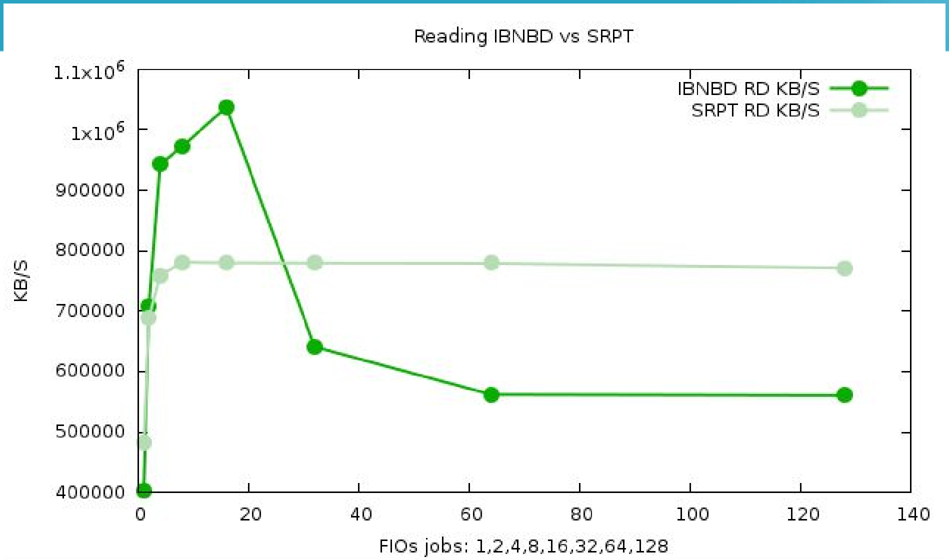
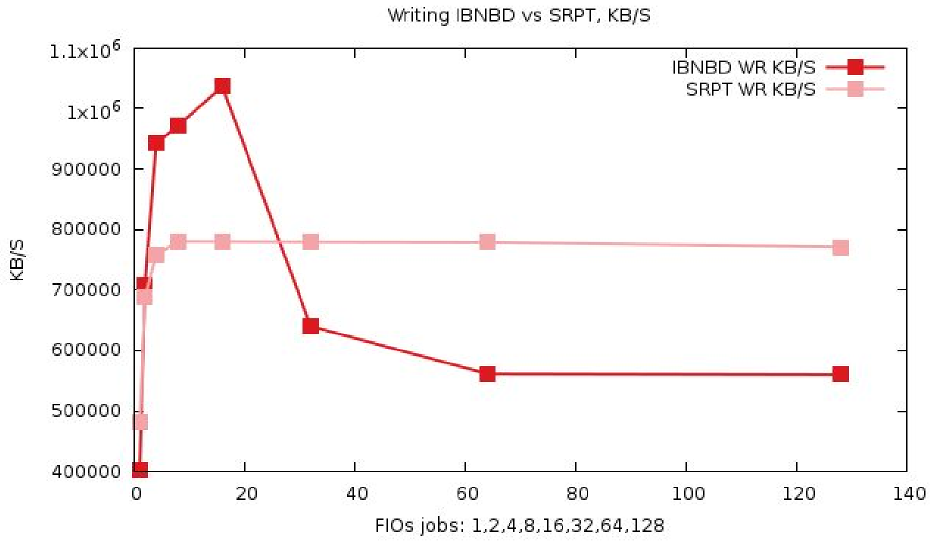
Original scalability problem





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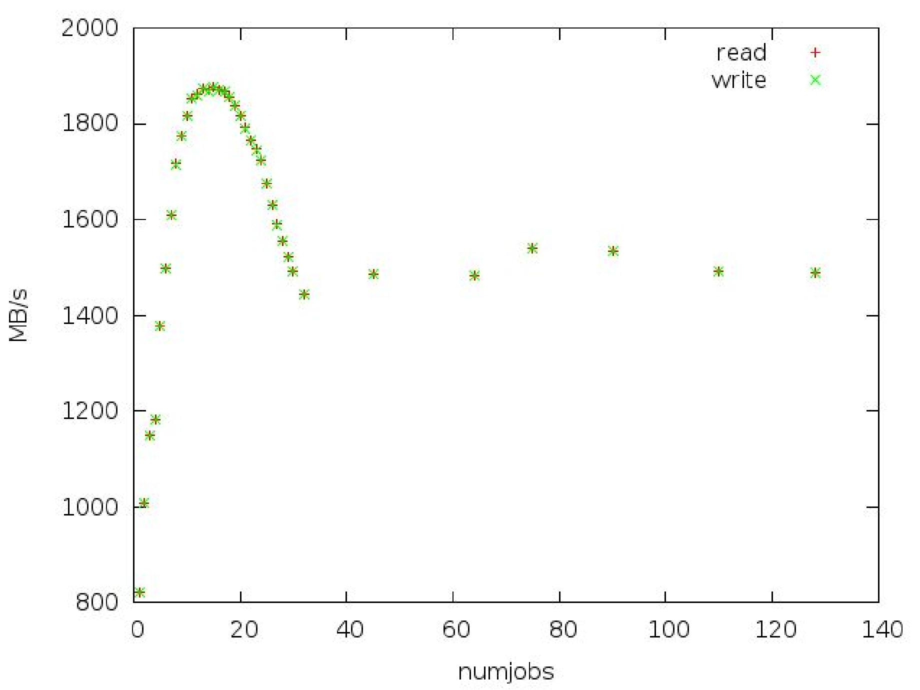
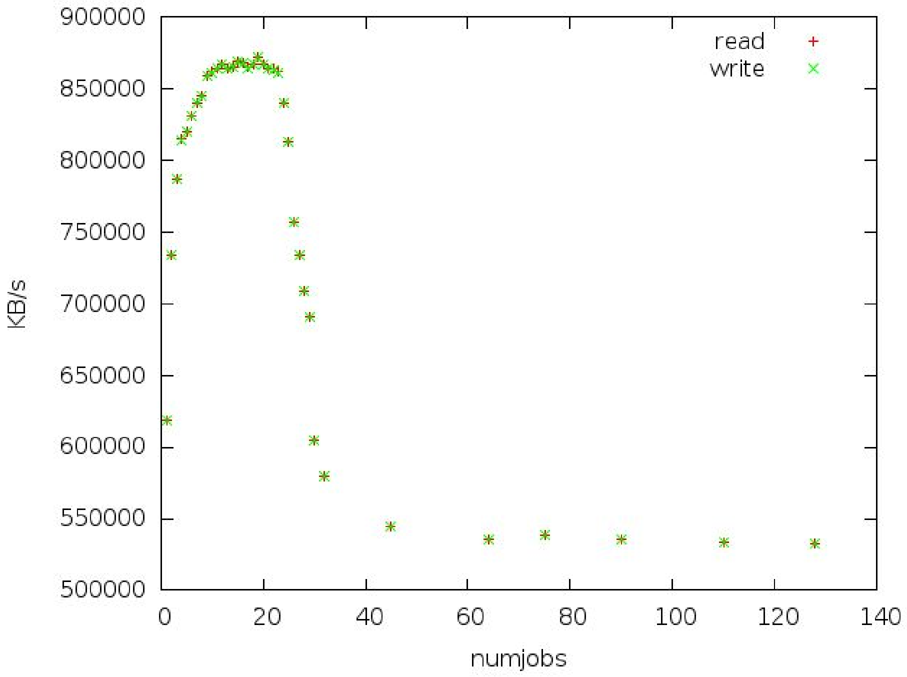
IOMMU

```
+   97.59%    0.00%          8            fio  [.] io_submit
+   97.58%    0.00%          0            fio  [k] sys_io_submit
+   97.54%    0.01%        397            fio  [k] do_io_submit
+   97.48%    0.01%        397            fio  [k] aio_run_iocb
+   97.07%    0.03%       2059            fio  [k] blkdev_direct_IO
+   97.04%    0.00%        172            fio  [k] __blockdev_direct_IO
+   96.99%    0.06%       3520            fio  [k] do_blockdev_direct_IO
+   95.11%    0.00%        282            fio  [k] submit_bio
+   95.09%    0.00%        168            fio  [k] generic_make_request
+   93.47%    0.04%       2577            fio  [k] map_sg
-   92.60%   92.60%    5786351            fio  [k] _raw_spin_lock_irqsave
   - _raw_spin_lock_irqsave
      + 50.39% map_sg
      + 49.38% unmap_sg
+   48.86%    0.00%        124            fio  [k] blkdev_write_iter
+   48.85%    0.01%        518            fio  [k] __generic_file_write_iter
+   48.82%    0.00%        269            fio  [k] generic_file_direct_write
```

IOMMU vs no IOMMU





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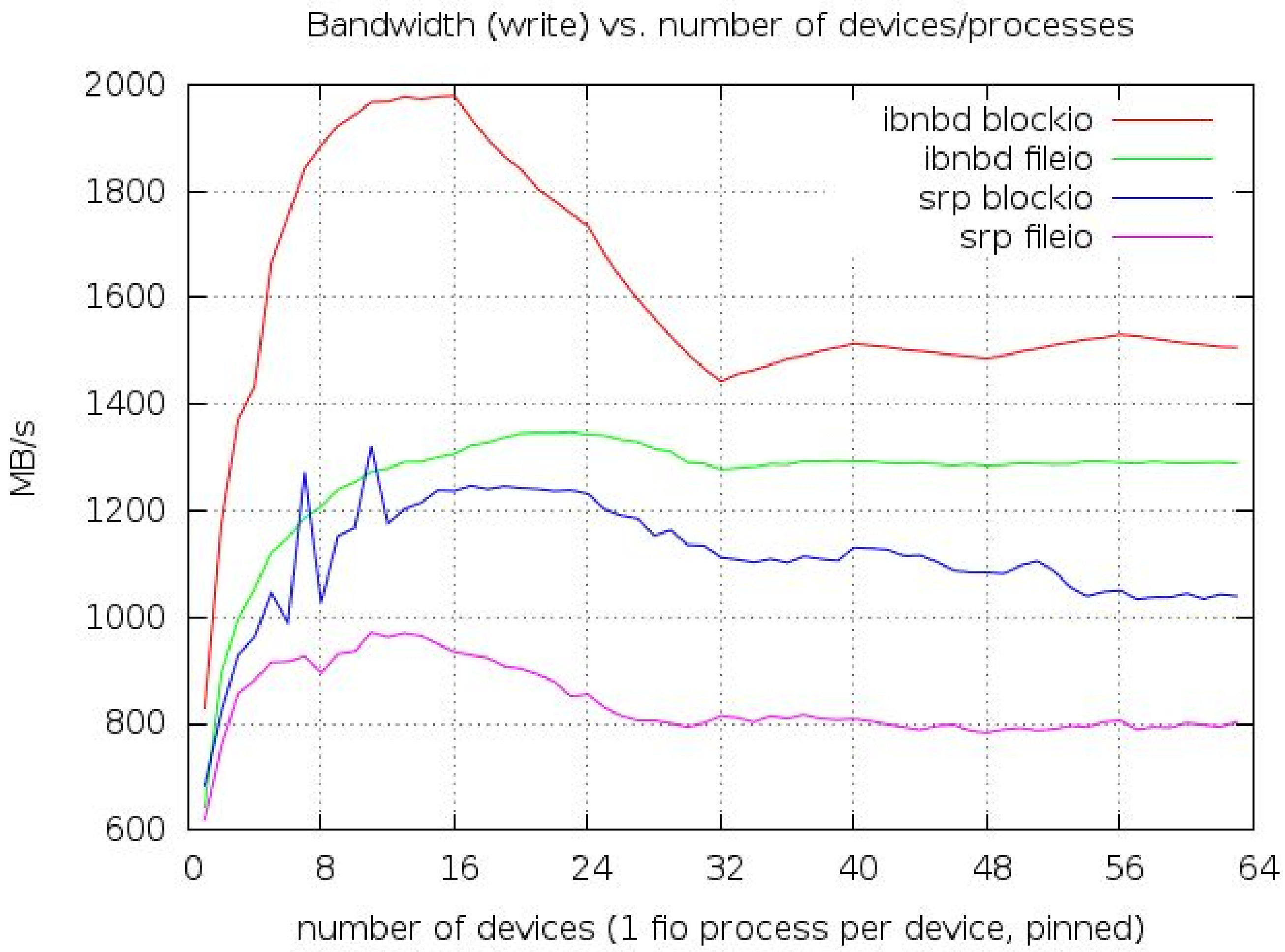
IBNBD vs SRP, block io vs, fileio, NUMA effects



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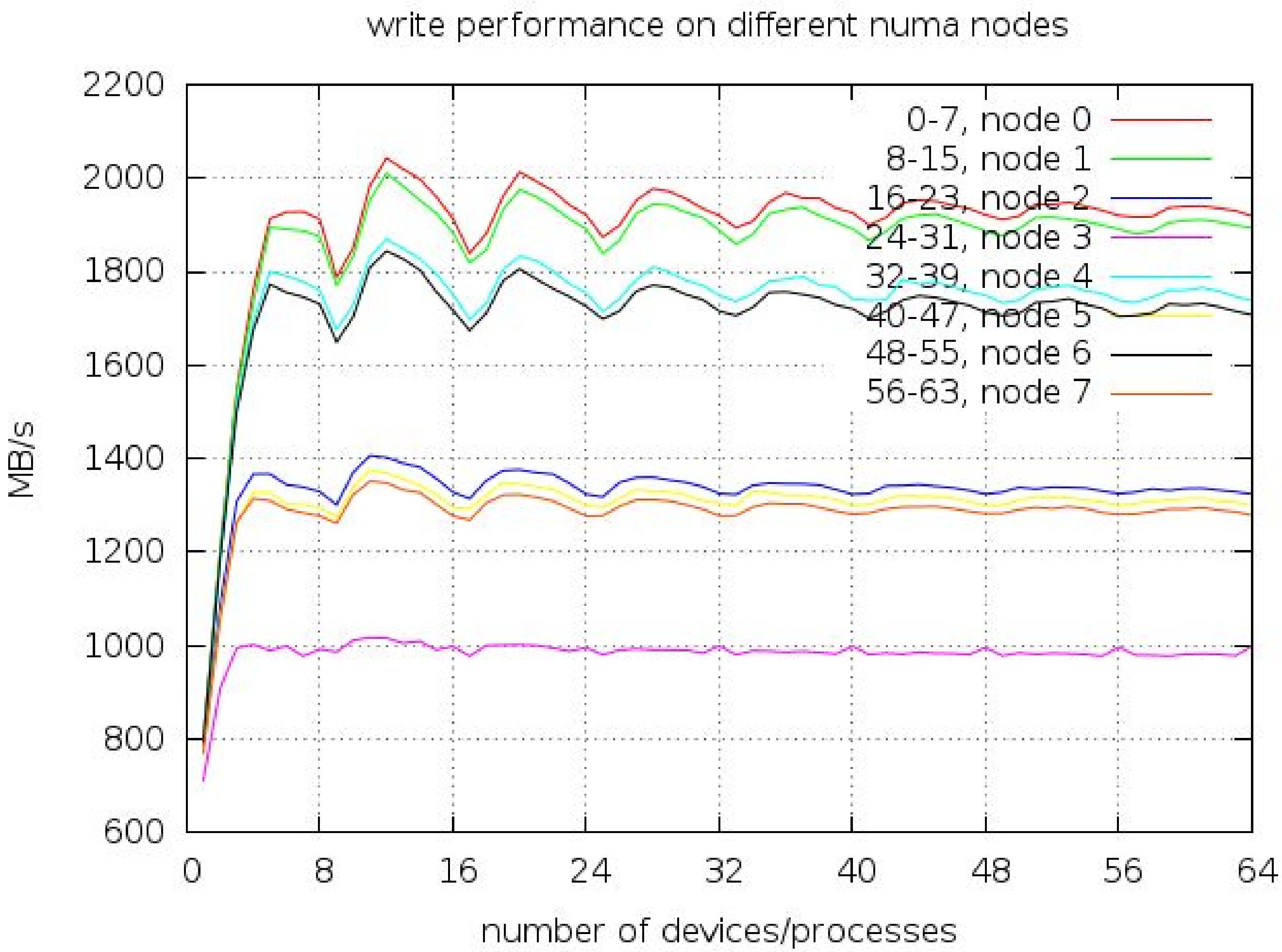
NUMA effects

```
numa-ctl --hardware
node    0   1   2   3   4   5   6   7
  0:   10  16  16  22  16  22  16  22
```



HCA is on NUMA 0

Summary: Major characteristics of the driver

- High throughput and low latency due to:
    - Only two rdma messages per IO
    - Simplified client side server memory management
    - Eliminated SCSI sublayer
- Simple configuration and handling
    - Server side is completely passive: volumes do not need to be explicitly exported
    - Only IB port GID and device path needed on client side to map a block device
    - A device can be remapped automatically i.e. after storage reboot
- Pinning of IO-related processing to the CPU of the producer

Existing Solutions

- SRP/SCST
  - SCSI RDMA Protocol
- ISER
  - iSCSI extension for RDMA
  - target executes RDMA operations
- accelio/nbdx
  - server side in user space
  - obsolete in favor of NVMEoF
- NVMEoF
  - transports NVME commands
  - target initiates RDMA transfers

Questions?

danil.kipnis@profitbricks.com

Backup: Test Hardware

- Mellanox Connnect X3 HCA
  - dualport, 40 Gb/sec
- AMD 64 Cores
  - AMD Opteron 6386 SE
  - 8 NUMA nodes

Backup: Existing Solutions

- SRP/SCST: SCSI RDMA Protocol
- ISER: iSCSI Extensions for RDMA
  - SCSI sub layer
  - Only target executes RDMA operations
- accelio/nbdx
  - server side in user space, libaio, obsolete
- NVMEoF
  - transports NVME commands
  - server executes RDMA operations

Backup: fio configuration

```
[global]
description=Emulation of Storage Server Access Pattern
bssplit=512/20:1k/16:2k/9:4k/12:8k/19:16k/10:32k/8:64k/4:128k/2
fadvise_hint=0
rw=randrw:2
direct=1
random_distribution=zipf:1.2
size=1G
ioengine=libaio
iodepth=128
iodepth_batch_submit=128
iodepth_batch_complete=128
gtod_reduce=1
group_reporting=1

# pinning options
cpus_allowed=0-63
cpus_allowed_policy=split
numa_mem_policy=local
```