RDMA Bonding

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Agenda

- Introduction
- Transport-level bonding
- RDMA bonding design
- Recovering from failure
- Implementation

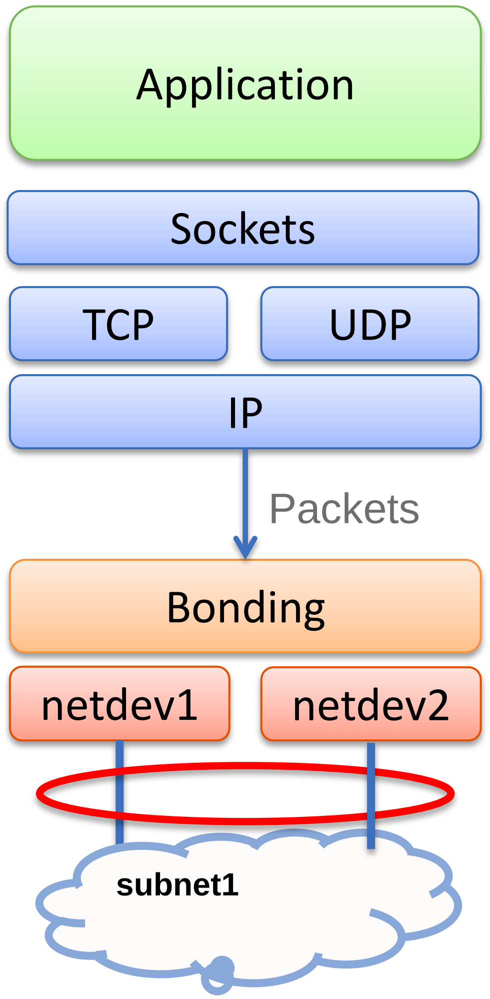
Bonding (Link Aggregation)

- Bond together multiple physical links into a single aggregate logical link
- Motivation
  - Aggregate bandwidth (active-active)
    - Distribute communication flows across all active links
  - High availability (active-backup)
    - If a link goes down, reassign traffic to remaining links
- Can we do the same for HCAs?

Link-level Bonding

- Example: Ethernet link aggregation
- Typically accomplished by a “Bonding” pseudo network interface
- Placed between the L3/4 stack and physical interfaces
  - Multiplexes ***packets*** across ***stateless*** network interfaces
  - Transparent to higher levels of the stack
  - Transport is implemented in SW

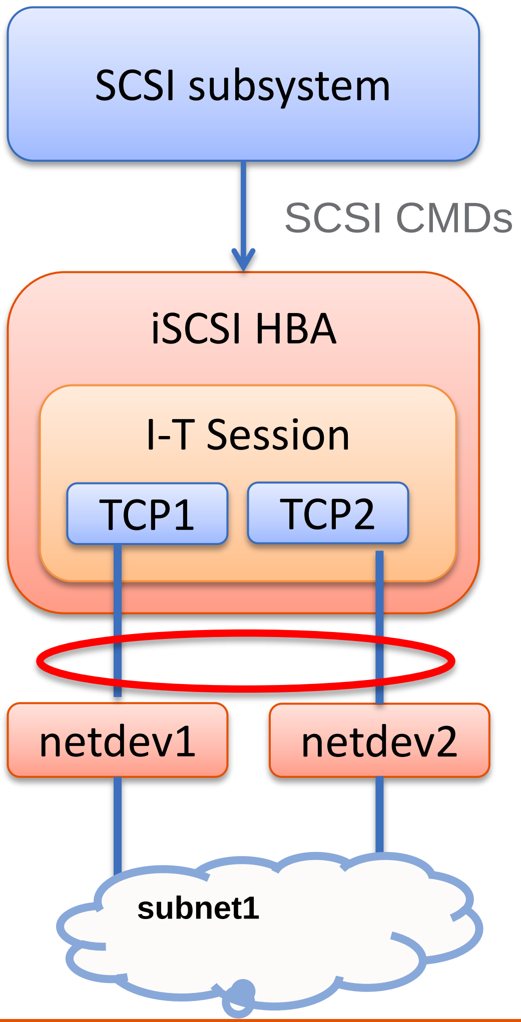
- RDMA challenge
  - Transport implemented at stateful network interfaces (HCAs)



Session-level Bonding

- Example: iSCSI
- Initiator establishes a session with Target
  - Session may comprise multiple TCP flows
- Connections are completely encapsulated within the iSCSI session
  - OS issues SCSI commands
- Alternatively, multiple sessions may be created to the same target/LUN
  - May be presented as single logical LUN by multi-path SW

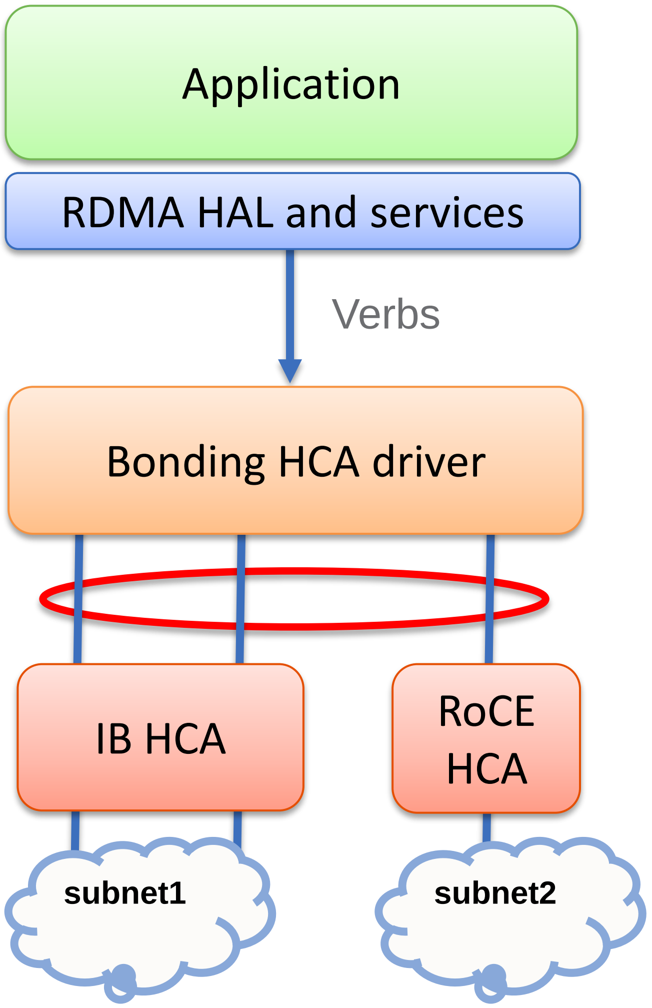
- RDMA challenge
  - Transport connections visible to ULPs
  - Multiple RDMA consumers



Idea: Transport-level Bonding

- Provided by a pseudo-HCA (vHCA)
- Applications open virtual resources
  - vPDs, vQPs, vSRQs, vCQs, vMRs
  - Mapped to physical resources by vHCA
- Namespace translated on the fly
  - Similar to transparent RDMA migration
    - IBM/OSU “Nomad” paper
    - VMware vRDMA
    - Oracle live-migration prototype

- Link aggregation
  - Distribute QPs across HCAs
  - Optionally bond different HCA types
  - Upon failover
    - Reconnect over a different device/port
    - Continue traffic from the point of failure
  - Transparent migration is a special HA case

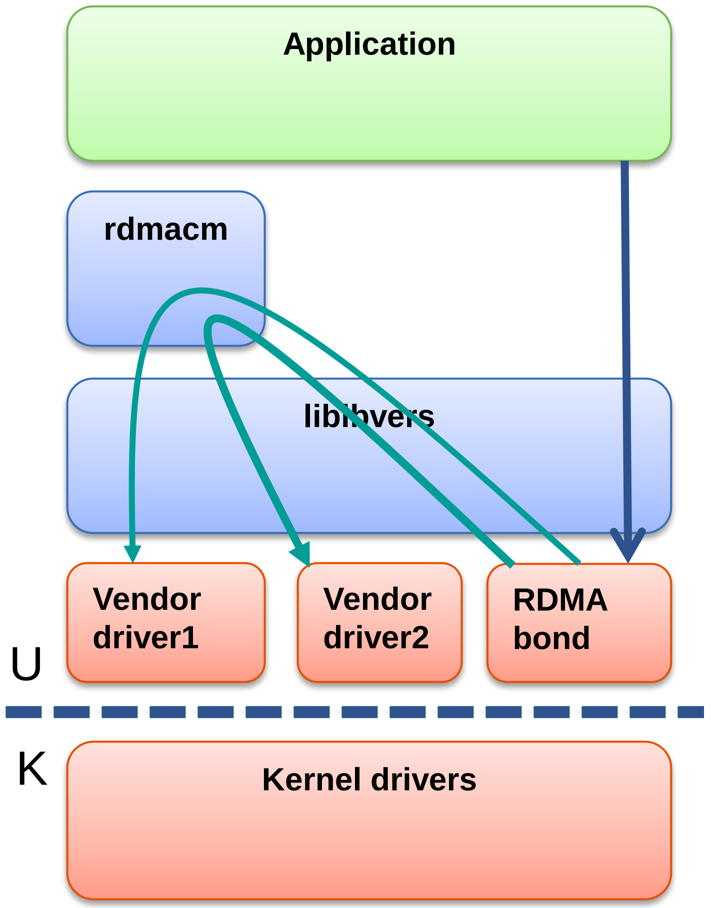


Requirements

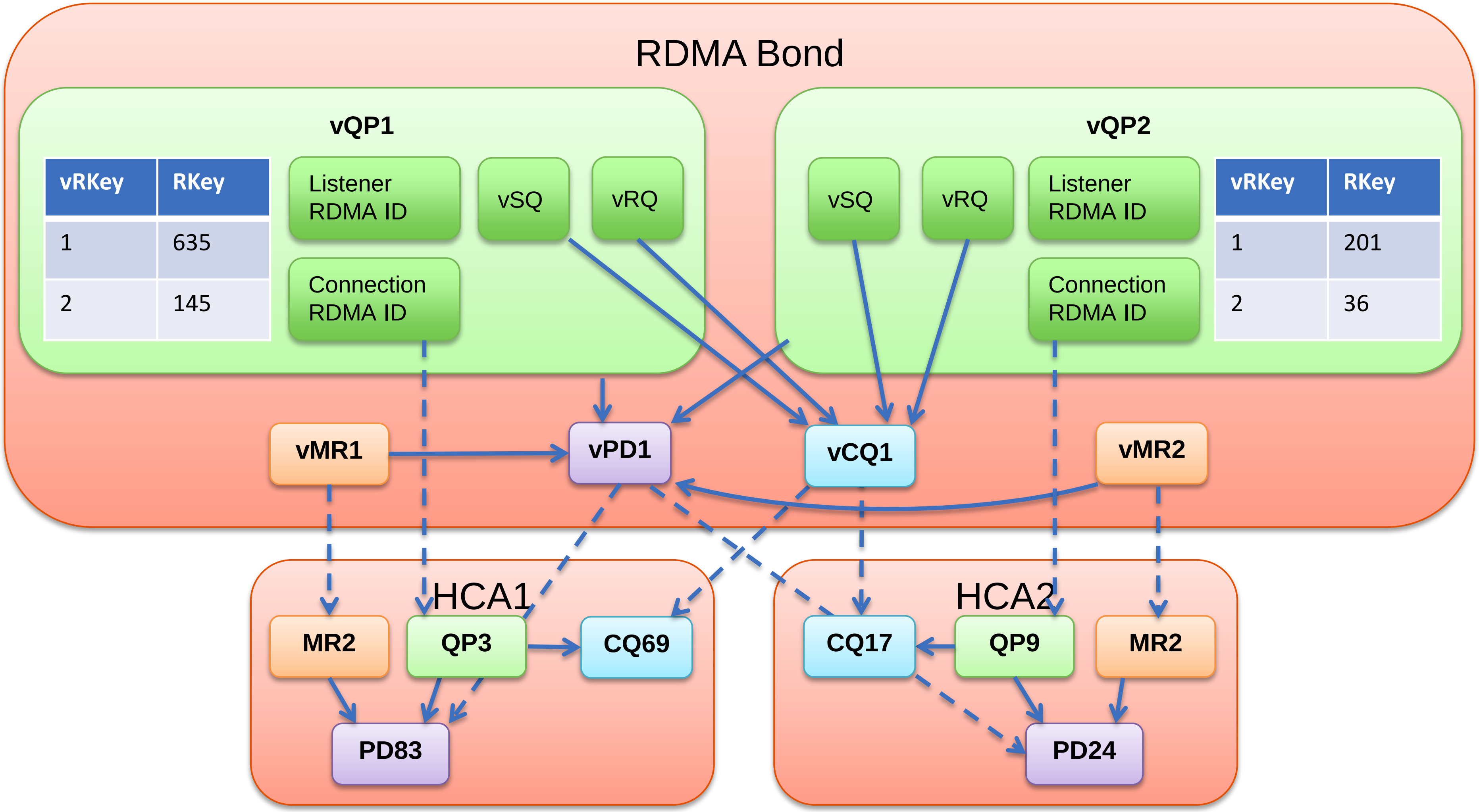
- Support aggregate across different physical HCAs
  - Optionally even different device types
- HW independent Bonding driver
- Strict semantics
  - Adhere to transport message ordering guarantees
  - Global visibility of all IO operations
- Transparent to consumers
  - Including failover events
- High performance

Design

- User-space solution
  - Bond driver is a Verbs provider
  - Uses RDMACM internally
    - To open connections
    - Negotiate state using private data
- IP addressing
  - GID = IP
  - QPN = Port number
  - HCA identity = alias IP
- 1:1 virtual→physical QP mapping
  - Leverage HW ordering guarantees
  - Zero copy messages
- Fast path done in app context
  - Post_Send(), Post_Recv(), PollCQ()



Object Relations (Example)



vRKey	RKey
1	635
2	145

vRKey	RKey
1	201
2	36

Posting WRs

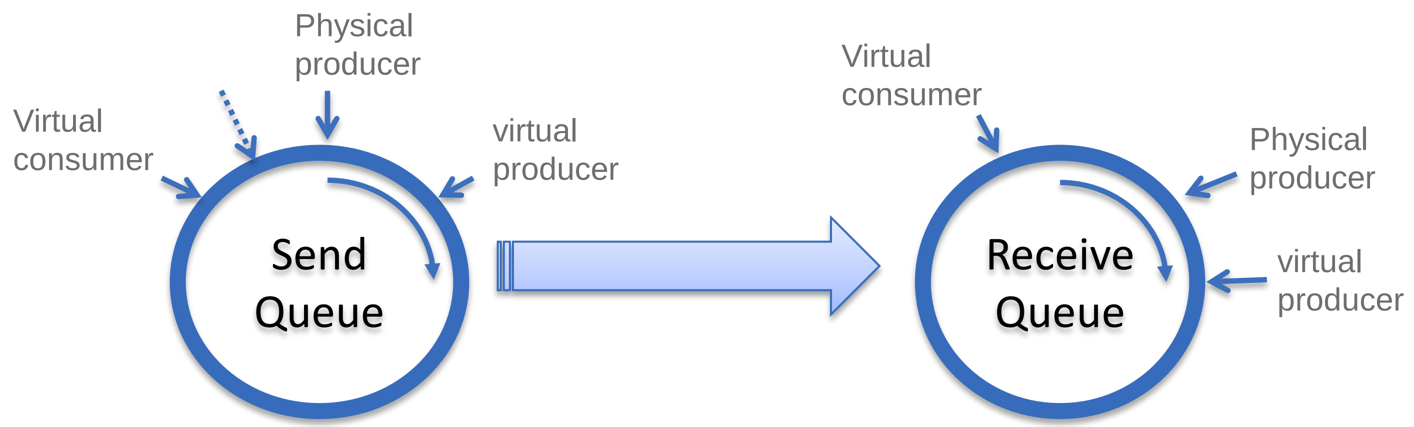
- If vQP is not in a suitable state or virtual queue is full
  - Return immediate error
- Enqueue WR in virtual Queue
- If associated HW Send / Receive queue is full
  - Return with success
- For Sends
  - If connection is not active
    - Schedule (re)connection and return with success
  - For UD
    - Resolve AH and remote QPN (if not already cached)
  - For RDMA
    - Resolve RKey (if not already cached)
- For Receives
  - If connection is not active, return with success
- Translate local SGE
- Post to HW

Polling Completions

- Poll next HW CQ associated with vCQ
- If not empty, process according to status
  - Case IBV_WC_RETRY_EXC_ERR
    - Schedule reconnection for associated vQP
    - Ignore completion
  - Case IBV_WC_WR_FLUSH_ERR
    - Ignore completion
  - Case IBV_WC_SUCCESS
    - Report successful completion
  - Default (any other error)
    - Modify vQP to error
    - Report erroneous completion
    - Add corresponding virtual Queue to CQ error list
- Poll next virtual queue on error list
- If it has in-flight WQEs
  - Generate ERROR_FLUSH for next WQE
- Report CQ empty if none of the above applies

RC Failure Recovery

- Re-establish connection
  - Over any active link and device
- Negotiate last committed operations
  - Generate corresponding completions
- Rewind physical queues
  - Resume operation



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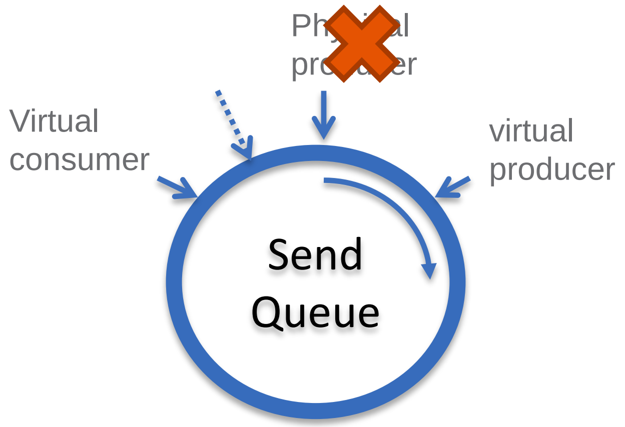

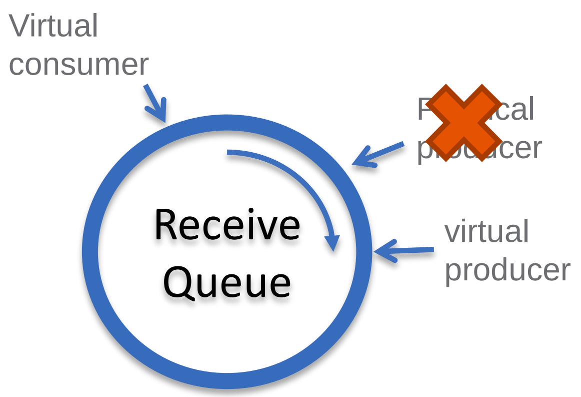

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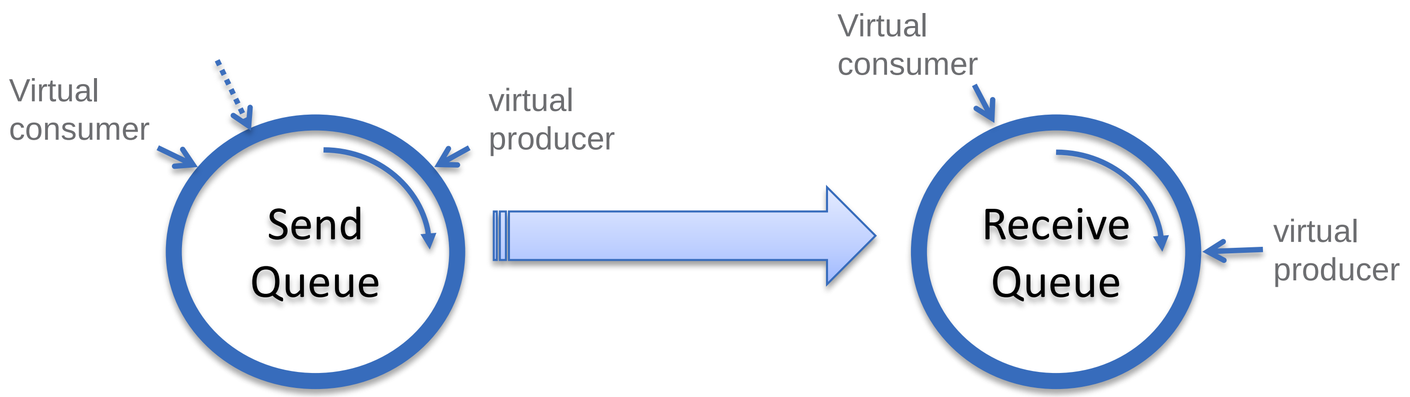

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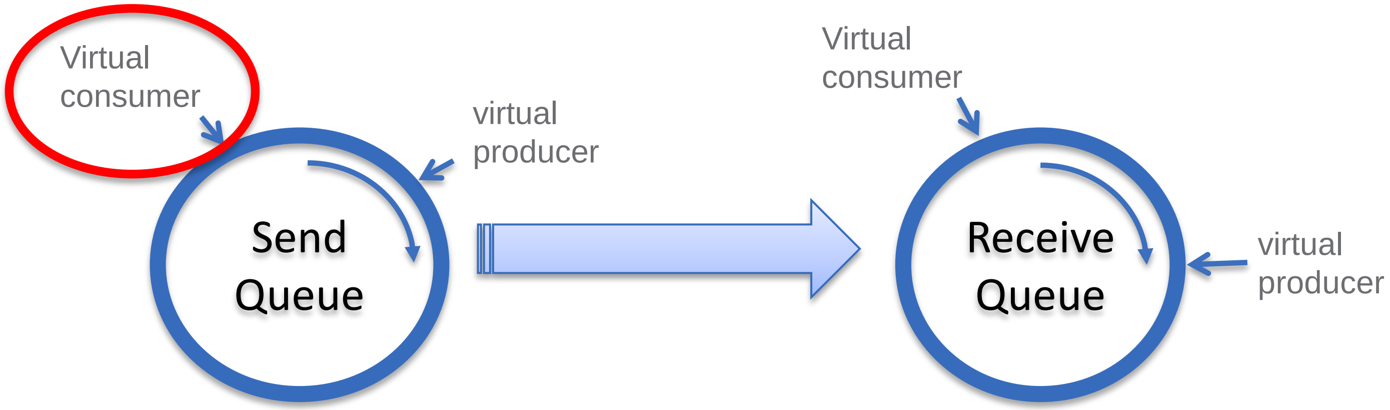

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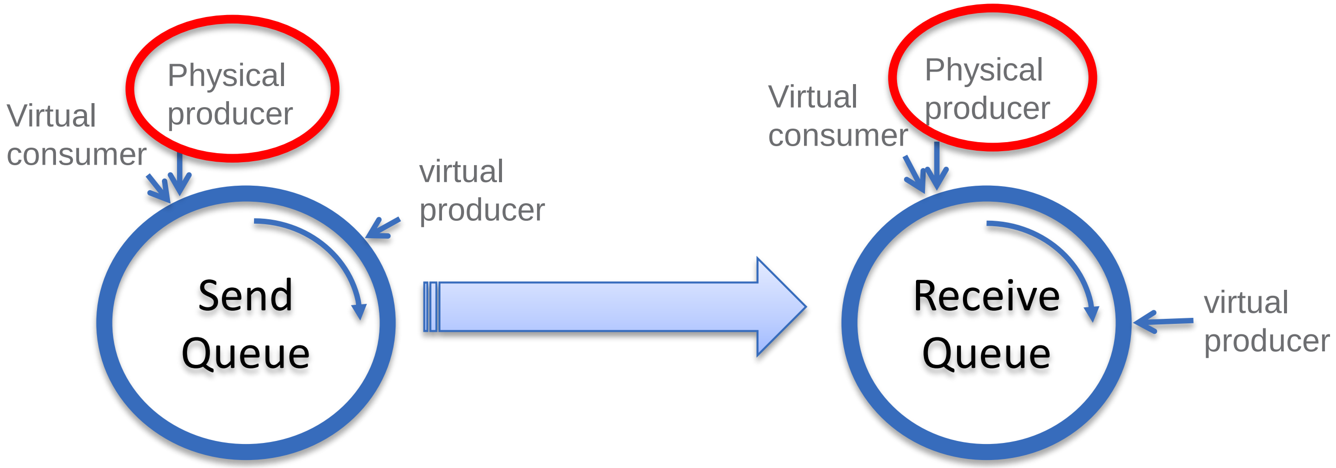

Implementation (Ongoing)

- Current status
  - POC implementation
  - Supported objects
    - CQs
    - PDs
    - RC QPs
    - MRs
  - Supported operations
    - Resource manipulation
    - Send-receive data traffic
  - QPs limited to single link
    - Tackle transient link failure

- Next steps
  - Complete Verbs coverage
  - RDMACM integration
  - Multi-link recovery
    - Continuously negotiate active links
  - Aggregation schemes
    - HA
    - RR
    - Static load balancing
    - Dynamic load balancing

Summary

- Bonding solution for stateful RDMA devices
  - HW agnostic
  - Aggregates ports from different devices
  - Communicating peers must run the Bonding driver
    - Out-of-band protocol via CM MADs
- Supports
  - High availability
  - Aggregate BW
  - Load balancing
  - Transparent migration
- Efficient user-space implementation
  - Could be extended to the kernel in a similar manner

Thank You