2021 OFA Virtual Workshop

ACCELERATING HPC RUNTIMES SUCH AS OPENSHMEM WITH COPA

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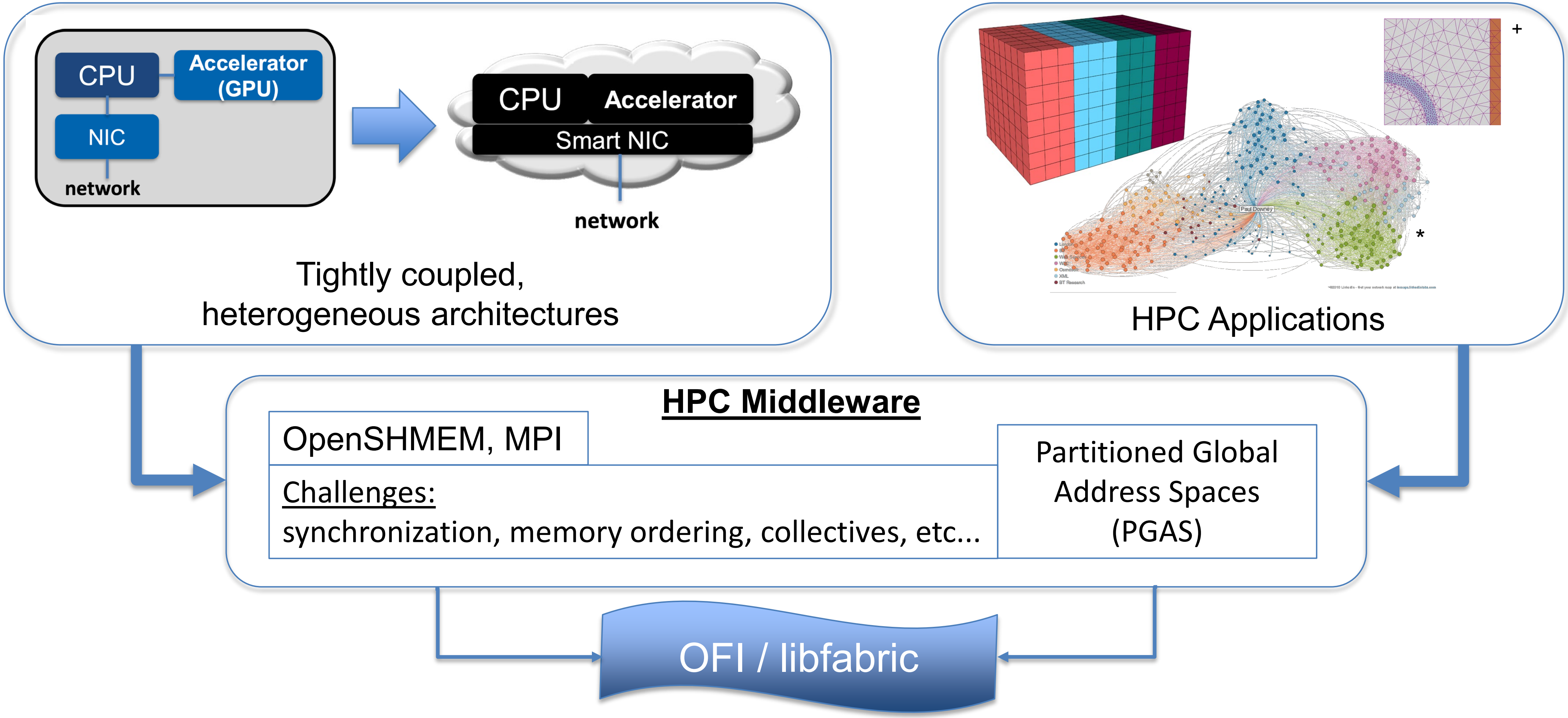
PROBLEM STATEMENT

FUTURE HPC ARCHITECTURES, APPLICATIONS, MIDDLEWARE



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HOW DO WE ACCELERATE APPLICATIONS?

Option 1:

Accelerate / improve middleware interface standards

For example:

OpenSHMEM v1.6:

- Non-blocking collectives
- Per-PE fence

Option 2:

Application-aware accelerator optimizations

Extend middleware interfaces

For example:

- FI_ACCELERATION*
- SHMEMX interfaces

Offload custom app-specific patterns

For example:

- Custom collective ops
- Data transformation (e.g. compression, filtering)

* Enhancing OFI for Invoking Acceleration Capabilities on an Integrated Networking/Accelerator Platform (COPA) (OFAWS 2020)

CAN COPA ACCELERATE MIDDLEWARE?

- Recently defined an acceleration model for COPA✯
- Can OpenSHMEM and MPI interfaces benefit from COPA's acceleration capabilities? *Likely – e.g. collectives, per-PE fence/quiet, put w/ signal, etc.*
- What about application-level optimizations? *Yes.*
- Co-design effort OpenSHMEM + COPA SW/HW teams.
- Our Primary Goal: Run full OpenSHMEM on COPA HW.
- Future Plan: Prototype and analyze our ideas for OpenSHMEM/MPI/collectives accelerations

✯ Configurable Network Protocol Accelerator (COPA)
For details, see Hot Interconnects (HOTI) Aug 2020 & IEEE Micro Jan 2021

COPA BACKGROUND

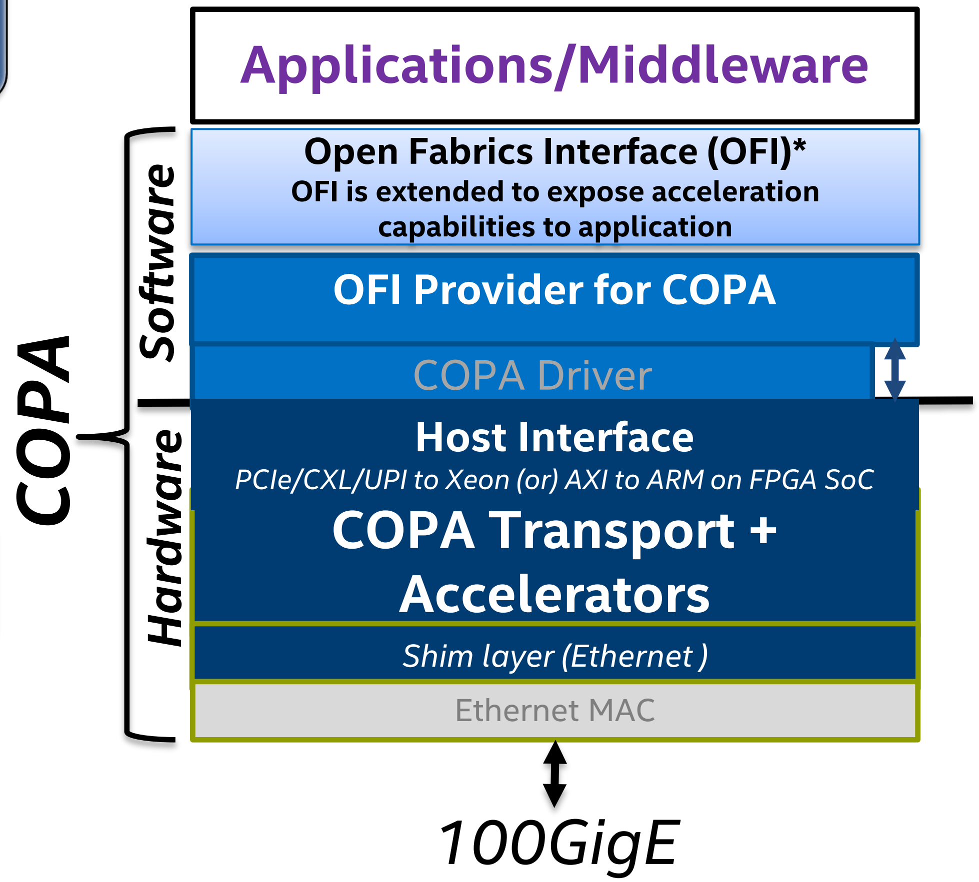
COPA† IS THE POC PLATFORM FOR OFI EXTENSIONS
(A SOFTWARE/HARDWARE FRAMEWORK FOR DISTRIBUTED FPGA COMPUTING)

Provides an integrated networking and accelerator framework with programming simplicity

- Supports RDMA (PUT/GET) based communication over commodity networks.
- Accelerators invoked as part of communication.
- Familiar environment developed around open standards (e.g. libfabric/OFI)

Customizable framework for specific deployments

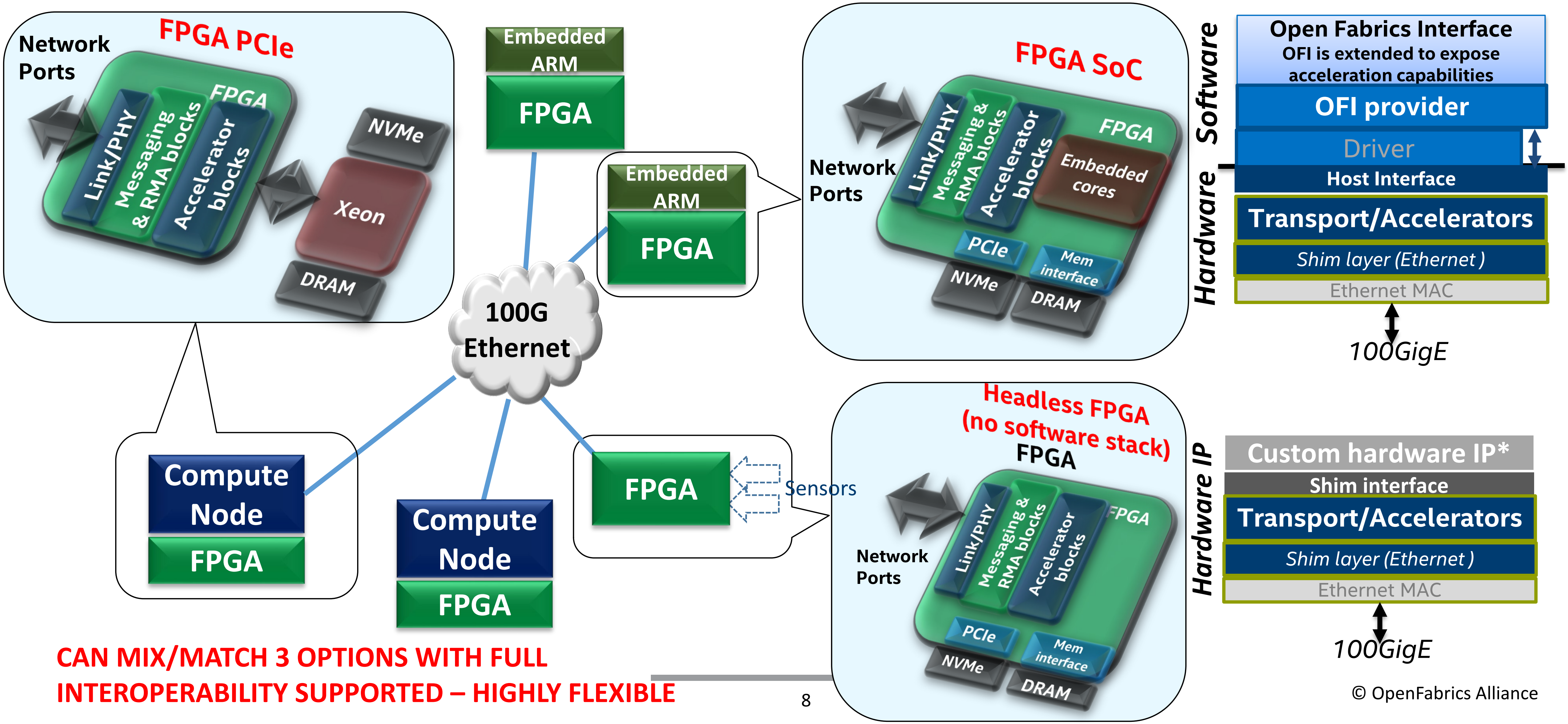
- Provides a modular architecture - can add necessary IP (accelerator) blocks and new features for a customized solution



†**COPA** = **CO**nfigurable network **P**rotocol **A**ccelerator

SYSTEM COMPONENTS

OFI stack on FPGA SOC and FPGA PCIe (currently on Stratix 10)



CAN MIX/MATCH 3 OPTIONS WITH FULL INTEROPERABILITY SUPPORTED – HIGHLY FLEXIBLE

COPA SOFTWARE STACK

Applications / Middleware

Open Fabrics Interface (OFI)

OFI provider for COPA (libfabric)

COPA hardware library (libchw)

COPA device driver

COPA FPGA hardware

- Open Fabrics Interface (OFI) implementation
- Main application programming interface to COPA functionality
- Extended for acceleration
- All access to COPA FPGA through COPA hardware library (libchw) for kernel bypass

- Main system programming interface to COPA FPGA hardware (ioctl syscalls)
- Opens device and mmap's hardware command queues and event queues into user process address space
- Optionally hardware emulation mode - COPA functional model

- Memory map CSRs and command queues at initialization time
- Initialize E2E connection table
- Provides memory pinning and virtual-to-physical address translation
- Not accessed on critical path - Userspace application software interacts with hardware using mmaped command queues

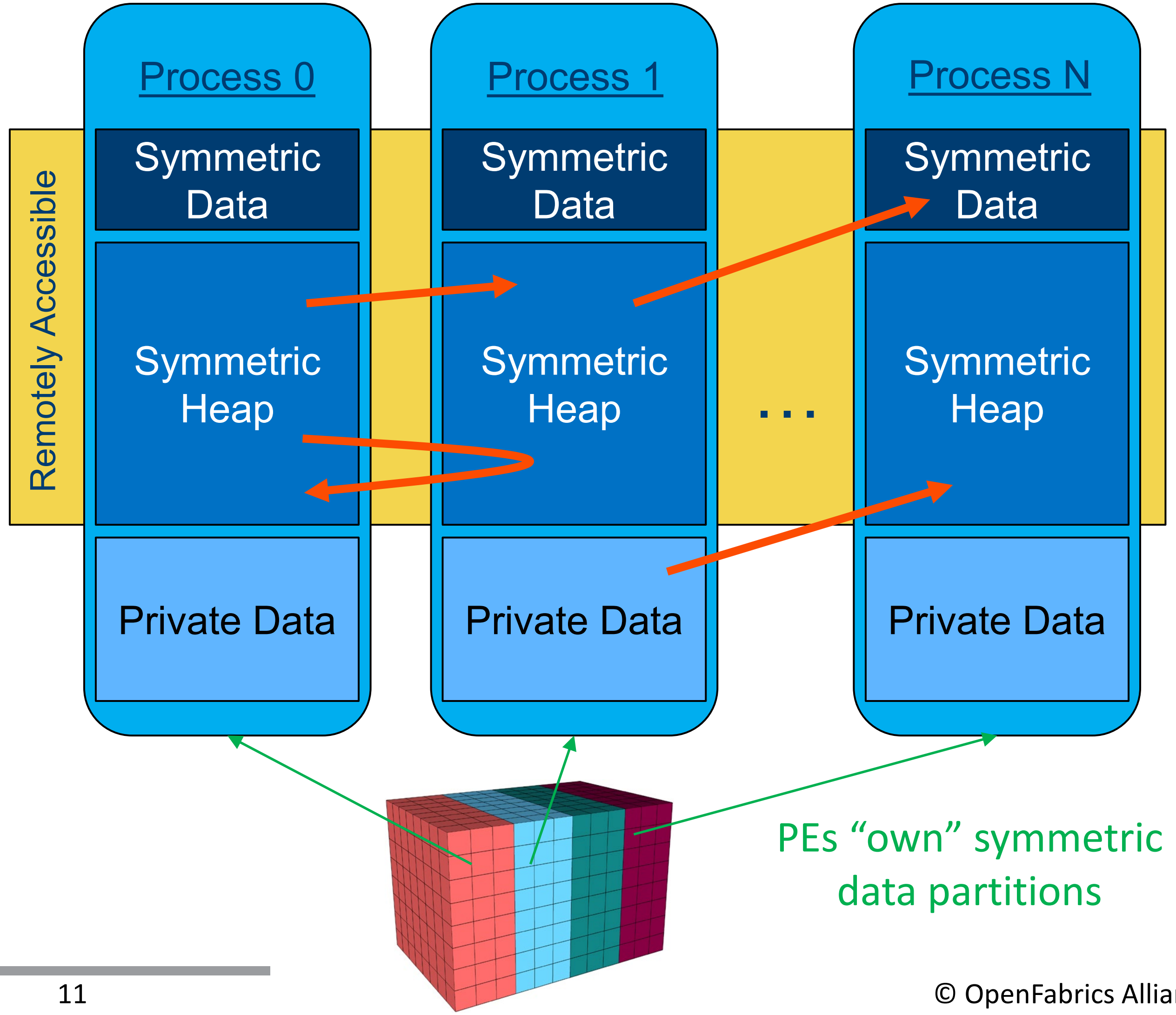
OPENSHMEM ACCELERATION

OPENSHMEM CRASH COURSE

OpenSHMEM:
- Open standard PGAS model: emphasizes one-sided operations (put/get/atomics w/ RDMA)
- Symmetric memory exposed for remote access across processing elements (PEs)
- This work uses Sandia OpenSHMEM (SOS) v1.5.0

Operations:
- *RMA/AMO*: put/get, remote atomics
- *Collectives*: barrier, broadcast, reductions, etc.
- *Memory ordering*: fence and quiet

Specification:
- Currently version 1.5
- Upcoming: spaces, NB collectives, per-PE fence/quiet, and more



* OpenSHMEM and OFI: Better Together (OFAWS 2018)

PRACTICAL MATTERS / WORKAROUNDS

- **Some practical matters need to be addressed to run SOS on COPA:**
  - **FI_CONTEXT2:**
    - COPA leverages FI_CONTEXT2 (64B), but SOS doesn't currently pass contexts to communication ops.
    - Solution: COPA now supports an internal context2 pool so apps don't need to bother with contexts.
  - **FI_PROGRESS_MANUAL:**
    - COPA does not yet support full automatic progress; SOS (the stable release) doesn't fully support manual.
    - Solution: hacked an unofficial version of SOS with a timer-based progress thread (caveat: no private contexts).
  - **FI_MR_LOCAL:**
    - HW requires *all* buffers to be registered, but OpenSHMEM supports src buffers outside symmetric heap.
  - Registered memory must be physically contiguous – this means we might have to strip out global/static variables.
  - Remote atomics support is currently in software only.
  - Optional, not yet supported: FI_THREAD_DOMAIN, FI_RMA_EVENT, FI_FENCE, FI_DELIVERY_COMPLETE
  - **<u>Fence/quiet operations leverage libfabric counters</u>**

- **Let's dive into the <u>counters</u> – they're interesting and important.**

SANDIA OPENSHMEM PUT/GET COUNTERS

Example "trace" of put/get counters througout a simple OpenSHMEM program:

SHMEM Program	pending put	pending get	put	get
`put(..., PE1)`	1	0	0	0
`put(..., PE2)`	2	0	0	0
`get(..., PE1)`	2	1	0	0
`get(..., PE2)`	2	2	1	0
`amo_inc(..., PE1)`	3	2	1	0
`amo_fetch(..., PE2)`	3	3	1	2
`fence*/quiet()`	3	3	3	3

Local atomics (pending put, pending get)

libfabric counters (put, get)

1 put/get counter pair per SHMEM ctx

Target (RX) counter support, if available

`* fence != quiet` on ordered networks in SOS, get_wait() only...

COPA HARDWARE COUNTERS

- Implemented as Control Status Registers (CSRs)
- CSRs are setup to atomically operate on counters (read/write, inc., trigger)
- COPA supports 512 counters now, but this number is flexible.
- All CSRs are mapped to individual PEs for counter isolation.
- Reading CSRs is expensive, so HW periodically performs a write-back of the counter values to host memory.
- Write-backs occur only during wait() operations:
  - no timer-based write-backs yet, but could be added later.
  - wait() has a desired trigger value. When met, HW does a write-back.
- Incrementing by 0 performs write-back to host memory.

COPA HARDWARE COUNTERS

COPA HW counters enable:

- An optimized per-PE fence/quiet interface (e.g., as proposed for OpenSHMEM v1.6):

  Current (v1.5) interface:

`shmem_fence()` `shmem_quiet()`	`shmem_ctx_fence(shmem_ctx_t ctx)` `shmem_ctx_quiet(shmem_ctx_t ctx)`

  Proposed (v1.6) interface:

`shmem_pe_fence(ctx, target_pe)` `shmem_pe_quiet(ctx, target_pe)`	`shmem_ctx_pe_fence(ctx, target_pe)` `shmem_ctx_pe_quiet(ctx, target_pe)`

- Per-operation completion tracking in the OpenSHMEM runtime
  - Applications *tend* to quiet many puts, gets, or AMOs in isolation (i.e. not mixed)
  - Possible advantage in tracking operation-specific completions

CURRENT STATUS

Current Status:

- We are very close to full SOS support with the COPA libfabric provider.
- Several temporary workarounds are in place (see slide 12), next steps are to modify them.

Future Work:

- MPI validation – potentially fewer workarounds (manual progress support, FI_CTX2, etc.)
- Implement proposed OpenSHMEM optimizations (in HW where possible).
- Performance analysis of microbenchmarks and key applications.

CLOSING REMARKS

OFI's open standard & definition of communication API agnostic to protocols/hardware makes it ideal to include acceleration extensions

Summary:

- COPA provider exposes acceleration capabilities via OFI.
- Several opportunities to accelerate OpenSHMEM with COPA+OFI.
- Co-design HW/SW effort is underway and inspiring promising ideas.
- COPA counters are flexible, performant, OFI/SOS compatible, and enable optimizations like per-PE fence/quiet and per-op tracking.

Future:

- Long-term prospects to extend OpenSHMEM, MPI, and OFI interfaces and capabilities.
- Compute is moving into the fabric, and COPA will customize for HPC application and middleware accelerations.

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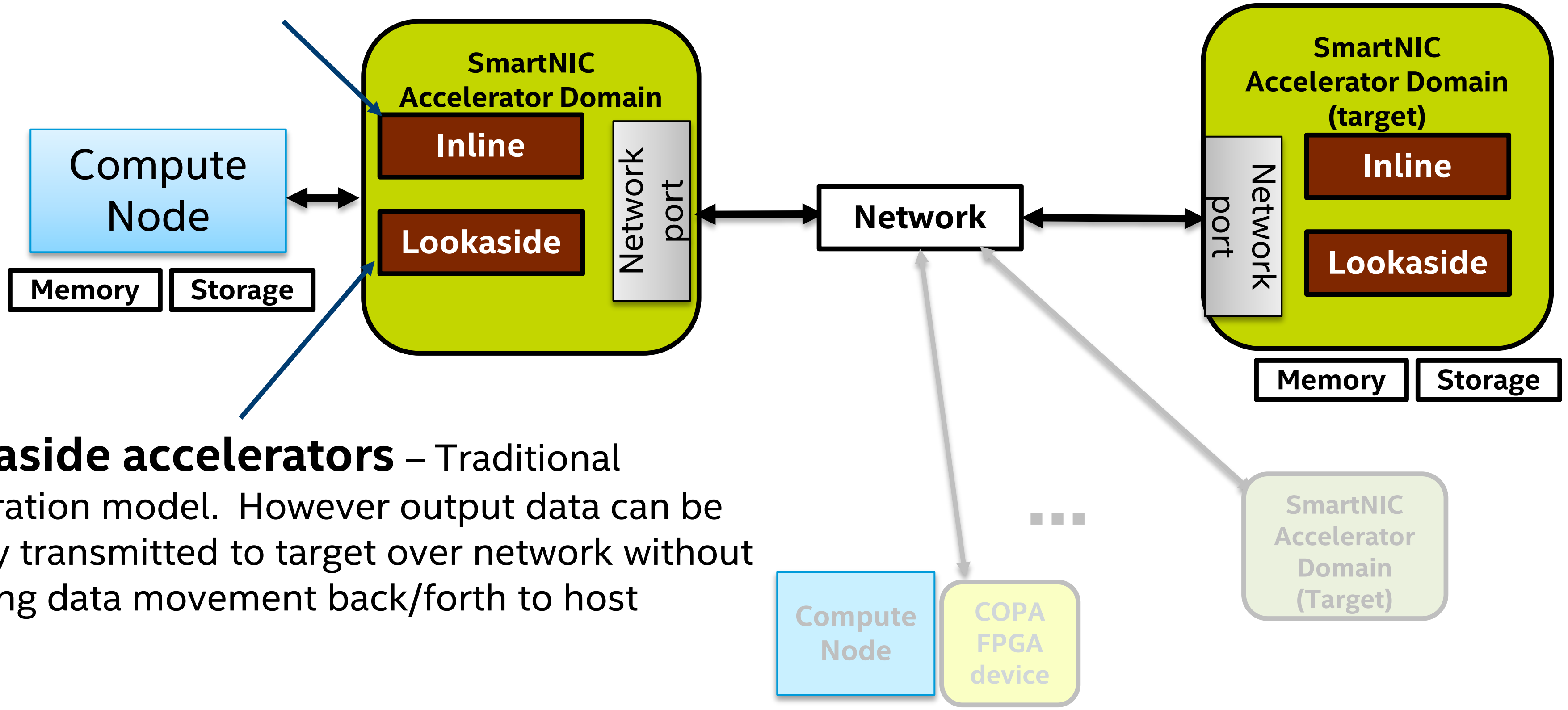
THANK YOU

BACKUP

ACCELERATOR MODELS (INTEGRATED WITH NETWORKING)

Inline accelerators perform compute on data during transmit/receive operation (streaming model)

Remote Mode Inline/Lookaside accelerators can be triggered by incoming packet. **No host/OS involvement**



Naturally extends to offloading collectives, reduction, atomics, distributed hash lookup etc.

Lookaside accelerators – Traditional acceleration model. However output data can be directly transmitted to target over network without requiring data movement back/forth to host

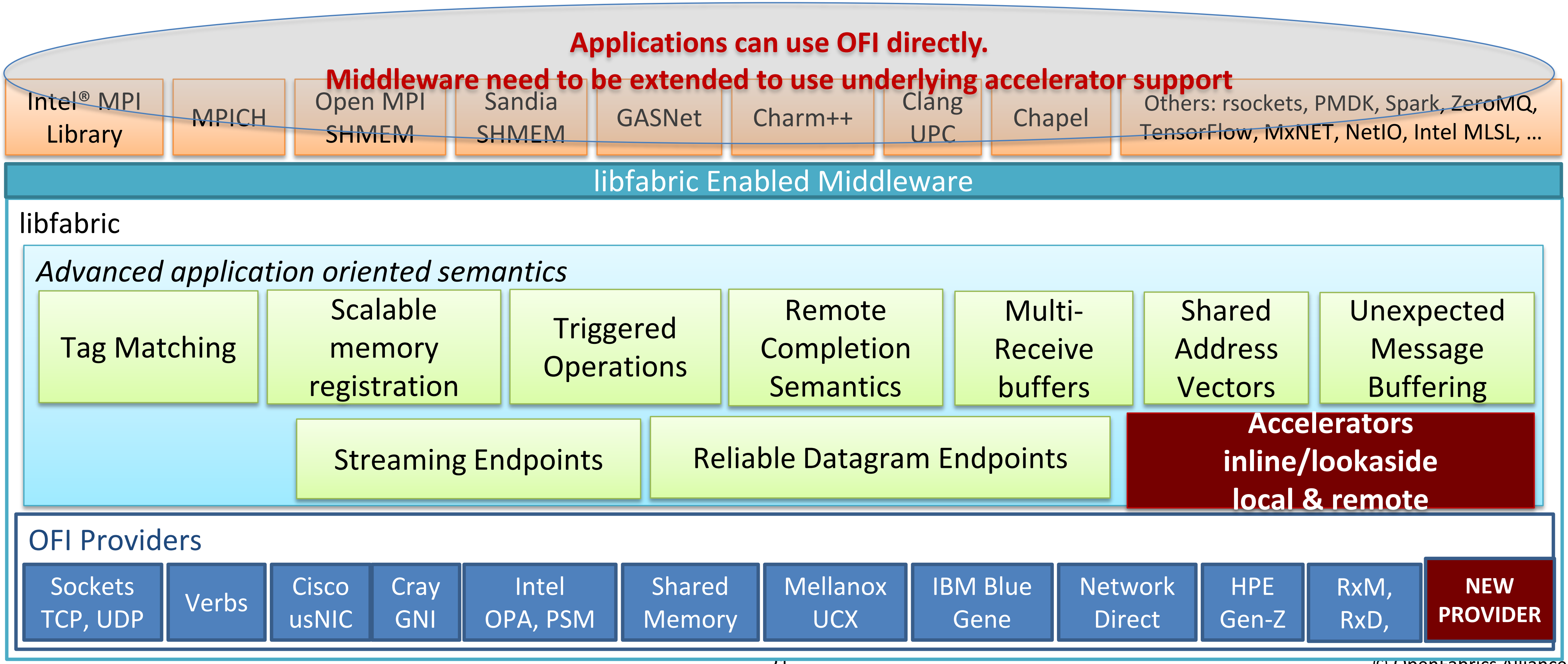
Could hang off a switch port (headless) or be an integral part of the switch

Need for a standard API to expose acceleration modes to middleware & applications

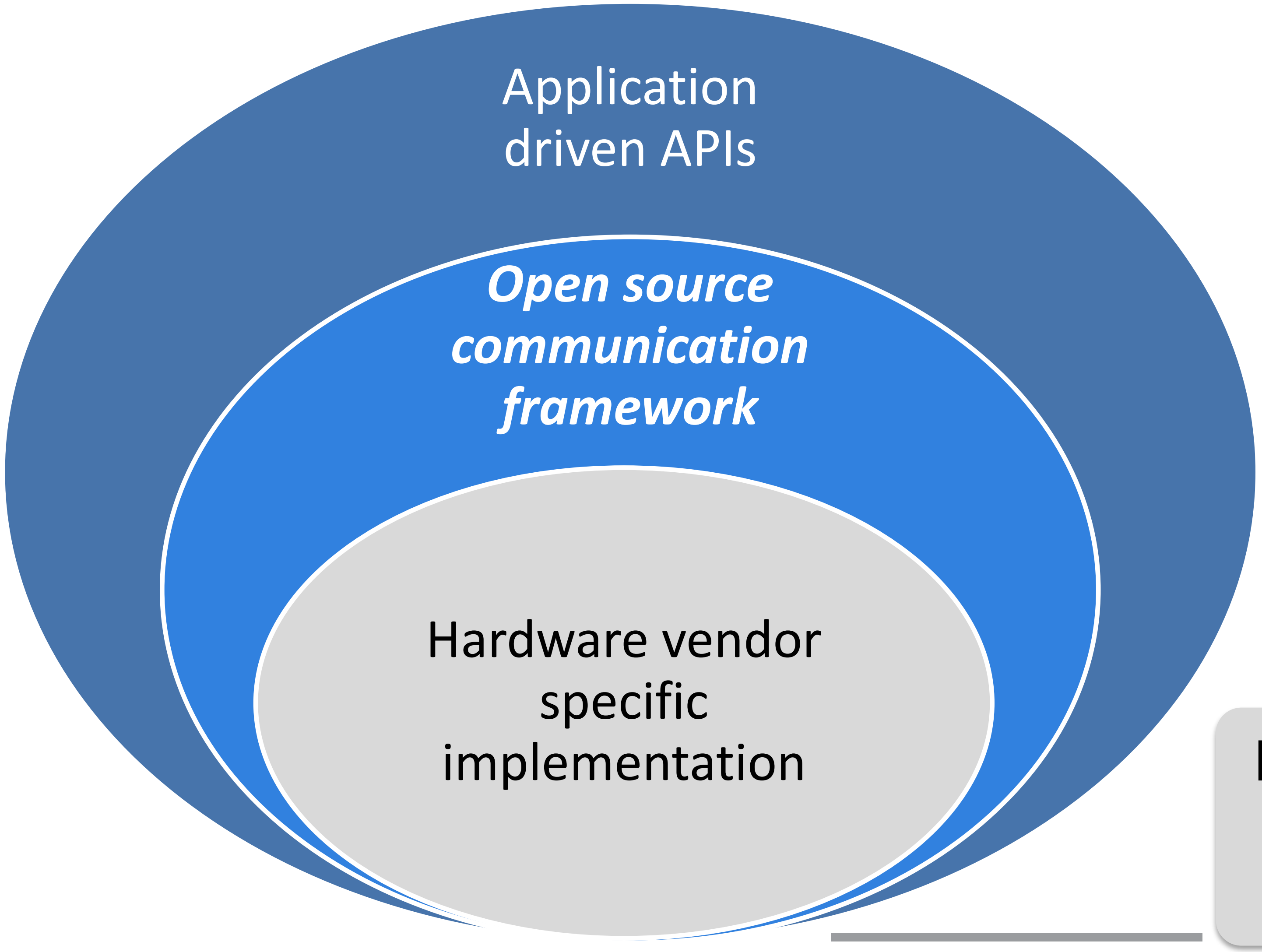
APPROACH – USE OFI (WITH EXTENSIONS)

Extend a network API to include acceleration support to support a truly scalable model

- **Extending an accelerator API (e.g. OpenCL) to support networking is not scalable**



CURRENT VISION OF SOLUTION



Based on internal hardware prototyping – FPGA-based

APIs targeting application use of specific accelerations

Extend existing communication framework to support acceleration functions

Define mechanism to pass input/output parameters and invoke acceleration

OFI COPA PROVIDER

- **Full featured OFI provider**
- **Only small changes needed to add acceleration to existing OFI-enabled middleware and applications**
- **<u>Temporary</u> until official OFI support**
- **Minimal OFI extensions to enable "inline" and "lookaside" COPA acceleration**
  - Extend semantics of data structures and operations
  - Define new FLAGS for acceleration
- **Implements a wide variety of interfaces to support many kinds of HPC middleware**
  - FI_MSG, FI_TAGGED, FI_RMA
  - FI_PROGRESS_MANUAL, FI_THREAD_COMPLETION, FI_AV_MAP
  - FI_EP_RDM

ENABLE ACCELERATION

- **New FI_ACCELERATION flag informs provider application wants inline accelerator to be invoked during a data movement operations**

- **FI_ACCELERATION flag can be set on the endpoint object to invoke acceleration on all endpoint data movement operations**
  - fi_control() with FI_SETOPTS

- **Alternatively, FI_ACCELERATION flag can be specified for individual data movement operations**
  - fi_write_msg()
  - fi_read_msg()

ACCELERATOR OUTPUTS

- **Output data may be provided as a result of acceleration**
- **Available for endpoints bound to a completion queue initialized with data format**
  - FI_CQ_FORMAT_DATA
  - FI_CQ_FORMAT_TAGGED
- **FI_ACCELERATION flags, etc., are set in the flags field**
  - FI_CQ_FORMAT_MSG

- **Normally the completion entry data field is for remote metadata**
- **Extend the data field semantics for initiator acceleration output**

```
struct fi_cq_data_entry {
  void     *op_context; /* operation context */
  uint64_t flags;       /* completion flags */
  size_t   len;         /* size of received data */
  void     *buf;        /* receive data buffer */
  uint64_t data;        /* completion data */
};
```

LOOKASIDE ACCELERATION

- **Local operation – no fabric communication involved**
- **Complex accelerators that do not fit in the packet pipeline (inline acceleration)**
- **Same mechanism as inline to invoke lookaside acceleration**
  - fi_read(), fi_write(), etc.
  - FI_ACCELERATION
- **Lookaside accelerator flags**
  - FI_LOOKASIDE_ACCELERATION_*
- **Current restrictions**
  - physically contiguous memory for all inputs and outputs