ALFA: A framework for building distributed applications

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Developed in common by FairRoot Group (GSI), FAIR experiments and ALICE
ALFA has a data-flow based model:

Message Queues based multi-processing
Works locally and across most networks!

- Ethernet
  - ZMQ, nanomsg
- InfiniBand (IPoverIB, RDMA)
  - ZMQ, nanomsg, OFI
- Shared Memory Transport
  - Boost
ALFA building block (FairMQ Devices)

- Device takes/passes ownership of data
- Framework user sees only the callback to his algorithm
- Different channels can use different transport engines
FairMQ Transport: General concepts:

- Hide all transport-specific details from the user.
- Clean, unified interface to different data transports.
- Combinations of different transport in one device in a transparent way.
- Transport switch via configuration only, without modifying device/user code -> same API for all transports.
FairMQ Transport: Ownership

- **Message owns data.**
- **Sender device (user code) passes ownership of data to framework with send call.**
- **Framework transfers to next device, passes ownership to receiver (no physical copy of the data with shared memory transport).**
- **No sharing of ownership between different devices - if the same message is needed by more than one receiver it is copied.**
FairMQ Shared Memory Transport

- **Device 1**
  - **msg**
  - Meta data: (handle + size)

- **Node**
  - **msg**
  - **shmem**
  - Handle (valid for node)
  - Pointer to data (valid for process)

- **Device 2**
  - **msg**
  - Meta data: (handle + size)

- **Shared memory segment (boost::interprocess::managed_shared_memory)**
FairMQ Shared Memory Transport
Implementation

• boost::interprocess library for management and allocation of shared memory - cross-platform shared memory implementation with many features such as different allocation algorithms, shmem STL-like containers, shmem smart pointers, message queues and many more.

• ZeroMQ library for transfer of the meta information associated with the memory - allows us to reuse communication patterns of ZeroMQ (PUSH/PULL, PAIR, REQ/REP) and offers higher performance than boost::interprocess::message_queue.
FairMQ Shared Memory Transport

Features

• PAIR, PUSH/PULL, REQ/REP communication patterns
• Support for multipart messages
• Managed shared memory that is completely transparent for the user.

Example: Time frame in Alice O2 data model

Headers defines the type of data. Different header types can be stacked to store extra metadata (mimicking a Type hierarchy structure). Headers and payloads are usable in a message passing environment.
FairMQ Shared Memory Transport

Features

• Automatic cleanup of orphan shared memory in case of device crashes. Optionally a cleanup/monitoring/debug tool provided for more control.

• Seamless integration with other transports – no copies of data between different transports (for transports that allow adopting foreign data buffer)

• Very high performance – transfer rates in high kHz/low MHz range, low CPU usage.
FairMQ Shared Memory Transport

Features

- Unmanaged shared memory regions for fine-grained control of buffer location and handling.
FairMQ for ReadOut in ALICE

- CRU test data, TPC decoder algorithm integrated in Readout
- Demonstrate usage of available CPU resources at target data throughput

Run chain for 8 hours, use as much CPU as possible at target data throughput

SUCCESS: # CRUs x 17.25 Gb/s with Local Processing active
Not only TCP/IP but also RDMA

High data throughput (>90% link capacity) and significantly reduced CPU load

afi_msg_bw: Benchmark in asiofi (base for new FairMQ transport)
fi_msg_bw: Benchmark from Libfabric
Tests on 200Gb/s IB in Feb’19
• Hardware setup provided by CBM/FIAS (Mellanox engineering sample)
FairMQ OFI Transport

Features

• Available in: FairMQ v1.4.9 + asiofi v0.4.3

• About 90% of the theoretical throughput is achieved on experimental systems:
  • CBMfles: 97 of max 107 Gb/s IB
  • Alice: 60 of max 65 Gb/s RoCE
  • Alice: 80-90 of max 100 Gb/s IB

• Optimizing the implementation to utilize the last 10% of available bandwidth is ongoing
Controlling FairMQ state machine
Controlling FairMQ state machine: on one device:

• The FairMQ core library provides two device controllers
  • Static: a fixed sequence of state transitions
  • Interactive: a read-eval-print-loop which reads keyboard commands from standard input

• A device controller only knows how steer a single FairMQ device (i.e: it runs in a thread within the device process)
Controlling FairMQ state machine: on a processing farm

- One has to make the **entire** cluster state available for the experiment control system and **not single process one**

Exported cluster state machine

EPNs internal state machine (FairMQ)
Controller Design

Resources
- EPNs
  - DDS session (owns DDS topology)

Processing nodes
- FairMQ processing topology
  - RMS_api

Service node
- RMS
  - Translates commands to create/shutdown RMS session via RMS_api
  - And control FairMQ devices via RMS_api

Other services, e.g.: CCDB, Data transfer, etc...

ECS
- control-client
  - Commands: init, config, start, stop, term, down

control-server
- Translates commands to create/shutdown RMS session via RMS_api
- And control FairMQ devices via RMS_api

FairMQ device
- Plugin (started by DDS Agent)
Controller example (DDS based)

One DDS session for all processing nodes
DDS-control

An example of how to control/communicate with a system backed by DDS and FairMQ.

https://github.com/FairRootGroup/DDS-control
libFairMQ_SDK.so

find_package(FairMQ COMPONENTS sdk)

Then link against

FairMQ::SDK

#include <fairmq/SDK.h>
Controller Example (PMIx based)

ECS

control-client

commands:
init
config
start
stop
term
down

gRPC

ccontrol-server

translates commands
to create session
Via PMIx/Slurm

PMIx::tools

and
ccontrol FairMQ devices
via

fair::mq::sdk::Topology
to change and query
device states

PMIx::tools_api

PMix plugin

FairMQ device
(started by DDS Agent)

DDS session
(owns DDS topology)

EPN Resources

EPN
(node)

(example)

EPN service

node

(example)
Summary

• ALFA allows developers to write their specific code in whatever language they choose as long as that language can send and receive data through message queues.

• allows non-expert to write message based code without going into the details of the transport or the system below

• offers a clean and maintainable and extendable interface to the existing different data transport (ZMQ, nanomsg, shared Memory, OFI, ..etc)

• provides utilities to deploy and control topologies on computing clusters, online clusters as well as on a laptop
Backup
**asiofi**  
(C++ Boost.Asio language bindings for OFI libfabric)

- The asiofi library provides a C++ Boost.Asio interface to OpenFabric Interface’s libfabric and is used to implement the FairMQ OFI transport.

https://github.com/FairRootGroup/asiofi
PMIx (Process Management Interface for Exascale)

- Originally developed and distributed as part of MPICH, has historically been used as a means of exchanging wireup information needed for interprocess communication and deployment of processes
  - Distributed key/value store for data exchange
  - Asynchronous events for coordination
  - Enable interactions with the resource manager
- PMIx also covers: Resource allocation, process/job mgmt (creation/deletion/monitoring), system information, error notifications
- PMIx provides server, tool, and client APIs
  - [https://github.com/pmix/pmix](https://github.com/pmix/pmix)
  - [https://github.com/pmix/pmix-standard](https://github.com/pmix/pmix-standard)
### FairMQ State Machine & Example ECS Command Mapping

<table>
<thead>
<tr>
<th>ECS command</th>
<th>DDS/FairMQ actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>init</td>
<td>DDS: Create session, submit agents, activate topology (\rightarrow) devices go in Idle state</td>
</tr>
<tr>
<td>configure</td>
<td>Devices: InitDevice(\rightarrow)CompleteInit(\rightarrow)Bind(\rightarrow)Connect(\rightarrow)InitTask</td>
</tr>
<tr>
<td>start</td>
<td>Devices: Run</td>
</tr>
<tr>
<td>stop</td>
<td>Devices: Stop</td>
</tr>
<tr>
<td>term</td>
<td>Devices: ResetTask(\rightarrow)ResetDevice(\rightarrow)End</td>
</tr>
<tr>
<td>down</td>
<td>DDS: Shutdown session</td>
</tr>
</tbody>
</table>

![State Machine Diagram](image-url)
Distributed Simulation with FairMQ

1. Each simulation device will generate nEvents;
2. Simulation devices ask ParameterMQServer for the RunId;
3. The ParameterMQServer numbers the devices (DevId=0,1,2,...) as they connect and sends the DevId back to device together with RunId;
4. The devices generate events with the same RunId, numbering events from DevId*nEvents on;

Radek Karabowicz: Move Simulation to FairMQ
https://github.com/FairRootGroup/FairRoot/tree/dev/examples/MQ/pixelDetector
FairMQ-based parallel simulation

Sandro Wenzel