NVIDIA DOCA RDMA Programming Guide

Programming Guide

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Chapter 1. Introduction

Note: This library is currently supported at beta level only.

DOCA RDMA enables direct access to the memory of remote machines, without interrupting the processing of their CPUs or operating systems. Avoiding CPU interruptions reduces context switching for I/O operations, leading to lower latency and higher bandwidth compared to traditional network communication methods.

DOCA RDMA library provides an API to execute the various RDMA operations.

This document is intended for software developers wishing to improve their applications by utilizing RDMA operations.

Chapter 2. Prerequisites

DOCA RDMA-based applications can run either on the host machine or on the NVIDIA® BlueField® DPU target.

Chapter 3. Architecture

DOCA RDMA consists of two connected sides, passing data between one another. This includes the option for one side to access the remote side's memory if the granted permissions allow it.

The connection between the two sides can either be based on InfiniBand (IB) or based on Ethernet using RoCE. Currently, only reliable connection (RC) transport type is supported.

The different operations that may be executed between the two sides, using DOCA RDMA, are:

- Receive
- Send
- Send with Immediate
- Write
- Write with Immediate
- Read
- Atomic Compare & Swap
- Atomic Fetch & Add

DOCA RDMA relies heavily on the underlying DOCA core architecture for its operation, including the memory map, buffer objects, context and workq. RDMA operations are requested by submitting an RDMA job on the relevant workq. The DOCA RDMA library then executes that operation asynchronously before posting a completion event on the work queue.

Note: Currently, each RDMA context supports only a single workq.

Note: The DOCA RDMA library supports scatter-gather (SG) DOCA buffers in some jobs utilizing the linked list option. For job-specific information, refer to DOCA RDMA Job Structures.

Chapter 4. API

This chapter details of the specific structures and enums related to the DOCA RDMA library.

Refer to Usage to learn how to use DOCA RDMA API (including all RDMA functions) to run a program from start to finish.

4.1. DOCA RDMA Job Structures

The API for DOCA RDMA consists of 4 unique DOCA RDMA unique job structures that can be used the execute a total of 7 different DOCA RDMA jobs. This section overviews the different job structures, their expected inputs, and results.

Each DOCA RDMA job structure includes a `doca_job` structure as its base:

```
struct doca_job {
    int type;                   /**< Defines the type of the job. */
    int flags;                  /**< Job submission flags (see `enum
 doca_job_flags`). */
    struct doca_ctx *ctx;       /**< Doca CTX targeted by the job. */
    union doca_data user_data;  /**< Job identifier provided by user. Will be
 returned back on completion. */
};
```

For each job submitted using DOCA RDMA, the following applies:

- It is expected that the `flags` field value is `DOCA_JOB_FLAGS_NONE` (part of `enum doca_job_flags`), since there are currently no jobs that use flags in DOCA RDMA.
- The `ctx` field should point to a valid DOCA RDMA context. The context can be retrieved once the RDMA instance is created using `doca_rdma_as_ctx()`.
- The `user_data` field can hold whatever value the user desires and is returned untouched to the user on completion of the given job.

4.1.1. DOCA RDMA Receive

This job should be submitted prior to an expected submission of a send/send with immediate/write with immediate job on the remote side.

```
struct doca_rdma_job_recv {
    struct doca_job base;       /**< Common job data */
    struct doca_buf *dst_buff;  /**< Destination data buffer,
                                 *  chain len must not exceed recv_buf_chain_len
 property
                                 */
```

```
};
```

To execute an DOCA RDMA receive job, the value of `base.type` field should be set to `DOCA_RDMA_JOB_RECV` (part of the `enum doca_rdma_job_types`).

The destination buffer (`dst_buff`) should point to a local memory address to which the received message is written on success.

The given destination buffer/chain of buffers (given in `dst_buff`) must have a total length sufficient for the expected message size or the job will fail.

The destination buffer is not mandatory and may be NULL when the requested DOCA RDMA job on the remote side is "write with immediate" or when the remote side is sending an empty message, with or without immediate (may be relevant when wanting to keep a connection alive).

Note: For the purpose of the DOCA RDMA receive job, the length of each buffer is considered as the length from the beginning of the data section until the end of the buffer. The data length is updated if data is written to the buffer once the job is successfully completed, according to the received data length. For more information, refer to the NVIDIA DOCA Core Programming Guide.

Note: The total length of the message must not exceed the `max_message_size` device capability or 2GB (whichever is lower). Also note that the number of chained buffers shall not exceed the `recv_buf_chain_len` property of the RDMA instance. Refer to Usage to understand how to retrieve `max_message_size` and `recv_buf_chain_len`.

4.1.2. DOCA RDMA Send

This job should be submitted to transfer a message to the remote side, with or without immediate data, and while the remote side is expecting a message and had submitted a receive job beforehand.

```
struct doca_rdma_job_send {
    struct doca_job base;                               /**< Common job data */
    struct doca_buf const *src_buff;                    /**< Source data buffer */
    doca_be32_t immediate_data;                         /**< Immediate data */
    struct doca_rdma_addr const *rdma_peer_addr;    /**< Optional: For RDMA context
 of type UD or DC */
};
```

To execute a DOCA RDMA send or send with immediate job, the value of the `base.type` field should be set to `DOCA_RDMA_JOB_SEND`/`DOCA_RDMA_JOB_SEND_IMM` respectively (part of `enum doca_rdma_job_types`).

The total length of the given source buffer/chain of buffers (in `src_buff`) may not exceed the expected message size on the remote side or the job will fail.

The source buffer is not mandatory and may be NULL when wishing to send an empty message, with or without immediate (may be relevant when wishing to keep a connection alive).

Note: For the purpose of the DOCA RDMA send job, the length of each buffer is considered as its data length.

Note: The total length of the message must not exceed the `max_message_size` device capability or 2GB (whichever is lower). Refer to Usage to understand how to retrieve `max_message_size`.

The `immediate_data` field is a 32-bit value sent to the remote side, out-of-band, and should be in Big-Endian format. This value is transferred only when the job type is `DOCA_RDMA_JOB_SEND_IMM`, and is received by the remote side only once a receive job is completed successfully.

Currently, the `rdma_peer_addr` field is not in use as DC and UD transport types are not yet supported.

4.1.3. DOCA RDMA Read/Write

These jobs should be submitted when wishing to access (read or write) data from remote memory (i.e., the memory on the remote side of the connection).

```
struct doca_rdma_job_read_write {
    struct doca_job base;                           /**< Common job data */
    struct doca_buf *dst_buff;                      /**< Destination data buffer */
    struct doca_buf const *src_buff;                /**< Source data buffer */
    doca_be32_t immediate_data;                     /**< Immediate data for write
 with imm */
    struct doca_rdma_addr const *rdma_peer_addr;    /**< Optional: For RDMA context
 of type DC */
};
```

Note that for each read or write job submitted using DOCA RDMA, the following applies:

- The source buffer (`src_buff`) is not mandatory and may be NULL when wishing to read or write zero bytes (might be relevant when wishing to keep a connection alive). In such a case, the destination buffer may be NULL as well.
- Currently, the `rdma_peer_addr` field is not in use as DC transport type is not yet supported.

4.1.3.1. DOCA RDMA Read

To execute a DOCA RDMA read job, the value of `base.type` field should be set to `DOCA_RDMA_JOB_READ` (part of the `enum doca_rdma_job_types`).

The destination buffer (`dst_buff`) should point to a local memory address to which the read data is written on success and the source buffer should point to a remote memory address from which the data should be read.

Note: For the purpose of the DOCA RDMA read job:

- The length of each destination buffer is considered as its data length.
- The data length of the source buffer is ignored. The length of data read from the source buffer depends on the total length of the given destination buffer/chain of buffers.

Note: The given source buffer length must not exceed the `max_message_size` device capability or 2GB (whichever is lower). Refer to Usage to understand how to retrieve `max_message_size`.

The `immediate_data` field is ignored.

4.1.3.2. DOCA RDMA Write

To execute a DOCA RDMA write or write with immediate job, the value of `base.type` field should be set to `DOCA_RDMA_JOB_WRITE`/`DOCA_RDMA_JOB_WRITE_IMM` respectively (part of the `enum doca_rdma_job_types`).

The destination buffer (`dst_buff`) should point to a remote memory address to which the data is written on success and the source buffer should point to a local memory address from which the data should be read.

Note: For the purpose of the DOCA RDMA write job:

- The length of each buffer is considered as its data length
- The data length of the destination buffer is ignored. The length of data written to the destination buffer depends on the total length of the given source buffer/chain of buffers

Note: The total length of the given source buffer/chain of buffers must be not exceed the `max_message_size` device capability or 2GB (whichever is lower). Refer to Usage to understand how to retrieve `max_message_size`.

The `immediate_data` field is a 32-bit value sent to the remote side, out-of-band, and should be in a Big-Endian format. This value is transferred only when the job type is `DOCA_RDMA_JOB_WRITE_IMM` and is received by the remote side only once a receive job is completed successfully.

Note: A write with immediate job succeeds only if the remote side is expecting the immediate and had submitted a receive job beforehand.

4.1.4. DOCA RDMA Atomic

These jobs should be submitted when wishing to execute an 8-byte atomic operation on the remote memory, the memory on the remote side.

```
struct doca_rdma_job_atomic {
    struct doca_job base;                           /**< Common job data */
    struct doca_buf *cmp_or_add_dest_buff;          /**< Destination data buffer */
    struct doca_buf *result_buff;                   /**< Result of the atomic
 operation:
```

```
                                                    *  remote original data before
add, or remote original data
                                                    *  before compare
                                                    */
   uint64_t swap_or_add_data;                      /**< For add, the increment
value
                                                    *  for cmp, the new value to
swap
                                                    */
   uint64_t cmp_data;                              /**< Value to compare for
compare and swap */
   struct doca_rdma_addr const *rdma_peer_addr;    /**< Optional: For RDMA context
of type DC */
};
```

For each atomic job submitted using DOCA RDMA, the following applies:

- The destination buffer (`cmp_or_add_dest_buff`) should point to a remote memory address and its data section must begin in a memory address aligned to 8 bytes.
- The result buffer (`result_buff`) should point to a local memory address and the original value of the destination buffer (before executing the atomic operation) will be written to it on success. The data length of this buffer must be exactly 8 bytes long.
- Currently, the `rdma_peer_addr` field is not in use as DC transport type is not yet supported.

4.1.4.1. DOCA RDMA Atomic Compare and Swap

To execute a DOCA RDMA atomic compare and swap job, the value of `base.type` field should be set to `DOCA_RDMA_JOB_ATOMIC_CMP_SWP` (part of the `enum doca_rdma_job_types`).

The compare data field (`cmp_data`) is a 64-bit value that is compared to the value in the destination buffer (the first 64-bit following the beginning of the data section of the buffer).

- If the compared values are equal, the value in the destination is swapped with the 64-bit value in the jobs swap data field (`swap_or_add_data`)
- If the compared values are not equal, the value in the destination value remains unchanged

4.1.4.2. DOCA RDMA Atomic Fetch and Add

When wishing to execute a DOCA RDMA atomic fetch and add job, the value of `base.type` field should be set to `DOCA_RDMA_JOB_ATOMIC_FETCH_ADD` (part of the `enum doca_rdma_job_types`).

The value in the destination is increased by the 64-bit value in the job's add data field (`swap_or_add_data`).

The compare data field (`cmp_data`) is ignored.

4.2. DOCA RDMA Job Result Structure

Once a job is submitted and its progress is successfully retrieved, the `doca_rdma_result` struct is updated as part of the `doca_event` returned (see Waiting for Job Completion for more information).

```
struct doca_rdma_result {
    doca_error_t result;                    /**< Operation result */
    enum doca_rdma_opcode_t opcode;         /**< Opcode in case of
 doca_rdma_job_recv completion */
    struct doca_rdma_addr *rdma_peer_addr;  /**< Peer Address for UD and DC */
    doca_be32_t immediate_data;             /**< Immediate data, valid only if
 opcode indicates */
    /** 'dst_buff' data positioning will get updated on RECV and READ ops */
};
```

The `result` field holds a `doca_error_t` representing the result of the job.

The `rdma_peer_addr` field is currently not in use as DC and UD transport types are not yet supported.

The following fields are valid only when the `doca_rdma_result` returns a successful completion of a receive job:

- The `opcode` field represents which job has been submitted by the remote side that required there to be a receive job
- The `immediate_data` field is valid only when the `opcode` field value is `DOCA_RDMA_OPCODE_RECV_SEND_WITH_IMM` or `DOCA_RDMA_OPCODE_RECV_WRITE_WITH_IMM`. This holds the 32-bit immediate data sent from the remote side in Big-Endian format.

4.3. DOCA RDMA State Enum

These values describe the state of the RDMA instance at any point:

```
enum doca_rdma_state {
    DOCA_RDMA_STATE_RESET = 0,
    DOCA_RDMA_STATE_INIT,
    DOCA_RDMA_STATE_CONNECTED,
    DOCA_RDMA_STATE_ERROR,
};
```

DOCA_RDMA_STATE_RESET
The initial state of any RDMA instance. This state can be returned to, at any time, by calling `doca_ctx_stop()`.

DOCA_RDMA_STATE_INIT
The RDMA instance is initialized (`doca_ctx_start()` has been called) and is ready to be connected (i.e., `doca_rdma_export()` and `doca_rdma_connect()` may be called).

DOCA_RDMA_STATE_CONNECTED
The RDMA instance is connected to another RDMA instance (`doca_rdma_connect()` has been called) and communication between the peers is possible.

DOCA_RDMA_STATE_ERROR
The RDMA instance is in an error state. Trying to communicate between the peers would result in an error. Both sides should be reset (i.e. call `doca_ctx_stop()`).

4.4. DOCA RDMA Transport Type Enum

This enum includes the possible transport types in RDMA:

```
enum doca_rdma_transport_type {
    DOCA_RDMA_TRANSPORT_RC, /**< RC transport */
    DOCA_RDMA_TRANSPORT_DC, /**< DC transport, currently not supported */
};
```

Note: Currently, only RC transport is supported.

Chapter 5. Usage

The following subsections go through the various stages required to initialize, execute, and clean up RDMA operations.

Note that the DOCA RDMA library relies on the use of `doca_ctx` and `doca_workq` to execute RDMA jobs. The following explanations regarding the flow and use of DOCA RDMA, require users to be familiar with these objects (as well as other DOCA Core objects such as `doca_dev`, `doca_mmap`, `doca_buf_inventory`, `doca_buf`, etc). For more information, see NVIDIA DOCA Core Programming Guide.

5.1. Preparation

The following section describes the necessary steps before executing any RDMA operation.

The order in which the following subsections are presented is non-biding. The user may perform whichever initialization process suits their needs best.

5.1.1. Choosing and Opening a DOCA Device

To execute RDMA operations, a device must be chosen. To choose a device, users may iterate over all DOCA devices (via `doca_devinfo_list_create()`) and query each for its capabilities relevant to RDMA operations, using `doca_rdma_get_*(struct doca_devinfo *, ...)` functions, and check whether the device is suitable for the RDMA job type that would be performed, using `doca_rdma_job_get_supported()`.

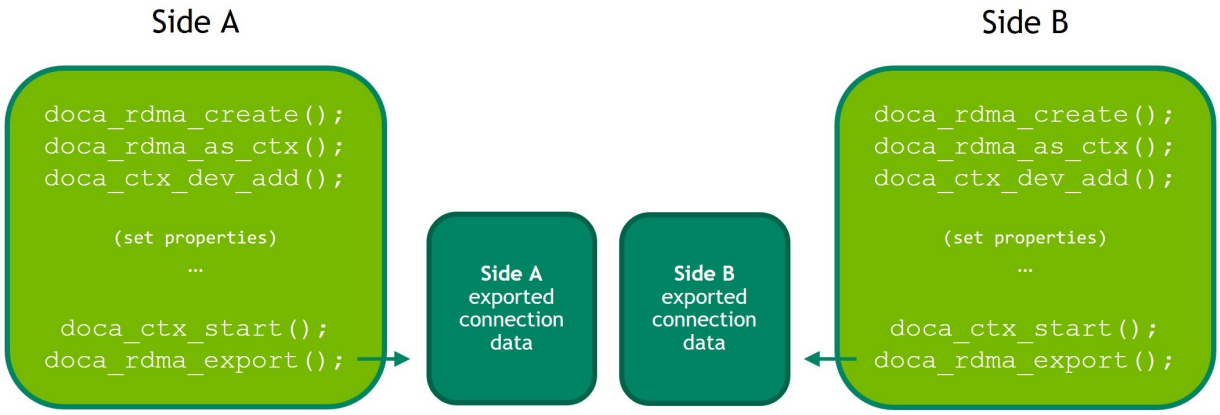
5.1.2. Setting up and Initializing DOCA RDMA Context

To use DOCA RDMA:

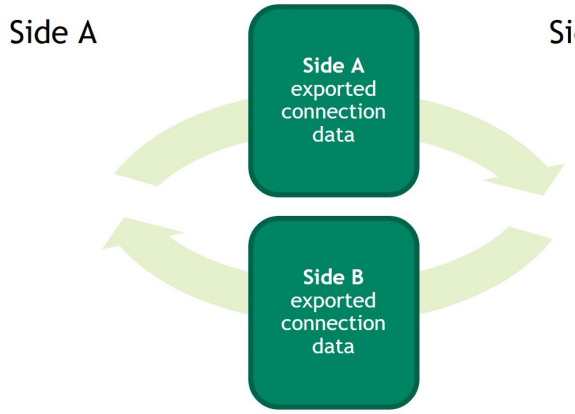
1. Create an RDMA instance using `doca_rdma_create()` and acquire its context using `doca_rdma_as_ctx()`. The state of a newly created RDMA instance is `DOCA_RDMA_STATE_RESET`.
2. The chosen device must be added to the RDMA context, using `doca_ctx_dev_add()`.

3. (Optional) Edit the default properties of the RDMA instance and query its properties using the `doca_rdma_set_<property>()` and `doca_rdma_get_<property>(struct doca_rdma *, …)` functions respectively.
4. Start the RDMA context by using `doca_ctx_start()`. Once started, the RDMA instance moves to state `DOCA_RDMA_STATE_INIT`.
5. Export each RDMA instance to the remote side to a blob by using `doca_rdma_export()`.
6. Transfer the blob to the opposite side out-of-band (OOB) and provide it as input to the `doca_rdma_connect()` function on that side. Connecting an RDMA instance moves its state to `DOCA_RDMA_STATE_CONNECTED` and it is ready to start running jobs.

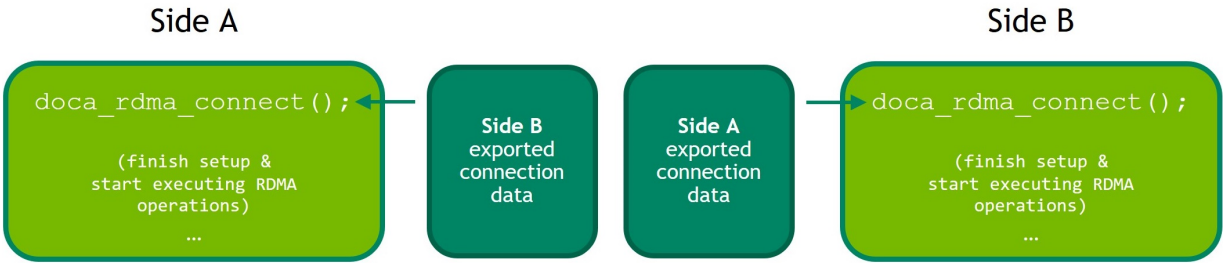
Step 1: Initiate the RDMA instance, and when ready, export it



Step 2: Transfer the exported connection data out-of-band



Step 3: Connect the two RDMA instances



5.1.3. Creating and Initializing DOCA Core Objects

DOCA RDMA requires several DOCA Core objects to be created, depending on the desired operations (see summary table under DOCA Core Object for RDMA Operations Summary) as specified in the following subsections.

5.1.3.1. WorkQ

Executing any RDMA operation requires creating a work queue using `doca_workq_create()`.

A workq can work in two different modes:

- The default polling mode where the program must check whether a job has finished its execution until receiving confirmation
- The event-driven mode where the program may receive a notification once the job is done

To set the workq to event-driven mode, use `doca_workq_set_event_driven_enable()`. Then call `doca_workq_get_event_handle()` to retrieve the workq event handle to be used by `epoll` (or other Linux wait-for-event interfaces) to wait on events.

Once the RDMA context is started, the workq may be added to it by calling `doca_ctx_workq_add()`.

5.1.3.2. Memory Map

Executing any job in which data is passed between the peers requires creating a memory map (MMAP) on each side using `doca_mmap_create()`.

1. Add the chosen device to the memory map using `doca_mmap_dev_add()`.
2. Set the relevant memory map properties. For example, setting the memory range of the MMAP is mandatory and can be done using `doca_mmap_set_memrang()`.
3. Set the MMAP's permissions according to the required RDMA operations using `doca_mmap_set_permissions()`:
   - To execute RDMA operations, the MMAP's permissions must include `DOCA_ACCESS_LOCAL_READ_WRITE` (from `enum doca_access_flags`)
   - To allow remote access to the memory region of the MMAP, one must set the relevant RDMA permission from the `enum doca_access_flags`, according to the required RDMA operations
4. Start the MMAP so it is ready to use by calling `doca_mmap_start()`.

To allow remote memory access:

1. Export the MMAP using `doca_mmap_export_rdma()` and pass it to the remote side (the side requesting the remote RDMA operation).
2. The remote side must create an MMAP from the exported blob (referred to as remote MMAP from here on) using `doca_mmap_create_from_export()`.

Both steps may be done later (even after RDMA jobs such as send/receive have executed) but they are necessary for allowing one side (or both) to request remote operations.

5.1.3.3. Buffer Inventory

Executing any job in which data is passed between the peers requires the requester to create a buffer inventory using `doca_buf_inventory_create()` and start it using `doca_buf_inventory_start()`.

5.1.3.4. DOCA Core Object for RDMA Operations Summary

Summary of the minimal DOCA Core object requirements for each RDMA operation:

DOCA RDMA Job Type	Minimal Permissions				Should ExportMMAP?[a]
	Requester Side		Responder Side		
	RDMA	MMAP	RDMA	MMAP	
Read	–	Local Read Write	RDMA Read	Local Read Write | RDMA Read	Yes
Write/ Write with Immediate	–	Local Read Write	RDMA Write	Local Read Write | RDMA Write	Yes
Atomic (Fetch and Add, Compare and Swap)	–	Local Read Write	RDMA Atomic	Local Read Write | RDMA Atomic	Yes
Send/ Send with Immediate	–	Local Read Write	–	Local Read Write	No
Receive	Depending on the received job	Local Read Write	Not relevant		

Note: [a] Responder side never requires exporting MMAP.

5.1.4. Constructing DOCA Buffers

Before setting up and submitting an RDMA operation, users must construct the relevant DOCA buffers for the desired job by calling `doca_buf_inventory_buf_by_addr()`, providing addresses that exist within the memory region registered with the given memory map (local or remote).

The data address and length of the DOCA buffers may need to be set using `doca_buf_set_data()` as this field may affect how many bytes are transferred. For more information on the affect of the data section on each job, refer to DOCA RDMA Job Structures.

5.2. RDMA Job Cycle

Once the preparations are complete as described in Preparation, RDMA jobs can be executed on the RDMA instance.

The following subsections describe the process of submitting a job and retrieving its result.

This cycle can be repeated for each desired job and these subsections may be executed in bulk; first by constructing all the desired jobs, then submitting them, and finally retrieving their result, all under the limitation of the workq depth and the queue size.

5.2.1. Constructing and Executing DOCA RDMA Operation

To begin an RDMA operation, enqueue an RDMA job on the previously created work queue object:

1. Create the DOCA RDMA job struct that contains the relevant job details. For further information about the different jobs and how to fill the job struct, refer to DOCA RDMA Job Structures.
2. Call `doca_workq_submit()` to submit the RDMA operation.

5.2.2. Waiting for Job Completion

To retrieve an RDMA operation result using `doca_workq_progress_retrieve()`, the user must provide a `doca_event` structure. This structure should point to an allocated `doca_rdma_result` struct in its `result.ptr` field.

It is the user's responsibility to allocate and manage the `doca_event` structure as well as the `doca_rdma_result`.

Code example for result preparation and retrieval:

```
struct doca_event event = {0};
struct doca_rdma_result rdma_result;
memset(&rdma_result, 0, sizeof(rdma_result));

event.result.ptr = (void *)(&rdma_result);
doca_workq_progress_retrieve(workq, &event, DOCA_WORKQ_RETRIEVE_FLAGS_NONE);
```

According to the workq mode, users may detect when the RDMA operation has been completed (via `doca_workq_progress_retrieve()`):

- Workq operating in polling mode – periodically poll the workq until the API call indicates that a valid event has been received (i.e., `DOCA_SUCCESS` returned).
- Workq operating in event mode – while `doca_workq_progress_retrieve()` does not return success as a result, perform the following loop:
  1. Arm the workq `doca_workq_event_handle_arm()`.
  2. Wait for an event using the event handle (e.g., using `epoll_wait()`).

3. Once the thread wakes up, call `doca_workq_event_handle_clear()`.

Regardless of the operating mode, once the event is successfully retrieved, the result of the operation can be read in the provided `rdma_result` structure. For further information about the fields of the result structure, refer to DOCA RDMA Job Result Structure.

For some of the operations, the buffer's data length field may be updated according to the written data. For further information, refer to DOCA RDMA Job Structures.

5.2.3. Error Handling

If any RDMA job fails to run, and its result is returned with an error status, the RDMA instance itself moves to an error state (`DOCA_RDMA_STATE_ERROR`). Once in error state, no more jobs can be submitted until an error recovery flow is performed.

To recover an RDMA instance from the error state, the context must be stopped using `doca_ctx_stop()`, restarted using `doca_ctx_start()`, and connected again as explained under Setting up and Initializing DOCA RDMA Context, including exporting the connection information and passing it between the peers.

5.3. Clean-up

This section describes the necessary steps to release all the resources allocated for executing RDMA operations.

The order in which the following subsections are presented is non-biding. The user may perform whichever clean up process suits their needs best.

5.3.1. Buffer and Buffer Inventory

1. Destroy all the buffers created during the run using `doca_buf_refcount_rm()` regardless of whether the operation is successful or not.
2. Only after all the buffers from the inventory are destroyed, destroy the buffer inventory using `doca_buf_inventory_destroy()`.

5.3.2. Memory Map

Both the memory map set with a local memory range and the memory map set with a remote memory range (remote MMAP), if created, must be destroyed using `doca_mmap_destroy()`.

5.3.3. WorkQ

1. Remove the workq from the RDMA context using `doca_ctx_workq_rm()`. If the workq has been set to event-driven mode, do not forget to clean up any resources created (apart from DOCA resources) to support wait-for-event.
2. Destroy the workq with `doca_workq_destroy()`.

5.3.4. DOCA RDMA Context

1. Stop the context using `doca_ctx_stop()`.
2. Destroy the context using `doca_rdma_destroy()`.

Chapter 6. DOCA RDMA Code Snippets

The following examples presume that all the necessary structures and objects were initialized as described under Preparation before the example code, and that all the structures and objects are cleaned up as described under in Clean-up afterwards.

Note: Return values may be ignored and functions presumed to have run successfully to simplify the code.

6.1. Write Job: Polling WorkQ Mode

On the receiving side, one must set the MMAP permissions to include the required RDMA operation (in this case, `RDMA_WRITE`) and then export and transfer the MMAP (either OOB or as a message between the peers), to the writing side.

Finally, the writing side should create an MMAP from the exported one (using `doca_mmap_create_from_export()`) which is referred to as `remote_mmap` in this code sample.

```
/*
 * The following parameters were already initiated as part of the preparations:
 * struct doca_buf_inventory *buf_inventory;
 * struct doca_workq *workq;
 * struct doca_ctx *rdma_ctx;
 * struct doca_mmap *local_mmap;
 * struct doca_mmap *remote_mmap;
 * char *local_mmap_memrange;
 * void *remote_addr;
 */

/* Step #1 - Declare and initiate structures */
doca_error_t status;
struct doca_buf *src_buf;
struct doca_buf *dst_buf;
struct doca_rdma_result rdma_result;
struct doca_event event = {0};
struct doca_rdma_job_read_write job_write = {0};

memset(&rdma_result, 0, sizeof(rdma_result));
event.result.ptr = (void *)(&rdma_result);

/* Step #2 - Create and a source buffer object from local mmap and prepare the data
 */
```

```
const char *string = "Hello World!";
size_t string_len = strlen(string) + 1;

doca_buf_inventory_buf_by_data(buf_inventory, local_mmap, local_mmap_memrange,
 string_len, &src_buf);
strcpy(local_mmap_memrange, string);

/* Step #3 - Create a destination buffer object from imported mmap */
doca_buf_inventory_buf_by_data(buf_inventory, remote_mmap, remote_addr, string_len,
 &dst_buf);

/* Step #4 - Prepare and submit the job */
job_write.base.ctx = rdma_ctx;
job_write.base.flags = DOCA_JOB_FLAGS_NONE;
job_write.base.type = DOCA_RDMA_JOB_WRITE;
job_write.src_buff = src_buf;
job_write.dst_buff = dst_buf;
doca_workq_submit(workq, (doca_job *)(&job_write));

/* Step #5 - Check for job result */
do {
    status = doca_workq_progress_retrieve(workq, &event,
 DOCA_WORKQ_RETRIEVE_FLAGS_NONE);
} while (status == DOCA_ERROR_AGAIN);

assert(status == DOCA_SUCCESS);
assert(rdma_result.result == DOCA_SUCCESS);
```

Notes:

- `remote_addr` – the agreed upon address for the write operation
- `string_len` – the agreed upon length of the data
- Local MMAP range start ≤ `local_mmap_memrange && local_mmap_memrange + string_len` ≤ local MMAP range end
- Imported MMAP range start ≤ `remote_addr && remote_addr + string_len` ≤ imported MMAP range end

6.2. Send with Immediate Job

On the receiving side, with workq in polling mode:

```
/*
 * The following parameters were already initiated as part of the preparations:
 * struct doca_buf_inventory *buf_inventory;
 * struct doca_workq *workq;
 * struct doca_ctx *rdma_ctx;
 * struct doca_mmap *local_mmap;
 * char *local_mmap_memrange;
 */

/* Step #1 - Declare and initiate structures */
doca_error_t status;
struct doca_buf *dst_buf;
struct doca_rdma_result rdma_result;
struct doca_event event = {0};
struct doca_rdma_job_recv job_recv = {0};

memset(&rdma_result, 0, sizeof(rdma_result));
event.result.ptr = (void *)(&rdma_result);
```

```
/* Step #2 - Create a destination buffer object from local mmap, to which the
 received data will be written */
doca_buf_inventory_buf_by_data(buf_inventory, local_mmap, local_mmap_memrange,
 data_len, &dst_buf);

/* Step #3 - Prepare and submit the job */
job_recv.base.ctx = rdma_ctx;
job_recv.base.flags = DOCA_JOB_FLAGS_NONE;
job_recv.base.type = DOCA_RDMA_JOB_RECV;
job_recv.dst_buff = dst_buf;
doca_workq_submit(workq, (doca_job *)(&job_recv));

/* Step #4 - Check for job result */
do {
    status = doca_workq_progress_retrieve(workq, &event,
 DOCA_WORKQ_RETRIEVE_FLAGS_NONE);
} while (status == DOCA_ERROR_AGAIN);

assert(status == DOCA_SUCCESS);
assert(rdma_result.result == DOCA_SUCCESS);
assert(rdma_result.immediate_data == 0xDEADBEEF); // The expected immediate value,
 received from the remote side
assert(strcmp(local_mmap_memrange, "Hello World!") == 0); // The expected data,
 received from the remote side
```

Notes:

- `data_len` – the agreed upon data length or an upper limit for data length expected to be received
- The expected values are known in this case according to the code of the sending side in this example

On the sending side, with event driven workq:

```
/*
 * The following parameters were already initiated as part of the preparations:
 * struct doca_buf_inventory *buf_inventory;
 * struct doca_workq *workq;
 * struct doca_ctx *rdma_ctx;
 * struct doca_mmap *local_mmap;
 * char *local_mmap_memrange;
 */

/* Step #1 - Set workQ to even driven mode - declare and initiate structures */
doca_event_handle_t workq_fd;
doca_event_handle_t epfd;
struct epoll_event handle_event;
struct epoll_event events_in = {EPOLLIN};
static const int no_timeout = -1;

doca_workq_set_event_driven_enable(workq, 1);
doca_workq_get_event_handle(workq, &workq_fd);

epfd = epoll_create1(0); // note that this fd should be closed at cleanup
epoll_ctl(epfd, EPOLL_CTL_ADD, workq_fd, &events_in);

doca_ctx_workq_add(rdma_ctx, workq); // note that this call can only be made after
 the workQ is set to event driven mode

/* Step #2 - Declare and initiate structures for job submission and retrieval of
 it's result */
doca_error_t status;
struct doca_buf *src_buf;
struct doca_rdma_result rdma_result;
struct doca_event event = {0};
struct doca_rdma_job_send job_send = {0};
```

```
memset(&rdma_result, 0, sizeof(rdma_result));
event.result.ptr = (void *)(&rdma_result);

/* Step #3 - Create a source buffer object from local mmap and prepare the data */
const char *string = "Hello World!";
size_t string_len = strlen(string) + 1;

doca_buf_inventory_buf_by_data(buf_inventory, local_mmap, local_mmap_memrange,
 string_len, &src_buf);
strcpy(local_mmap_memrange, string);

/* Step #4 - Prepare and submit the job */
job_send.base.ctx = rdma_ctx;
job_send.base.flags = DOCA_JOB_FLAGS_NONE;
job_send.base.type = DOCA_RDMA_JOB_SEND_IMM;
job_send.src_buff = src_buf;
job_send.immediate_data = 0xDEADBEEF;
doca_workq_submit(workq, (doca_job *)(&job_send));

/* Step #5 - Check for job result */
status = doca_workq_progress_retrieve(workq, &event,
 DOCA_WORKQ_RETRIEVE_FLAGS_NONE);
while (DOCA_ERROR_AGAIN == status) {
    doca_workq_event_handle_arm(workq);
    epoll_wait(epfd, &handle_event, /*maxevents=*/1, no_timeout);
    doca_workq_event_handle_clear(workq, /*handle=*/0);
    status = doca_workq_progress_retrieve(workq, &event,
 DOCA_WORKQ_RETRIEVE_FLAGS_NONE);
}

assert(status == DOCA_SUCCESS);
assert(rdma_result.result == DOCA_SUCCESS);
```

Notes:

- MMAP range start ≤ `local_mmap_memrange && local_mmap_memrange + string_len` ≤ MMAP range end

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