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Porting UNH EXS from verbs to OFI

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#OFADevWorkshop

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Background

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UNH EXS (Extended Sockets)

https://www.iol.unh.edu/expertise/unh-exs

- Based on ES-API (Extended Sockets API) published by the Open Group
- Extensions to sockets API to provide asynchronous, zero-copy transfers
  - Memory registration (exs_mregister(), exs_mderegister())
  - Event queues for completion of asynchronous events (exs_qcreate(), exs_qdequeue(), exs_qdelete())
  - Asynchronous operations (exs_send(), exs_recv(), exs_accept(), exs_connect())
- UNH EXS supports SOCK SEQPACKET (reliable message-oriented) and SOCK STREAM (reliable stream-oriented) modes
- No SOCK DGRAM (unreliable datagram) mode (yet)

Motivation

- Enable porting UNH EXS to future non-IB fabrics
- Prepare for future Windows Network Direct port
- Battle-test implementation of libfabric providers

Status of OFI port

- Successfully runs over OFI verbs provider and OFI sockets provider
- Still some missing functionality (due to missing functionality in both providers)

Connection Establishment Issues

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EXS Connection Establishment

- ES-API specifies asynchronous exs_accept() and exs_connect() functions
- How to create a socket not specified by ES-API—intention was to rely on existing sockets API functions
  - socket(), bind(), listen()
- UNH EXS provides exs_socket(), exs_bind(), exs_listen() with same interface as POSIX

Server connected socket setup

POSIX Sockets

```
struct addrinfo *ai;
hints.flags = AI_PASSIVE;
getaddrinfo(name, service, &hints,
   &ai);
lfd = socket(ai->ai_family,
             ai->ai_socktype,
             ai->ai_protocol);
bind(lfd, ai->ai_addr, ai->ai_addrlen);

listen(lfd, 0);

afd = accept(lfd, &peer_addr,
             &peer_addrlen);
```

UNH EXS

```
exs_init(EXS_VERSION1);
struct addrinfo *ai;
hints.flags = AI_PASSIVE;
getaddrinfo(name, service, &hints,
   &ai);
fd = exs_socket(ai->ai_family,
                ai->ai_socktype,
                ai->ai_protocol);
exs_bind(lfd, ai->ai_addr,
             ai->ai_addrlen);
exs_listen(lfd, 0);
accept_queue = exs_qcreate(n);
exs_accept(lfd, &av, n, 0,
           accept_queue);
/* ... */
exs_qdequeue(accept_queue,
             &events, n, NULL);
afd = EXS_EVT_NEW_SOCKET(events[m]);
```

Client connected socket setup

POSIX Sockets

```
getaddrinfo(name, service, &hints,
            &ai);
fd = socket(ai->ai_family,
            ai->ai_socktype,
            ai->ai_protocol);
bind(fd, ai->ai_addr,
     ai->ai_addrlen);

connect(fd, ai->ai_addr,
        ai->ai_addrlen);
```

UNH EXS

```
exs_init(EXS_VERSION1);
getaddrinfo(name, service, &hints,
            &ai);
fd = exs_socket(ai->ai_family,
                ai->ai_socktype,
                ai->ai_protocol);
exs_bind(fd, ai->ai_addr,
         ai->ai_addrlen);
connect_queue = exs_qcreate(n);
exs_connect(fd, ai->ai_addr,
            ai->ai_addrlen, 0, NULL,
            connect_queue, &ctx);
/* ... */
exs_qdequeue(connect_queue,
             &events, n, NULL);
```

POSIX/EXS: getaddrinfo()

- POSIX-defined function used to perform name resolution in protocol-agnostic fashion
  - **Not** part of original sockets API, came in with IPv6
  - Use of getaddrinfo() is **optional** in sockets
- Arguments
  - Node and service strings
  - Hints structure limiting returned entries
- returns linked list of struct addrinfo
  - **Elements** of this structure are passed to socket(), bind(), and connect()
  - **No POSIX/EXS function takes struct addrinfo as input**

OFI: fi_getinfo()

- Functionally analogous to POSIX getaddrinfo() and verbs rdma_getaddrinfo()
- Address of local/remote host specified as either:
  - node and service strings
  - src_addr and dst_addr fields of hints structure
- Returns struct fi_info which is **directly passed** to OFI “constructor” calls
  - Users **required** to call fi_getinfo() before any other OFI function
  - **Different from sockets (POSIX and EXS), in which no call takes struct addrinfo as a parameter**
- How to deal with this requirement?

fi_getinfo(): Obvious Strategy

- Implement new exs_getaddrinfo() in terms of fi_getinfo()
  - Pass arguments directly to fi_getinfo()
  - Embed corresponding struct fi_info in each returned struct addrinfo
  - Allows user some limited choice of fabric provider
- Problem: fi_info structure needed to perform exs_listen()/exs_connect() calls, but struct addrinfo not passed in
  - **Makes this solution untenable without new EXS API functions**

fi_getinfo(): Actual Strategy

- Call fi_getinfo() within exs_listen() and exs_connect() that take sockaddr parameter
- Pass struct sockaddr via hints to fi_getinfo()
- fi_info struct stored as part of connection state
- **Disadvantage: hides decision of which fabric provider to use from user**
  - Current policy is to use first fi_info entry for which listen/connect succeeds

OFI: Endpoints

- Listening and connecting sockets both created with socket() system call
  - EXS retains this behavior
  - Verbs mimics behavior with rdma_create_id()
- OFI: Listening (passive) and connecting endpoints are completely separate types! (This is good API design)
- **Cannot associate socket with OFI endpoint at time of exs_socket() call**

Implementation Issues

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exs_socket() implementation

Problem: need a unique fd to return to user

Existing Verbs

```
conn->channel =
        rdma_create_event_channel();
rdma_create_id(conn->channel, ...);
return conn->channel->fd;
```

- RDMA CM **event channel** and **cm_id** are provider independent
- Return event channel fd as the fd of the socket

Libfabric

```
dummy_fd = socket(...);
conn->hints = fi_allocinfo();
/* initialize hints */
return dummy_fd;
```

- Event queues and endpoint structures provider-dependent
- Does not allocate any fabric resources yet
- Create dummy socket and return its fd

exs_bind() implementation

Existing Verbs

```
rdma_bind_addr(conn->cm_id,
               address);
```

libfabric

```
new_conn->hints->src_addrlen
        = address_len;
memcpy(new_conn->hints->src_addr,
       address, address_len);
```

Libfabric implementation does not actually bind socket.

This means that exs_getsockname() on bound but not listening/connected socket will not return ephemeral port number—**incompatibility with Linux sockets**

exs_listen() implementation

Existing Verbs

```
rdma_listen(conn->cm_id, backlog);
```

libfabric

```
fi_getinfo(EXS_FI_VERSION, NULL, NULL,
           0, &new_conn->hints,
           &all_info);
for (auto &info : all_info) {
    fi_fabric(info->fabric_attr,
        &new_conn->fabric, new_conn);
    fi_passive_ep(fabric, info,
        &new_conn->pep, new_conn);
    fi_eq_open(fabric, eq_attr,
         &new_conn->cm_eq, new_conn);
    fi_pep_bind(new_conn->pep,
         &new_conn->cm_eq->fid, 0);
    fi_listen(new_conn->pep);
    break;
}
```

exs_connect() implementation

Existing Verbs

```
/* User thread */
ret = rdma_resolve_addr(conn->cm_id,
          address, 2000);
return ret;

/* EXS internal thread */
rdma_get_cm_event(conn->event_channel,
          &event);
rdma_resolve_route(conn->cm_id, 2000);
rdma_get_cm_event(conn->event_channel,
          &event);
/* Set up CQ, QP, etc. */
rdma_connect(conn->cm_id, ...);
```

libfabric

```
fi_getinfo(EXS_FI_VERSION, NULL, NULL,
           0, &new_conn->hints, &info);
fi_fabric(info->fabric_attr,
    &new_conn->fabric, new_conn);
fi_domain(new_conn->fabric, info,
    &new_conn->domain, new_conn);
fi_endpoint(new_conn->domain, info,
    &new_conn->ep, new_conn);

/* Set up/bind CQ, EQ, etc. */
fi_connect(new_conn->ep,
           info->dest_addr, ...);
```

Connection Establishment: Summary of Differences

- CM event queues
  - Verbs: provider independent
  - OFI: provider-specific
- Address resolution
  - Verbs: rdma_getaddrinfo optional
  - OFI: fi_info struct required
- Listening endpoint
  - Verbs: same type as connecting endpoint
  - OFI: listening and connecting endpoint distinct types with distinct constructors
- Client connection establishment
  - Verbs: requires multiple asynchronous operations in sequence
  - OFI: single fi_connect operation

Verbs Inline Data vs. OFI Injected Data

- Both copy data into HW memory at post time; remove need to register memory
- OFI Injected data:
  - **FI_INJECT flag** to fi_sendmsg, fi_writemsg: Behaves identically to verbs IBV_SEND_INLINE flag to ibv_post_send
  - **fi_inject call**: Injects data and suppresses completion, **even if completions were requested for all operations**!
  - fi_inject call may lead to CQ overrun unless application maintains and checks counter on every send

Write with remote CQ data

- Verbs: incoming RDMA WRITE with immediate data consumes a posted receive WR
  - This makes no sense semantically
- OFI: optional to consume a posted receive WR
  - If no recv WR consumed, op_context field of completion entry will be NULL
  - **Missing feature: detect this at initialization time, to avoid creating “dummy” buffers/receive work requests**
    - GitHub: libfabric issue #666

fi_shutdown() vs. rdma_disconnect()

- rdma_disconnect()
  - Transitions QP to error state
  - Flushes all pending WRs to CQ
  - Causes completion event on completion channel
  - In UNH EXS: wakes up completion thread and signals connection shutdown
- fi_shutdown()
  - Behavior for outstanding operations not specified
  - **No guaranteed wakeup for thread blocked on completion queue**
    - EXS Workaround: use timeout on blocking CQ read call

Performance

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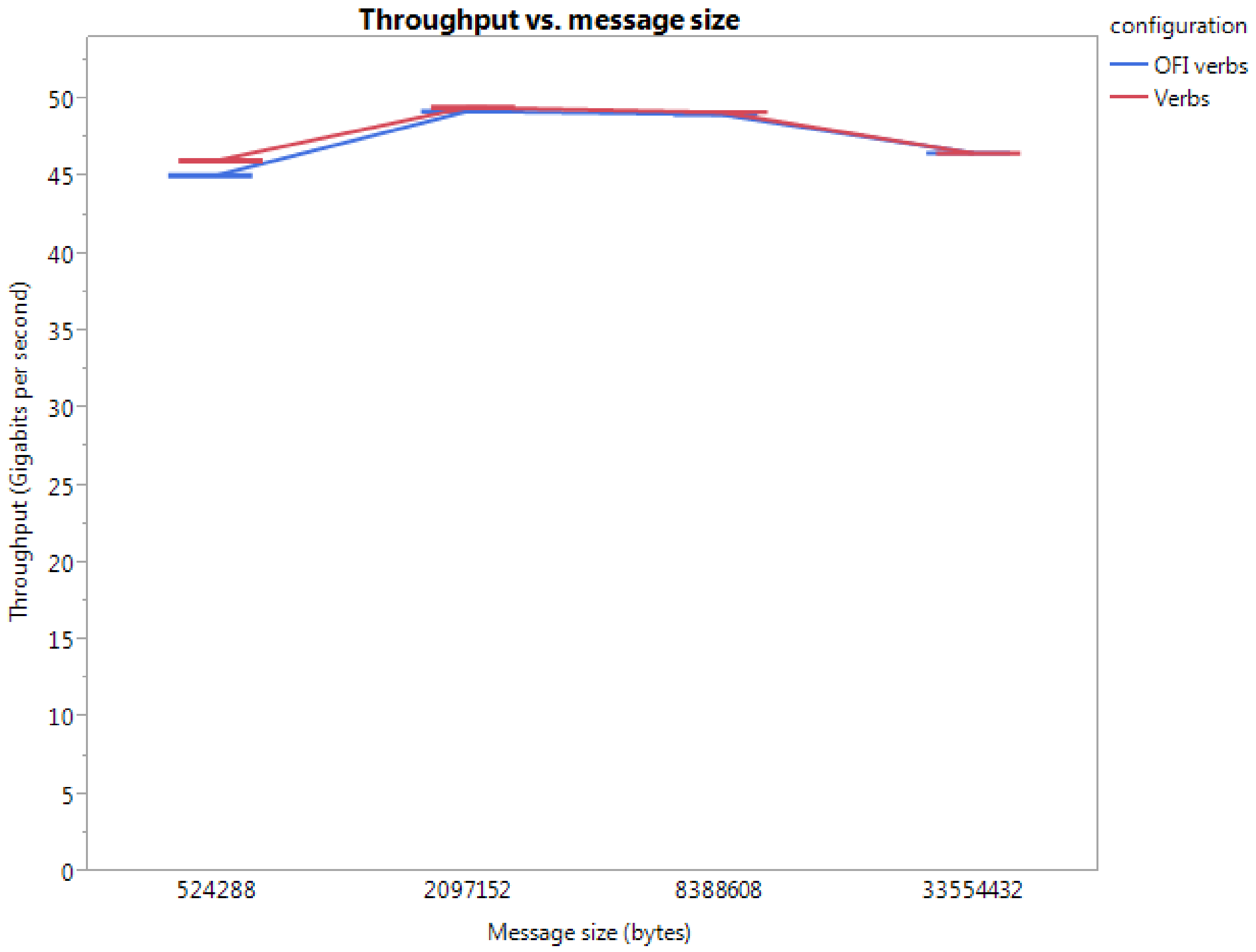
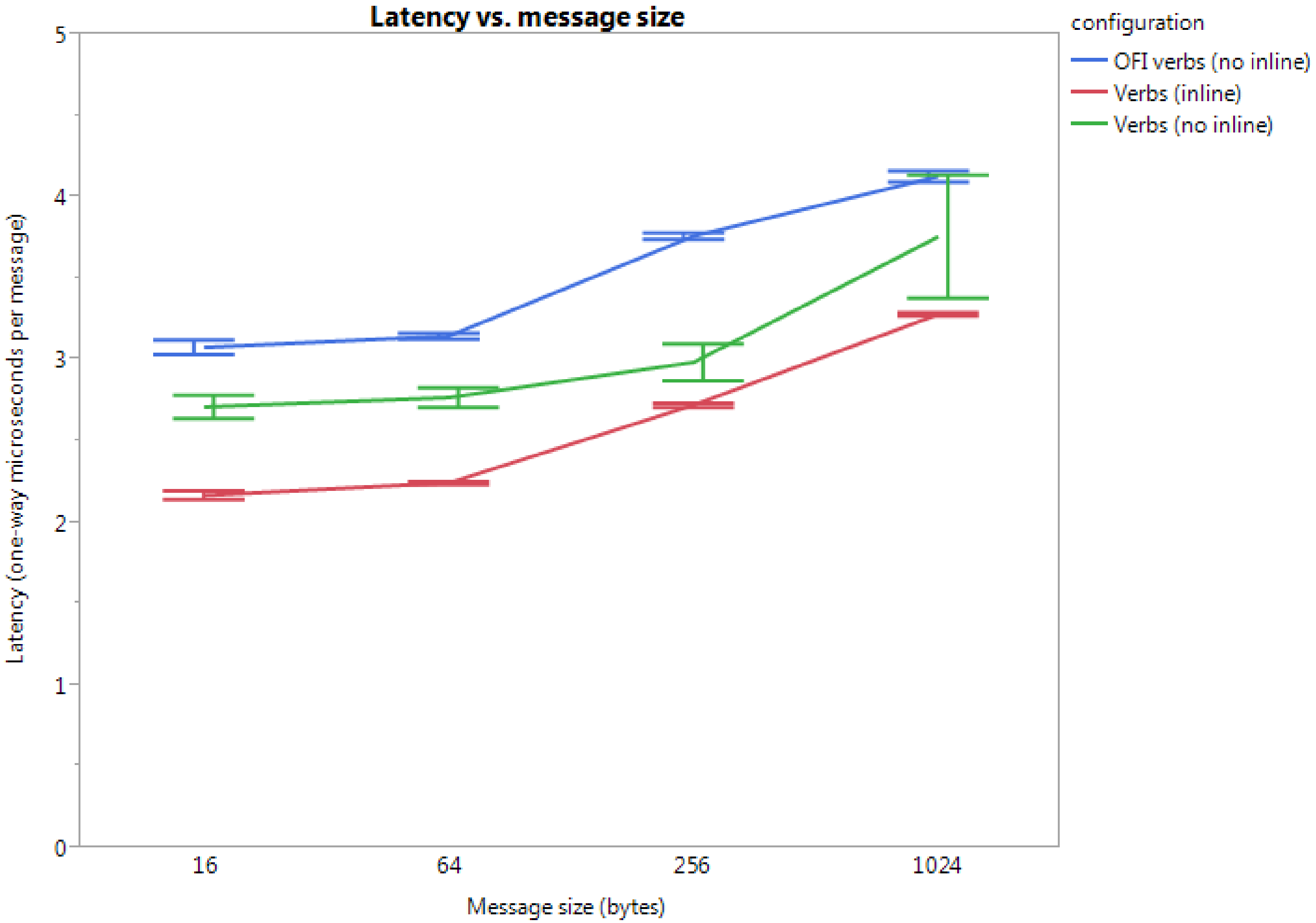
Performance Tests

- Using Mellanox ConnectX-3 FDR InfiniBand HCAs
  - Connected via Mellanox SX6036 FDR InfiniBand switch
- Scientific Linux 6.4 with OFED 3.5-2
  - libibverbs 1.1.7
  - librdmacm 1.0.17
  - libfabric git master
- OFI verbs provider vs. existing Verbs
- Message-oriented sockets
- Tests performed: blast (throughput), ping (latency)

Throughput—little difference



Latency—big difference



Conclusions

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Conclusions

- Successfully ported UNH EXS to OFI verbs, sockets providers
- Porting UNH EXS uncovered many bugs and missing features in providers
- Revealed some differences between OFI and Verbs:
  - OFI distinguishes between listening and connecting endpoints, Verbs doesn’t
  - OFI “constructors” take fi_info as a parameter, Verbs don’t
  - OFI event queues, wait sets, etc. are per-provider, Verbs are system-wide
  - OFI received immediate data may or may not consume a receive WR, Verbs always does
  - OFI doesn’t guarantee wakeup from blocking EQ/CQ calls on connection shutdown, Verbs does

Thank You

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Backup

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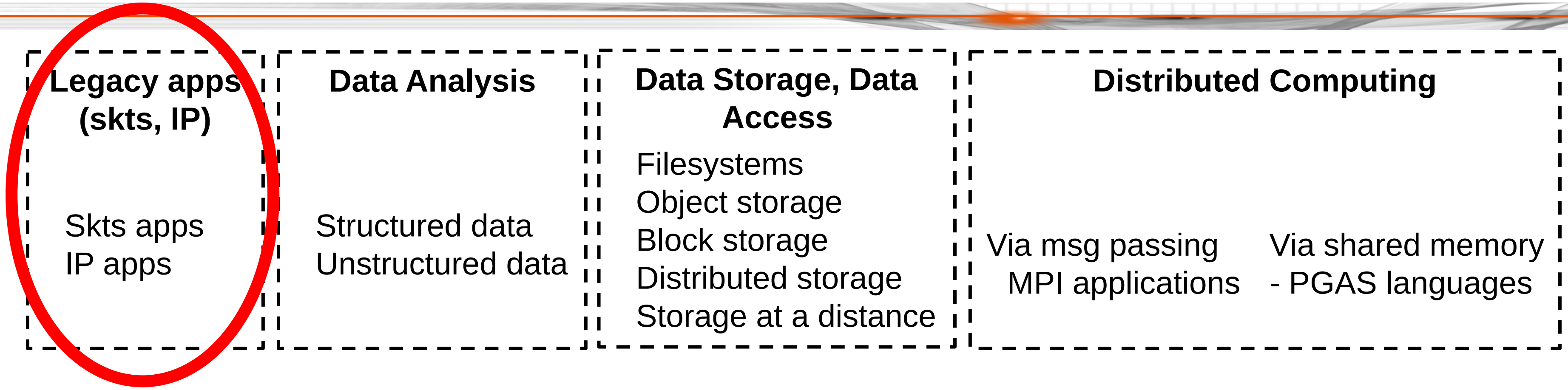
UNH EXS Classification



Legacy apps (skts, IP)	Data Analysis	Data Storage, Data Access	Distributed Computing	
Skts apps IP apps	Structured data Unstructured data	Filesystems Object storage Block storage Distributed storage Storage at a distance	Via msg passing MPI applications	Via shared memory - PGAS languages

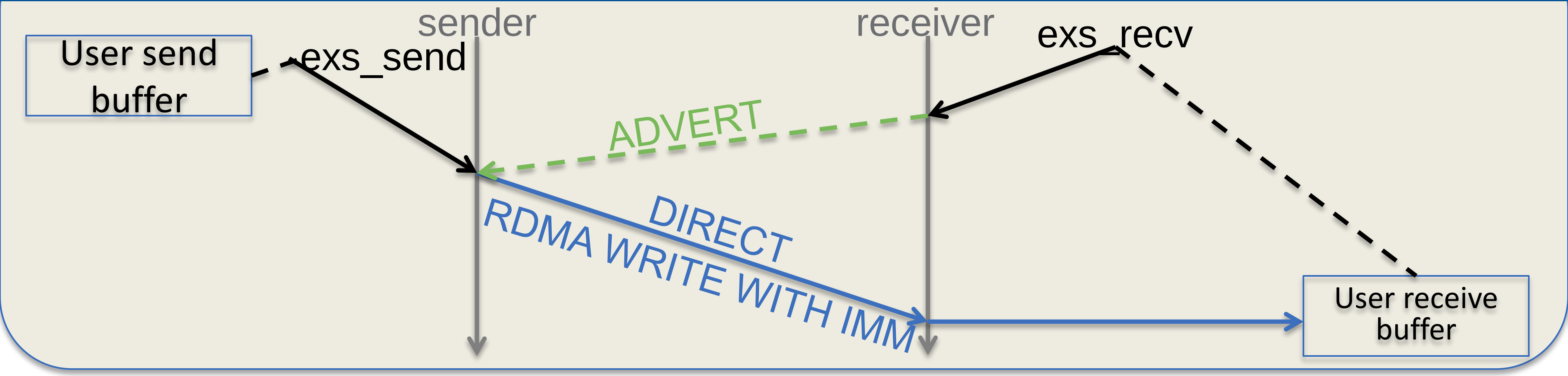
- Middleware for legacy applications
- Use of multiple providers (possibly at same time)
- Limited to reliable connected endpoints for now
- Required data transfer operations:
  - – SEND/RECV (for control messages)
  - – RDMA WRITE WITH IMM (for data)

Status of OFI port

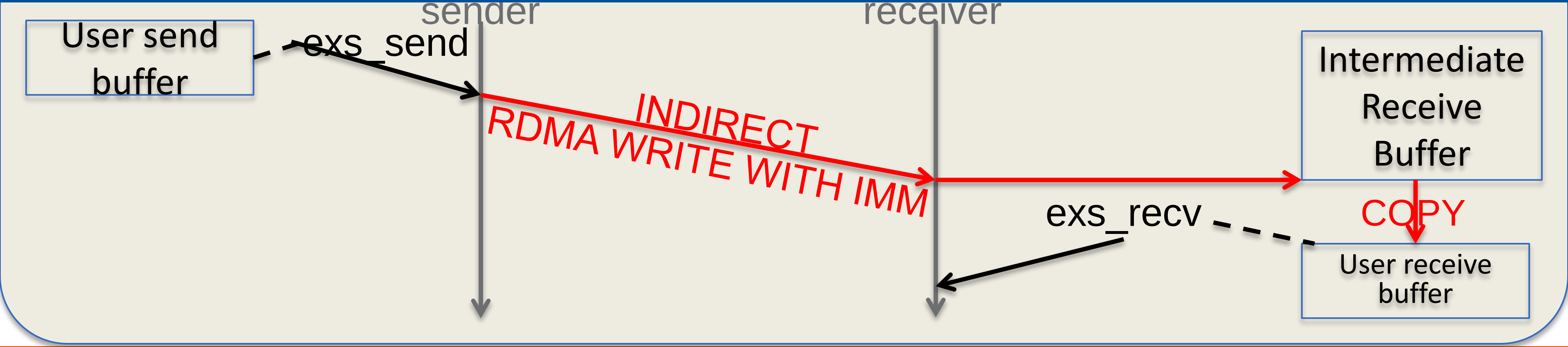
- OFI port on separate branch; mainline still uses Verbs
  - Plan to merge OFI support into mainline when complete
  - OFI (libfabric) or Verbs (libibverbs + librdmacm) will be selectable at compile time

EXS Data Transfer Protocols

Direct Transfer (Message and Stream Sockets)



Indirect Transfer (Stream sockets only)



exs_shutdown()/exs_close()

- We wish to ensure that all messages arrive at destination endpoint prior to disconnect
- Verbs EXS shutdown: EOF message exchange
  - User calls exs_close()
    - Local fd invalidated
    - Returns immediately; completes asynchronously
  - Local endpoint completes outstanding sends
  - Local endpoint sends EOF message
  - On receive EOF, remote endpoint sends EOF reply
  - On receive EOF reply completion, local endpoint calls rdma_disconnect()
  - Disconnected CM event fires and all WRs flushed
  - Once socket refcount == 0, close event posted