MPI Requirements of the Network Layer

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Quick MPI overview

- High-level abstraction API
  - No concept of a connection

- All communication:
  - Is reliable
  - Has some ordering rules
  - Is comprised of typed messages

- Peer address is (communicator, integer) tuple
  - I.e., virtualized
  - Specifies a process, not a server / network endpoint
Quick MPI overview

• Communication modes
  • Blocking and non-blocking (polled completion)
  • Point-to-point: two-sided and one-sided
  • Collective operations: broadcast, scatter, reduce, …etc.
  • …and others, but those are the big ones

• Async. progression is required/strongly desired

• Message buffers are provided by the application
  • They are not “special” (e.g., registered)
Quick MPI overview

- **MPI specification**
  - Governed by the MPI Forum standards body
  - Currently at MPI-3.0

- **MPI implementations**
  - Software + hardware implementation of the spec
  - Some are open source, some are closed source
  - Generally don’t care about interoperability (e.g., wire protocols)
MPI is a large community

- Community feedback represents union of:
  - Different viewpoints
  - Different MPI implementations
  - Different hardware perspectives

- …and not all agree with each other

- For example…
### Different MPI camps

<table>
<thead>
<tr>
<th>Those who want high level interfaces</th>
<th>Those who want low level interfaces</th>
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<tbody>
<tr>
<td>• Do not want to see memory registration</td>
<td>• Want to have good memory registration infrastructure</td>
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<tr>
<td>• Want tag matching</td>
<td>• Want direct access to hardware capabilities</td>
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</table>
  • E.g., PSM |  • Want to fully implement MPI interfaces themselves |
  • Trust the network layer to do everything well under the covers |  • Or, the MPI implementers are the kernel / firmware / hardware developers |
Be careful what you ask for…

• …because you just got it

• Members of the MPI Forum would like to be involved in the libfabric design on an ongoing basis

• Can we get an MPI libfabric listserv?
Basic things MPI needs

- Messages (not streams)
- Efficient API
  - Allow for low latency / high bandwidth
  - Low number of instructions in the critical path
  - Enable “zero copy”
- Separation of local action initiation and completion
- One-sided (including atomics and shared locks) and two-sided semantics
- No requirement for communication buffer alignment (!!!)
Basic things MPI needs

- Asynchronous progress independent of API calls
  - Including asynchronous progress from multiple consumers (e.g., MPI and PGAS in the same process)
  - Preferably via dedicated hardware
Basic things MPI needs

- Scalable communications with millions of peers
  - With both one-sided and two-sided semantics
  - Think of MPI as a fully-connected model
    (even though it usually isn’t implemented that way)
  - Today, runs with 3 million MPI *processes* in a job
Things MPI likes in verbs

- (all the basic needs from previous slide)
- Different modes of communication
  - Reliable vs. unreliable
  - Scalable connectionless communications (i.e., UD)
- Specify peer read/write address (i.e., RDMA)
- RDMA write with immediate (*)
  - …but we want more (more on this later)
Things MPI likes in verbs

- Ability to re-use (short/inline) buffers immediately
- Polling and OS-native/fd-based blocking QP modes
- Discover devices, ports, and their capabilities (*)
  - ...but let's not tie this to a specific hardware model
- Scatter / gather lists for sends
- Atomic operations (*)
  - ...but we want more (more on this later)
Things MPI likes in verbs

- Can have multiple consumers in a single process
  - API handles are independent of each other
Things MPI likes in verbs

- Verbs does not:
  - Require collective initialization across multiple processes
  - Require peers to have the same process image
  - Restrict completion order vs. delivery order
  - Restrict source/target address region (stack, data, heap)
  - Require a specific wire protocol (*)
    - ...but it does impose limitations, e.g., 40-byte GRH UD header
Things MPI likes in verbs

- Ability to connect to “unrelated” peers
- Cannot access peer (memory) without permission
- Ability to block while waiting for completion
  - *assumedly without consuming host CPU cycles*
- Cleans up everything upon process termination
  - E.g., kernel and hardware resources are released
Other things MPI wants (described as verbs improvements)

- MTU is an int (not an enum)
- Specify timeouts to connection requests
  - ...or have a CM that completes connections asynchronously
- All operations need to be non-blocking, including:
  - Address handle creation
  - Communication setup / teardown
  - Memory registration / deregistration
Other things MPI wants (described as verbs improvements)

- Specify buffer/length as function parameters
  - Specified as struct requires extra memory accesses
  - ...more on this later

- Ability to query how many credits currently available in a QP
  - To support actions that consume more than one credit

- Remove concept of “queue pair”
  - Have standalone send channels and receive channels
Other things MPI wants (described as verbs improvements)

- Completion at target for an RDMA write
- Have ability to query if loopback communication is supported
- Clearly delineate what functionality *must* be supported vs. what is optional
  - Example: MPI provides (almost) the same functionality everywhere, regardless of hardware / platform
  - Verbs functionality is wildly different for each provider
Other things MPI wants (described as verbs improvements)

• Better ability to determine causes of errors

• In verbs:
  • Different providers have different (proprietary) interpretations of various error codes
  • Difficult to find out why `ibv_post_send()` or `ibv_poll_cq()` failed, for example

• Perhaps a better `strerr()` type of functionality (that can also obtain provider-specific strings)?
Other things MPI wants: Standardized high-level interfaces

- Examples:
  - Tag matching
  - MPI non-blocking collective operations (TBD)
  - Remote atomic operations
  - …etc.
  - *The MPI community wants input in the design of these interfaces*

- Divided opinions from MPI community:
  - Providers must support these interfaces, even if emulated
  - Run-time query to see which interfaces are supported
Other things MPI wants: Vendor-specific interfaces

- Direct access to vendor-specific features
  - *Lowest-common denominator API is not always enough*
  - Allow all providers to *extend* all parts of the API

- Implies:
  - Robust API to query what devices and providers are available at run-time (and their various versions, etc.)
  - Compile-time conventions and protections to allow for safe non-portable codes

- *This is a radical difference from verbs*
Core libfabric functionality

Application (e.g., MPI)

libfabric core

Provider A

Provider B

Direct function calls to libfabric
Example options for direct access to vendor-specific functionality

Example 1: Access to provider A extensions without going through libfabric core
Example options for direct access to vendor-specific functionality

Example 2: Access to provider B extensions via “pass through” functionality in libfabric
Other things MPI wants: Regarding memory registration

- Run-time query: is memory registration necessary?
  - I.e., explicit or implicit memory registration

- If explicit
  - Need robust notification of involuntary memory de-registration (e.g., munmap)

- If the cost of de/registration were “free”, much of this debate would go away 😊
Other things MPI wants: Regarding fork() behavior

• In child:
  • All memory is accessible (no side effects)
  • Network handles are stale / unusable
  • Can re-initialize network API (i.e., get new handles)

• In parent:
  • All memory is accessible
  • Network layer is still fully usable
  • Independent of child process effects
Other things MPI wants

- If network header knowledge is required:
  - Provide a run-time query
  - Do not mandate a specific network header
  - E.g., incoming verbs datagrams require a GRH header

- Request ordered vs. unordered delivery
  - Potentially by traffic type (e.g., send/receive vs. RDMA)

- Completions on both sides of a remote write
Other things MPI wants

- Allow listeners to request a specific network address
  - Similar to TCP sockets asking for a specific port

- Allow receiver providers to consume buffering directly related to the size of incoming messages
  - Example: “slab” buffering schemes
Other things MPI wants

- Generic completion types. Example:
  - Aggregate completions
  - Vendor-specific events
- Out-of-band messaging
Other things MPI wants

- Noncontiguous sends, receives, and RDMA opns.
- Page size irrelevance
  - Send / receive from memory, regardless of page size
- Access to underlying performance counters
  - For MPI implementers and MPI-3 “MPI_T” tools
- Set / get network quality of service
Other things MPI wants: More atomic operations

- Datatypes (minimum): int64_t, uint64_t, int32_t, uint32_t
  - Would be *great*: all C types (to include double complex)
  - Would be *ok*: all <stdint.h> types
  - Don’t require more than natural C alignment

- Operations (minimum)
  - accumulate, fetch-and-accumulate, swap, compare-and-swap

- Accumulate operators (minimum)
  - add, subtract, or, xor, and, min, max

- Run-time query: are these atomics coherent with the host?
  - If support both, have ability to request one or the other
Other things MPI wants: MPI RMA requirements

- Offset-based communication (not address-based)
  - Performance improvement: potentially reduces cache misses associated with offset-to-address lookup

- Programmatic support to discover if VA based RMA performs worse/better than offset based
  - Both models could be available in the API
  - But not required to be supported simultaneously

- Aggregate completions for MPI Put/Get operations
  - Per endpoint
  - Per memory region
Other things MPI wants: MPI RMA requirements

- **Ability to specify remote keys when registering**
  - Improves MPI collective memory window allocation scalability

- **Ability to specify arbitrary-sized atomic ops**
  - Run-time query supported size

- **Ability to specify/query ordering and ordering limits of atomics**
  - Ordering mode: rar, raw, war and waw
  - Example: “rar” – reads after reads are ordered
“New,” but becoming important

- Network topology discovery and awareness
  - …but this is (somewhat) a New Thing
  - Not much commonality across MPI implementations

- Would be nice to see some aspect of libfabric provide fabric topology and other/meta information
  - Need read-only access for regular users
API design considerations

- With no tag matching, MPI frequently sends / receives two buffers
  - (header + payload)
  - Optimize for that
- MPI sometimes needs thread safety, sometimes not
  - May need both in a single process
- Support for checkpoint/restart is desirable
  - Make it safe to close stale handles, reclaim resources
API design considerations

• Do not assume:
  • Max size of any transfer (e.g., inline)
  • The memory translation unit is in network hardware
  • All communication buffers are in main RAM
  • Onload / offload, but allow for both
  • API handles refer to unique hardware resources

• Be “as reliable as sockets” (e.g., if a peer disappears)
  • Have well-defined failure semantics
  • Have ability to reclaim resources on failure
Conclusions

- Many different requirements
  - High-level, low-level, and vendor-specific interfaces
- The MPI community would like to continue to collaborate
  - Tag matching is well-understood, but agreeing on a common set of interfaces for them will take work
  - Creating other high-level MPI-friendly interfaces (e.g., for collectives) will take additional work
Thank you!