# Intel® Data Plane Development Kit (Intel® DPDK)

## Sample Applications User Guide

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# 1.0 Introduction

This document describes the sample applications that are included in the Intel® Data Plane Development Kit (Intel® DPDK). Each chapter describes a sample application that showcases specific functionality and provides instructions on how to compile, run and use the sample application.

## 1.1 Documentation Roadmap

The following is a list of Intel® DPDK documents in suggested reading order:

- **Release Notes**: Provides release-specific information, including supported features, limitations, fixed issues, known issues and so on. Also, provides the answers to frequently asked questions in FAQ format.
- **Getting Started Guide**: Describes how to install and configure the Intel® DPDK software; designed to get users up and running quickly with the software.
- **Programmer's Guide**: Describes:
  - The software architecture and how to use it (through examples), specifically in a Linux* application (linuxapp) environment
  - The content of the Intel® DPDK, the build system (including the commands that can be used in the root Intel® DPDK Makefile to build the development kit and an application) and guidelines for porting an application
  - Optimizations used in the software and those that should be considered for new development

  A glossary of terms is also provided.
- **API Reference**: Provides detailed information about Intel® DPDK functions, data structures and other programming constructs.
- **Sample Applications User Guide**: Describes a set of sample applications. Each chapter describes a sample application that showcases specific functionality and provides instructions on how to compile, run and use the sample application.

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# 2.0 Command Line Sample Application

This chapter describes the Command Line sample application that is part of the Intel® Data Plane Development Kit (Intel® DPDK).

## 2.1 Overview

The Command Line sample application is a simple application that demonstrates the use of the command line interface in the Intel® DPDK. This application is a readline-like interface that can be used to debug an Intel® DPDK application, in a Linux* application environment.

***Caution:*** The `rte_cmdline` library should not be used in production code since it is not validated to the same standard as other Intel® DPDK libraries. See also the "rte_cmdline library should not be used in production code due to limited testing" item in the "Known Issues" section of the Release Notes.

The Command Line sample application supports some of the features of the `GNU readline` library such as, completion, cut/paste and some other special bindings that make configuration and debug faster and easier.

The application shows how the `rte_cmdline` application can be extended to handle a list of objects. There are three simple commands:

- `add obj_name IP`: Add a new object with an IP/IPv6 address associated to it.
- `del obj_name`: Delete the specified object.
- `show obj_name`: Show the IP associated with the specified object.

*Note:* To terminate the application, use **Ctrl**-**D**.

## 2.2 Compiling the Application

1. Go to example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/cmdline
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   Refer to the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 2.3 Running the Application

To run the application in linuxapp environment, issue the following command:

```
$ ./build/cmdline -c f -n 4
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 2.4 Explanation

The following sections provide some explanation of the code.

### 2.4.1 EAL Initialization and cmdline Start

The first task is the initialization of the Environment Abstraction Layer (EAL). This is achieved as follows:

```
int
    MAIN(int argc, char **argv)
    {
        ret = rte_eal_init(argc, argv);
        if (ret < 0)
            rte_panic("Cannot init EAL\n");
```

Then, a new command line object is created and started to interact with the user through the console:

```
    cl = cmdline_stdin_new(main_ctx, "example> ");
    cmdline_interact(cl);
    cmdline_stdin_exit(cl);
```

The `cmdline_interact()` function returns when the user types **Ctrl-d** and in this case, the application exits.

### 2.4.2 Defining a cmdline Context

A `cmdline` context is a list of commands that are listed in a NULL-terminated table, for example:

```
cmdline_parse_ctx_t main_ctx[] = {
    (cmdline_parse_inst_t *)&cmd_obj_del_show,
    (cmdline_parse_inst_t *)&cmd_obj_add,
    (cmdline_parse_inst_t *)&cmd_help,
    NULL,
};
```

Each command (of type `cmdline_parse_inst_t`) is defined statically. It contains a pointer to a callback function that is executed when the command is parsed, an opaque pointer, a help string and a list of tokens in a NULL-terminated table.

The `rte_cmdline` application provides a list of pre-defined token types:

- String Token: Match a static string, a list of static strings or any string.
- Number Token: Match a number that can be signed or unsigned, from 8-bit to 32-bit.

- IP Address Token: Match an IPv4 or IPv6 address or network.
- Ethernet* Address Token: Match a MAC address.

In this example, a new token type `obj_list` is defined and implemented in the `parse_obj_list.c` and `parse_obj_list.h` files.

For example, the `cmd_obj_del_show` command is defined as shown below:

```
struct cmd_obj_add_result {
    cmdline_fixed_string_t action;
    cmdline_fixed_string_t name;
    struct object *obj;
};


static void cmd_obj_del_show_parsed(void *parsed_result,
                    struct cmdline *cl,
                    __attribute__((unused)) void *data)
{
    /* ...*/
}


cmdline_parse_token_string_t cmd_obj_action =
    TOKEN_STRING_INITIALIZER(struct cmd_obj_del_show_result,
                    action, "show#del");

parse_token_obj_list_t cmd_obj_obj =
    TOKEN_OBJ_LIST_INITIALIZER(struct cmd_obj_del_show_result, obj,
                    &global_obj_list);

cmdline_parse_inst_t cmd_obj_del_show = {
    .f = cmd_obj_del_show_parsed,  /* function to call */
    .data = NULL,      /* 2nd arg of func */
    .help_str = "Show/del an object",
    .tokens = {        /* token list, NULL terminated */
        (void *)&cmd_obj_action,
        (void *)&cmd_obj_obj,
        NULL,
        },
    };
```

This command is composed of two tokens:

- The first token is a string token that can be `show` or `del`.
- The second token is an object that was previously added using the `add` command in the `global_obj_list` variable.

Once the command is parsed, the `rte_cmdline` application fills a `cmd_obj_del_show_result` structure. A pointer to this structure is given as an argument to the callback function and can be used in the body of this function.

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# 3.0 Exception Path Sample Application

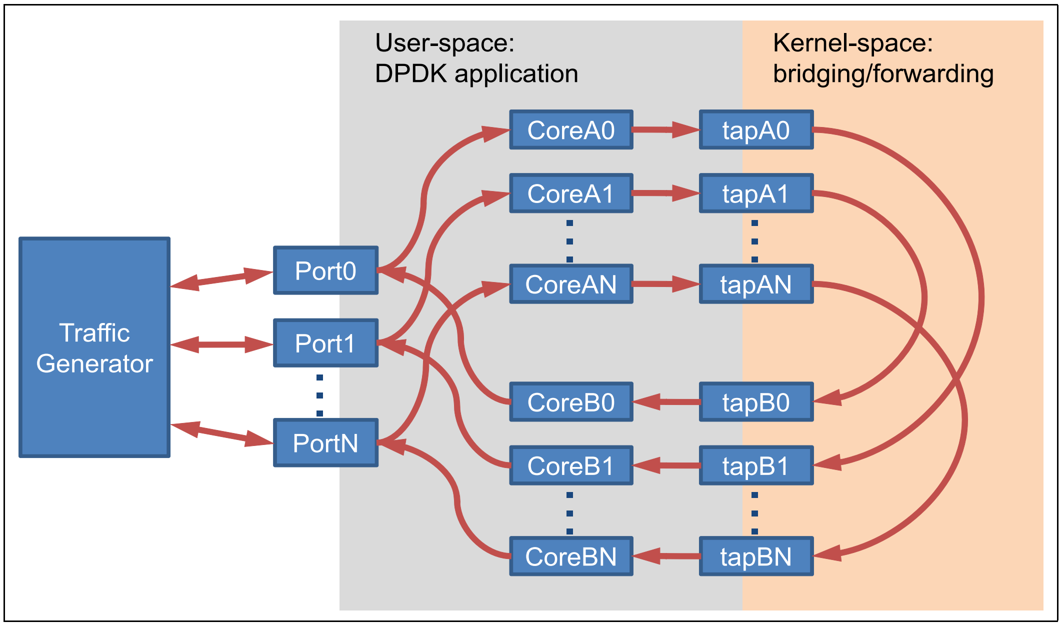
The Exception Path sample application is a simple example that demonstrates the use of the Intel® DPDK to set up an *exception path* for packets to go through the Linux* kernel. This is done by using virtual TAP network interfaces. These can be read from and written to by the Intel® DPDK application and appear to the kernel as a standard network interface.

## 3.1 Overview

The application creates two threads for each NIC port being used. One thread reads from the port and writes the data unmodified to a thread-specific TAP interface. The second thread reads from a TAP interface and writes the data unmodified to the NIC port.

The packet flow through the exception path application is as shown in the following figure.

**Figure 1. Packet Flow**




To make throughput measurements, kernel bridges must be setup to forward data between the bridges appropriately.

## 3.2 Compiling the Application

1. Go to example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/exception_path
```

2. Set the target (a default target will be used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   This application is intended as a linuxapp only. See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 3.3 Running the Application

The application requires a number of command line options:

```
.build/exception_path [EAL options] -- -p PORTMASK -i IN_CORES -o OUT_CORES
```

where:

- `-p PORTMASK`: A hex bitmask of ports to use
- `-i IN_CORES`: A hex bitmask of cores which read from NIC
- `-o OUT_CORES`: A hex bitmask of cores which write to NIC

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

The number of bits set in each bitmask must be the same. The `coremask -c` parameter of the EAL options should include `IN_CORES` and `OUT_CORES`. The same bit must not be set in `IN_CORES` and `OUT_CORES`. The affinities between ports and cores are set beginning with the least significant bit of each mask, that is, the port represented by the lowest bit in `PORTMASK` is read from by the core represented by the lowest bit in `IN_CORES`, and written to by the core represented by the lowest bit in `OUT_CORES`.

For example to run the application with two ports and four cores:

```
./build/exception_path -c f -n 4 -- -p 3 -i 3 -o c
```

### 3.3.1 Getting Statistics

While the application is running, statistics on packets sent and received can be displayed by sending the SIGUSR1 signal to the application from another terminal:

```
killall -USR1 exception_path
```

The statistics can be reset by sending a `SIGUSR2` signal in a similar way.

## 3.4 Explanation

The following sections provide some explanation of the code.

### 3.4.1 Initialization

Setup of the mbuf pool, driver and queues is similar to the setup done in the L2 Forwarding sample application (see Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for details). In addition, the TAP interfaces must also be created. A TAP interface is created for each lcore that is being used. The code for creating the TAP interface is as follows:

```
/*
 * Create a tap network interface, or use existing one with same name.
 * If name[0]='\0' then a name is automatically assigned and returned in name.
 */

static int tap_create(char *name)
{
    struct ifreq ifr;
    int fd, ret;

    fd = open("/dev/net/tun", O_RDWR);
    if (fd < 0)
        return fd;

    memset(&ifr, 0, sizeof(ifr));

    /* TAP device without packet information */
    ifr.ifr_flags = IFF_TAP | IFF_NO_PI;
    if (name && *name)
        rte_snprinf(ifr.ifr_name, IFNAMSIZE, name);

    ret = ioctl(fd, TUNSETIFF, (void *) &ifr);
    if (ret < 0) {
        close(fd);
        return ret;
    }

    if (name)
        rte_snprintf(name, IFNAMSIZ, ifr.ifr_name);
    return fd;
}
```

The other step in the initialization process that is unique to this sample application is the association of each port with two cores:

- One core to read from the port and write to a TAP interface
- A second core to read from a TAP interface and write to the port

This is done using an array called `port_ids[]`, which is indexed by the lcore IDs. The population of this array is shown below:

```
tx_port = 0;
rx_port = 0;
RTE_LCORE_FOREACH(i) {
    if (input_cores_mask & (1 << i)) {
        /* Skip ports that are not enabled */
        while ((ports_mask & (1 << rx_port)) == 0) {
            rx_port++;
            if (rx_port > (sizeof(ports_mask) * 8))
                goto fail; /* not enough ports */
        }
        port_ids[i] = rx_port++;
    } else if (output_cores_mask & (1 << i)) {
        /* Skip ports that are not enabled */
        while ((ports_mask & (1 << tx_port)) == 0) {
            tx_port++;
```

```
            if (tx_port > (sizeof(ports_mask) * 8))
                goto fail; /* not enough ports */
        }
        port_ids[i] = tx_port++;
    }
}
```

### 3.4.2 Packet Forwarding

After the initialization steps are complete, the `main_loop()` function is run on each lcore. This function first checks the `lcore_id` against the user provided `input_cores_mask` and `output_cores_mask` to see if this core is reading from or writing to a TAP interface.

For the case that reads from a NIC port, the packet reception is the same as in the L2 Forwarding sample application (see Section 9.4.6, “Receive, Process and Transmit Packets” on page 48). The packet transmission is done by calling `write()` with the file descriptor of the appropriate TAP interface and then explicitly freeing the mbuf back to the pool.

```
/* Loop forever reading from NIC and writing to tap */
for (;;) {
    struct rte_mbuf *pkts_burst[PKT_BURST_SZ];
    unsigned i;
    const unsigned nb_rx = rte_eth_rx_burst(port_ids[lcore_id], 0,
                                        pkts_burst, PKT_BURST_SZ);
    lcore_stats[lcore_id].rx += nb_rx;
    for (i = 0; likely(i < nb_rx); i++) {
        struct rte_mbuf *m = pkts_burst[i];
        int ret = write(tap_fd, rte_pktmbuf_mtod(m, void*),
                        rte_pktmbuf_data_len(m));
        rte_pktmbuf_free(m);
        if (unlikely(ret<0))
            lcore_stats[lcore_id].dropped++;
        else
            lcore_stats[lcore_id].tx++;
    }
}
```

For the other case that reads from a TAP interface and writes to a NIC port, packets are retrieved by doing a `read()` from the file descriptor of the appropriate TAP interface. This fills in the data into the mbuf, then other fields are set manually. The packet can then be transmitted as normal.

```
/* Loop forever reading from tap and writing to NIC */
for (;;) {
    int ret;
    struct rte_mbuf *m = rte_pktmbuf_alloc(pktmbuf_pool);
    if (m == NULL)
        continue;

    ret = read(tap_fd, m->pkt.data, MAX_PACKET_SZ);
    lcore_stats[lcore_id].rx++;
    if (unlikely(ret < 0)) {
        FATAL_ERROR("Reading from %s interface failed",
                    tap_name);
    }
    m->pkt.nb_segs = 1;
    m->pkt.next = NULL;
    m->pkt.pkt_len = (uint16_t)ret;
    m->pkt.data_len = (uint16_t)ret;
    ret = rte_eth_tx_burst(port_ids[lcore_id], 0, &m, 1);
    if (unlikely(ret < 1)) {
        rte_pktmuf_free(m);
```

```
        lcore_stats[lcore_id].dropped++;
    }
    else {
        lcore_stats[lcore_id].tx++;
    }
}
```

To set up loops for measuring throughput, TAP interfaces can be connected using bridging. The steps to do this are described in the Managing TAP Interfaces and Bridges section that follows.

### 3.4.3 Managing TAP Interfaces and Bridges

The Exception Path sample application creates TAP interfaces with names of the format `tap_dpdk_nn`, where `nn` is the lcore ID. These TAP interfaces need to be configured for use:

```
ifconfig tap_dpdk_00 up
```

To set up a bridge between two interfaces so that packets sent to one interface can be read from another, use the `brctl` tool:

```
brctl addbr "br0"
brctl addif br0 tap_dpdk_00
brctl addif br0 tap_dpdk_03
ifconfig br0 up
```

The TAP interfaces created by this application exist only when the application is running, so the steps above need to be repeated each time the application is run. To avoid this, persistent TAP interfaces can be created using `openvpn`:

```
openvpn --mktun --dev tap_dpdk_00
```

If this method is used, then the steps above have to be done only once and the same TAP interfaces can be reused each time the application is run. To remove bridges and persistent TAP interfaces, the following commands are used:

```
ifconfig br0 down
brctl delbr br0
openvpn --rmtun --dev tap_dpdk_00
```

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# 4.0 Hello World Sample Application

The Hello World sample application is an example of the simplest Intel® DPDK application that can be written. The application simply prints an “helloworld” message on every enabled lcore.

## 4.1 Compiling the Application

1. Go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/helloworld
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 4.2 Running the Application

To run the example in a linuxapp environment:

```
$ ./build/helloworld -c f -n 4
```

Refer to *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 4.3 Explanation

The following sections provide some explanation of code.

### 4.3.1 EAL Initialization

The first task is to initialize the Environment Abstraction Layer (EAL). This is done in the `main()` function using the following code:

```
int
MAIN(int argc, char **argv)
{
    ret = rte_eal_init(argc, argv);
    if (ret < 0)
        rte_panic("Cannot init EAL\n");
```

This call finishes the initialization process that was started before main() is called (in case of a Linuxapp environment). The `argc` and `argv` arguments are provided to the `rte_eal_init()` function. The value returned is the number of parsed arguments.

### 4.3.2 Starting Application Unit Lcores

Once the EAL is initialized, the application is ready to launch a function on an lcore. In this example, `lcore_hello()` is called on every available lcore. The following is the definition of the function:

```
static int
lcore_hello(__attribute__((unused)) void *arg)
{
    unsigned lcore_id;
    lcore_id = rte_lcore_id();
    printf("hello from core %u\n", lcore_id);
    return 0;
}
```

The code that launches the function on each lcore is as follows:

```
    /* call lcore_hello() on every slave lcore */
    RTE_LCORE_FOREACH_SLAVE(lcore_id) {
        rte_eal_remote_launch(lcore_hello, NULL, lcore_id);
    }

    /* call it on master lcore too */
    lcore_hello(NULL);
```

The following code is equivalent and simpler:

```
    rte_eal_mp_remote_launch(lcore_hello, NULL, CALL_MASTER);
```

Refer to the *Intel® DPDK API Reference* for detailed information on the `rte_eal_mp_remote_launch()` function.

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# 5.0 IPv4 Fragmentation Sample Application

The IPv4 Fragmentation application is a simple example of packet processing using the Intel® Data Plane Development Kit (Intel® DPDK). The application does L3 forwarding with IPv4 packet fragmentation.

## 5.1 Overview

The application demonstrates the use of zero-copy buffers for packet fragmentation. The initialization and run-time paths are very similar to those of the L2 forwarding application (see Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for more information). This guide highlights the differences between the two applications.

There are two key differences from the L2 Forwarding sample application:

- The first difference is that the IPv4 Fragment sample application makes use of indirect buffers.
- The second difference is that the forwarding decision is taken based on information read from the input packet's IPv4 header.

The Longest Prefix Match (LPM) table is used to store/lookup an outgoing port number, associated with that IPv4 address.

By default, input frame sizes up to 9.5 KB are supported. Before forwarding, the input IPv4 packet is fragmented to fit into the "standard" Ethernet* v2 MTU (1500 bytes).

## 5.2 Building the Application

To build the application:

1. Go to the sample application directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/ipv4_frag
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 5.3 Running the Application

The LPM object is created and loaded with the pre-configured entries read from a global `l3fwd_route_array` table. For each input packet, the packet forwarding decision (that is, the identification of the output interface for the packet) is taken as a result of LPM lookup. If the IP packet size is greater than default output MTU, then the input packet is fragmented and several fragments are sent via the output interface.

Application usage:

```
./build/ipv4_frag [EAL options] -- -p PORTMASK [-q NQ]
```

where:

- `-p PORTMASK` is a hexadecimal bitmask of ports to configure
- `-q NQ` is the number of queue (=ports) per lcore (the default is 1)

To run the example in linuxapp environment with 2 lcores (2,4) over 2 ports(0,2) with 1 RX queue per lcore:

```
./build/ipv4_frag -c 0x14 -n 3 -- -p 5
EAL: coremask set to 14
EAL: Detected lcore 0 on socket 0
EAL: Detected lcore 1 on socket 1
EAL: Detected lcore 2 on socket 0
EAL: Detected lcore 3 on socket 1
EAL: Detected lcore 4 on socket 0
...
Initializing port 0 on lcore 2...  Address:00:1B:21:76:FA:2C, rxq=0 txq=2,0 txq=4,1
done:  Link Up - speed 10000 Mbps - full-duplex
Skipping disabled port 1
Initializing port 2 on lcore 4...  Address:00:1B:21:5C:FF:54, rxq=0 txq=2,0 txq=4,1
done:  Link Up - speed 10000 Mbps - full-duplex
Skipping disabled port 3
Adding route 0x640a0000 / 16 (2)
Adding route 0x64140000 / 16 (2)
...
L3FWD: entering main loop on lcore 4
L3FWD:  -- lcoreid=4 portid=2
L3FWD: entering main loop on lcore 2
L3FWD:  -- lcoreid=2 portid=0
```

To run the example in linuxapp environment with 1 lcore (4) over 2 ports(0,2) with 2 RX queues per lcore:

```
./build/ipv4_frag -c 0x10 -n 3 -- -p 5 -q 2
```

To test the application, flows should be set up in the flow generator that match the values in the `l3fwd_route_array` table.

The default `l3fwd_route_array` table is:

```
struct l3fwd_route l3fwd_route_array[] = {
        {IPv4(100,10,0,0), 16, 2},
        {IPv4(100,20,0,0), 16, 2},
        {IPv4(100,30,0,0), 16, 0},
        {IPv4(100,40,0,0), 16, 0},
};
```

For example, for the input IPv4 packet with destination address: 100.10.1.1 and packet length 9198 bytes, seven IPv4 packets will be sent out from port #2 to the destination address 100.10.1.1: six of those packets will have length 1500 bytes and one packet will have length 318 bytes.

Unlike the L3 Forwarding sample application, no NUMA support is provided in the IPv4 Fragmentation sample application.

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

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# 6.0 IPv4 Multicast Sample Application

The IPv4 Multicast application is a simple example of packet processing using the Intel® Data Plane Development Kit (Intel® DPDK). The application performs L3 multicasting.

## 6.1 Overview

The application demonstrates the use of zero-copy buffers for packet forwarding. The initialization and run-time paths are very similar to those of the L2 forwarding application (see Chapter 9.0, “L2 Forwarding Sample Application (in Real and Virtualized Environments)” for more information). This guide highlights the differences between the two applications. There are two key differences from the L2 Forwarding sample application:

- The IPv4 Multicast sample application makes use of indirect buffers.
- The forwarding decision is taken based on information read from the input packet’s IPv4 header.

The lookup method is the Four-byte Key (FBK) hash-based method. The lookup table is composed of pairs of destination IPv4 address (the FBK) and a port mask associated with that IPv4 address.

For convenience and simplicity, this sample application does not take IANA-assigned multicast addresses into account, but instead equates the last four bytes of the multicast group (that is, the last four bytes of the destination IP address) with the mask of ports to multicast packets to. Also, the application does not consider the Ethernet addresses; it looks only at the IPv4 destination address for any given packet.

## 6.2 Building the Application

To compile the application:

1. Go to the sample application directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/ipv4_multicast
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

*Note:* The compiled application is written to the `build` subdirectory. To have the application written to a different location, the `O=/path/to/build/directory` option may be specified in the `make` command.

## 6.3 Running the Application

The application has a number of command line options:

```
./build/ipv4_multicast [EAL options] -- -p PORTMASK [-q NQ]
```

where,

- `-p PORTMASK`: Hexadecimal bitmask of ports to configure
- `-q NQ`: determines the number of queues per lcore

*Note:* Unlike the basic L2/L3 Forwarding sample applications, NUMA support is not provided in the IPv4 Multicast sample application.

Typically, to run the IPv4 Multicast sample application, issue the following command (as root):

```
./build/ipv4_multicast -c 0x00f -n 3 -- -p 0x3 -q 1
```

In this command:

- The `-c` option enables cores 0, 1, 2 and 3
- The `-n` option specifies 3 memory channels
- The `-p` option enables ports 0 and 1
- The `-q` option assigns 1 queue to each lcore

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 6.4 Explanation

The following sections provide some explanation of the code. As mentioned in the overview section, the initialization and run-time paths are very similar to those of the L2 Forwarding sample application (see Chapter 9.0, “L2 Forwarding Sample Application (in Real and Virtualized Environments)” for more information). The following sections describe aspects that are specific to the IPv4 Multicast sample application.

### 6.4.1 Memory Pool Initialization

The IPv4 Multicast sample application uses three memory pools. Two of the pools are for indirect buffers used for packet duplication purposes. Memory pools for indirect buffers are initialized differently from the memory pool for direct buffers:

```
packet_pool = rte_mempool_create("packet_pool", NB_PKT_MBUF,
    PKT_MBUF_SIZE, 32, sizeof(struct rte_pktmbuf_pool_private),
    rte_pktmbuf_pool_init, NULL, rte_pktmbuf_init, NULL,
    rte_socket_id(), 0);

header_pool = rte_mempool_create("header_pool", NB_HDR_MBUF,
    HDR_MBUF_SIZE, 32, 0, NULL, NULL, rte_pktmbuf_init, NULL,
    rte_socket_id(), 0);

clone_pool = rte_mempool_create("clone_pool", NB_CLONE_MBUF,
```

```
    CLONE_MBUF_SIZE, 32, 0, NULL, NULL, rte_pktmbuf_init, NULL,
    rte_socket_id(), 0);
```

The reason for this is because indirect buffers are not supposed to hold any packet data and therefore can be initialized with lower amount of reserved memory for each buffer.

### 6.4.2 Hash Initialization

The hash object is created and loaded with the pre-configured entries read from a global array:

```
static int
init_mcast_hash(void)
{
    uint32_t i;

    mcast_hash_params.socket_id = rte_socket_id();
    mcast_hash = rte_fbk_hash_create(&mcast_hash_params);
    if (mcast_hash == NULL){
        return -1;
    }

    for (i = 0; i < N_MCAST_GROUPS; i ++){
        if (rte_fbk_hash_add_key(mcast_hash,
            mcast_group_table[i].ip,
            mcast_group_table[i].port_mask) < 0) {
            return -1;
        }
    }

    return 0;
}
```

### 6.4.3 Forwarding

All forwarding is done inside the `mcast_forward()` function. Firstly, the Ethernet* header is removed from the packet and the IPv4 address is extracted from the IPv4 header:

```
/* Remove the Ethernet header from the input packet */
    iphdr = (struct ipv4_hdr *)rte_pktmbuf_adj(m, sizeof(struct ether_hdr));
    RTE_MBUF_ASSERT(iphdr != NULL);

    dest_addr = rte_be_to_cpu_32(iphdr->dst_addr);
```

Then, the packet is checked to see if it has a multicast destination address and if the routing table has any ports assigned to the destination address:

```
if(!IS_IPV4_MCAST(dest_addr) ||
        (hash = rte_fbk_hash_lookup(mcast_hash, dest_addr)) <= 0 ||
        (port_mask = hash & enabled_port_mask) == 0) {
        rte_pktmbuf_free(m);
        return;
    }
```

Then, the number of ports in the destination `portmask` is calculated with the help of the `bitcnt()` function:

```
/* Get number of bits set. */
static inline uint32_t bitcnt(uint32_t v)
{
    uint32_t n;
```

```
    for (n = 0; v != 0; v &= v - 1, n++)
        ;

    return (n);
}
```

This is done to determine which forwarding algorithm to use. This is explained in more detail in the next section.

Thereafter, a destination Ethernet address is constructed:

```
    /* construct destination ethernet address */
    dst_eth_addr = ETHER_ADDR_FOR_IPV4_MCAST(dest_addr);
```

Since Ethernet addresses are also part of the multicast process, each outgoing packet carries the same destination Ethernet address. The destination Ethernet address is constructed from the lower 23 bits of the multicast group ORed with the Ethernet address 01:00:5e:00:00:00, as per RFC 1112:

```
# define ETHER_ADDR_FOR_IPV4_MCAST(x) \
    (rte_cpu_to_be_64(0x01005e000000ULL | ((x) & 0x7fffff)) >> 16)
```

Then, packets are dispatched to the destination ports according to the `portmask` associated with a multicast group:

```
    for (port = 0; use_clone != port_mask; port_mask >>= 1, port++) {

        /* Prepare output packet and send it out. */
        if ((port_mask & 1) != 0) {
            if (likely ((mc = mcast_out_pkt(m, use_clone)) != NULL))
                mcast_send_pkt(mc,
                    &dst_eth_addr.as_addr,
                    qconf, port);
            else if (use_clone == 0)
                rte_pktmbuf_free(m);
        }
    }
```

The actual packet transmission is done in the `mcast_send_pkt()` function:

```
static inline void mcast_send_pkt(struct rte_mbuf *pkt,
    struct ether_addr *dest_addr, struct lcore_queue_conf *qconf, uint8_t port)
{
    struct ether_hdr *ethdr;
    uint16_t len;

    /* Construct Ethernet header. */
    ethdr = (struct ether_hdr *)rte_pktmbuf_prepend(pkt,
                                                    (uint16_t) sizeof(*ethdr));

    RTE_MBUF_ASSERT(ethdr != NULL);

    ether_addr_copy(dest_addr, &ethdr->d_addr);
    ether_addr_copy(&ports_eth_addr[port], &ethdr->s_addr);
    ethdr->ether_type = rte_be_to_cpu_16(ETHER_TYPE_IPv4);

    /* Put new packet into the output queue */
    len = qconf->tx_mbufs[port].len;
    qconf->tx_mbufs[port].m_table[len] = pkt;
    qconf->tx_mbufs[port].len = ++len;

    /* Transmit packets */
    if (unlikely(MAX_PKT_BURST == len))
```

```
        send_burst(qconf, port);
}
```

### 6.4.4 Buffer Cloning

This is the most important part of the application since it demonstrates the use of zero-copy buffer cloning. There are two approaches for creating the outgoing packet and although both are based on the data zero-copy idea, there are some differences in the detail.

The first approach creates a clone of the input packet, for example, walk though all segments of the input packet and for each of segment, create a new buffer and attach that new buffer to the segment (refer to `rte_pktmbuf_clone()` in the *rte_mbuf* library for more details). A new buffer is then allocated for the packet header and is prepended to the cloned buffer.

The second approach does not make a clone, it just increments the reference counter for all input packet segment, allocates a new buffer for the packet header and prepends it to the input packet.

Basically, the first approach reuses only the input packet's data, but creates its own copy of packet's metadata. The second approach reuses both input packet’s data and metadata.

The advantage of first approach is that each outgoing packet has its own copy of the metadata, so we can safely modify the data pointer of the input packet. That allows us to skip creation if the output packet is for the last destination port and instead modify input packet’s header in place. For example, for N destination ports, we need to invoke `mcast_out_pkt()` (N-1) times.

The advantage of the second approach is that there is less work to be done for each outgoing packet, that is, the “clone” operation is skipped completely. However, there is a price to pay. The input packet’s metadata must remain intact, so for N destination ports, we need to invoke `mcast_out_pkt()` (N) times.

Therefore, for a small number of outgoing ports (and segments in the input packet), first approach is faster. As the number of outgoing ports (and/or input segments) grows, the second approach becomes more preferable.

Depending on the number of segments or the number of ports in the outgoing portmask, either the first (with cloning) or the second (without cloning) approach is taken:

```
    use_clone = (port_num <= MCAST_CLONE_PORTS &&
        m->pkt.nb_segs <= MCAST_CLONE_SEGS);
```

It is the `mcast_out_pkt()` function that performs the packet duplication (either with or without actually cloning the buffers):

```
static inline struct rte_mbuf *mcast_out_pkt(struct rte_mbuf *pkt,
    int use_clone)
{
    struct rte_mbuf *hdr;

    /* Create new mbuf for the header. */
    if (unlikely ((hdr = rte_pktmbuf_alloc(header_pool)) == NULL))
        return (NULL);

    /* If requested, then make a new clone packet. */
    if (use_clone != 0 &&
```

```
        unlikely ((pkt = rte_pktmbuf_clone(pkt, clone_pool)) == NULL)) {
        rte_pktmbuf_free(hdr);
        return (NULL);
    }

    /* prepend new header */
    hdr->pkt.next = pkt;

    /* update header's fields */
    hdr->pkt.pkt_len = (uint16_t)(hdr->pkt.data_len + pkt->pkt.pkt_len);
    hdr->pkt.nb_segs = (uint8_t)(pkt->pkt.nb_segs + 1);

    /* copy metadata from source packet*/
    hdr->pkt.in_port = pkt->pkt.in_port;
    hdr->pkt.vlan_macip = pkt->pkt.vlan_macip;
    hdr->pkt.hash = pkt->pkt.hash;

    hdr->ol_flags = pkt->ol_flags;

    __rte_mbuf_sanity_check(hdr, RTE_MBUF_PKT, 1);
    return (hdr);
}
```

# 7.0 IP Reassembly Sample Application

The L3 Forwarding application is a simple example of packet processing using the Intel® DPDK. The application performs L3 forwarding with reassembly for fragmented IPv4 packets.

## 7.1 Overview

The application demonstrates the use of the Intel® DPDK libraries to implement packet forwarding with reassembly for IPv4 fragmented packets. The initialization and run-time paths are very similar to those of the L3 forwarding application (see Chapter 10.0, "L3 Forwarding Sample Application" for more information). The main difference from the L3 Forwarding sample application is that it reassembles fragmented IPv4 packets before forwarding. The maximum allowed size of reassembled packet is 9.5 KB.

The lookup method is either hash-based or LPM-based and is selected at compile time. For more information about lookup methods and forwarding decisions, please refer to Chapter 10.0, "L3 Forwarding Sample Application"

## 7.2 Compiling the Application

To compile the application:

1. Go to the sample application directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/ip_reassembly
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 7.3 Running the Application

The application has a number of command line options:

```
./build/ip_reassembly [EAL options] -- -p PORTMASK [-P]
--config(port,queue,lcore)[,(port,queue,lcore)] [--enable-jumbo [--max-pkt-len PKTLEN]]
[--maxflows=FLOWS>] [--flowttl=TTL[(s|ms)]]
```

where:

- `-p PORTMASK`: Hexadecimal bitmask of ports to configure

- `-P`: Sets all ports to promiscuous mode so that packets are accepted regardless of the packet's Ethernet MAC destination address. Without this option, only packets with the Ethernet MAC destination address set to the Ethernet address of the port are accepted.
- `--config (port,queue,lcore)[,(port,queue,lcore)]`: determines which queues from which ports are mapped to which cores
- `--enable-jumbo:` enable jumbo frame which max packet len is PKTLEN in decimal (64-9600)
- `--maxflows=FLOWS`: determines maximum number of active fragmented flows (1-65535). Default value: 4096.
- `--flowttl=TTL[(s|ms)]`: determines maximum Time To Live for fragmented packet. If all fragments of the packet wouldn't appear within given time-out, then they are considered as invalid and will be dropped. Valid range is 1ms - 3600s. Default value: 1s.

For example, consider a dual processor socket platform where cores 0, 2, 4, 6, 8 and 10 appear on socket 0, while cores 1, 3, 5, 7, 9 and 11 appear on socket 1. Let's say that the programmer wants to use memory from both NUMA nodes, the platform has only two ports and the programmer wants to use two cores from each processor socket to do the packet processing.

To enable L3 forwarding with IPv4 reassembly between two ports, using two cores from each processor, while also taking advantage of local memory access by optimizing around NUMA, the programmer must enable two queues from each port, pin to the appropriate cores and allocate memory from the appropriate NUMA node. This is achieved using the following command:

```
./build/ip_reassembly -c f -n 4 -- -p 0x3 --config="(0,0,0),(0,1,2),(1,0,1),(1,1,3)"
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 7.4 Explanation

The following sections provide some explanation of the sample application code. As mentioned in the overview section, the initialization and run-time paths are very similar to those of the L3 forwarding application (see Chapter 10.0, "L3 Forwarding Sample Application" for more information). The following sections describe aspects that are specific to the IP reassemble sample application.

### 7.4.1 IPv4 Fragment Table Initialization

Fragment table maintains information about already received fragments of the packet. Each packet IPv4 is uniquely identified by triple <Source IP address>, <Destination IP address>, <ID>. To avoid lock contention, each RX queue has it's own Fragment Table, e.g. the application can't handle the situation when different fragments of the same packet arrive through different RX queues. Each table entry can hold information about packet consisting of up to MAX_FRAG_NUM(by default: 4) fragments.

```
frag_cycles = (rte_get_tsc_hz() + MS_PER_S - 1) / MS_PER_S *
               max_flow_ttl;

if ((qconf->frag_tbl[queue] = ipv4_frag_tbl_create(max_flow_num,
        IPV4_FRAG_TBL_BUCKET_ENTRIES, max_flow_num, frag_cycles,
            socket)) == NULL)
```

```
    rte_exit(EXIT_FAILURE, "ipv4_frag_tbl_create(%u) on "
        "lcore: %u for queue: %u failed\n",
        max_flow_num, lcore, queue);
```

### 7.4.2 Mempools Initialization

The reassembly application demands a lot of mbuf's to be allocated. At any given time up to (2 * `max_flow_num * MAX_FRAG_NUM * <maximum number of mbufs per packet>`) can be stored inside Fragment Table waiting for remaining fragments. To keep mempool size under reasonable limits and to avoid situation when one RX queue can starve other queues, each RX queue uses it's own mempool.

```
nb_mbuf = max_flow_num * MAX_FRAG_NUM;
nb_mbuf = 2 * RTE_MAX(max_flow_num, 2UL * MAX_PKT_BURST) * MAX_FRAG_NUM;
nb_mbuf *= (port_conf.rxmode.max_rx_pkt_len + BUF_SIZE - 1) / BUF_SIZE;
nb_mbuf += RTE_TEST_RX_DESC_DEFAULT + MAX_PKT_BURST + RTE_TEST_TX_DESC_DEFAULT;
nb_mbuf += RTE_TEST_RX_DESC_DEFAULT + RTE_TEST_TX_DESC_DEFAULT;


nb_mbuf = RTE_MAX(nb_mbuf, (uint32_t)DEF_MBUF_NUM);

    rte_snprintf(buf, sizeof(buf), "mbuf_pool_%u_%u", lcore, queue);

if ((qconf->pool[queue] = rte_mempool_create(buf, nb_mbuf, MBUF_SIZE, 0,
        sizeof(struct rte_pktmbuf_pool_private),
        rte_pktmbuf_pool_init, NULL, rte_pktmbuf_init, NULL,
        socket, MEMPOOL_F_SP_PUT | MEMPOOL_F_SC_GET)) == NULL)
    rte_exit(EXIT_FAILURE, "mempool_create(%s) failed", buf);
```

### 7.4.3 Packet Reassembly and Forwarding

For each input packet, the packet forwarding operation is done by the `l3fwd_simple_forward()` function. If the packet is an IPv4 fragment, then it calls `ipv4_frag_mbuf()`. `ipv4_frag_mbuf()` either returns a pointer to valid mbuf that contains reassembled packet, or `NULL` (if the packet can't be reassembled for some reason). Then `3fwd_simple_forward()` continues with the code for the packet forwarding decision (that is, the identification of the output interface for the packet) and actual transmit of the packet.

The `ipv4_frag_mbuf()` is responsible for:

1. Search the Fragment Table for entry with packet's <IPv4 Source Address, IPv4 Destination Address, Packet ID>
2. If the entry is found, then check if that entry already timed-out. If yes, then free all previously received fragments, and remove information about them from the entry.
3. If no entry with such key is found, then try to create a new one by one of two ways:
    a. Use as empty entry
    b. Delete a timed-out entry, free mbufs associated with it mbufs and store a new entry with specified key in it.
4. Update the entry with new fragment information and check if a packet can be reassembled (the packet's entry contains all fragments).
    a. If yes, then, reassemble the packet, mark table's entry as empty and return the reassembled mbuf to the caller.
    b. If no, then just return a NULL to the caller.

If at any stage of packet processing ipv4_frag_mbuf() encounters an error (can't insert new entry into the Fragment table, or invalid/timed-out fragment), then ipv4_frag_mbuf() will free all associated with the packet fragments, mark the table entry as invalid and return NULL to the caller.

### 7.4.4 Debug logging and Statistics Collection

The IPV4_FRAG_TBL_STAT controls statistics collection for the IPv4 Fragment Table. This macro is enabled by default. To make ip_reassembly print the statistics to the standard output, the user must send either an USR1, INT or TERM signal to the process. For all of these signals, the ip_reassembly process prints Fragment table statistics for each RX queue, plus the INT and TERM will cause process termination as usual.

The IPV4_FRAG_DEBUG controls debug logging of IPv4 fragments processing and reassembling. This macro is disabled by default. Note that while logging contains a lot of detailed information, it slows down packet processing and might cause the loss of a lot of packets.

§ §

# 8.0 Kernel NIC Interface Sample Application

The Kernel NIC Interface (KNI) is an Intel® DPDK control plane solution that allows userspace applications to exchange packets with the kernel networking stack. To accomplish this, Intel® DPDK userspace applications use an IOCTL call to request the creation of a KNI virtual device in the Linux* kernel. The IOCTL call provides interface information and the Intel® DPDK's physical address space, which is re-mapped into the kernel address space by the KNI kernel loadable module that saves the information to a virtual device context. The Intel® DPDK creates FIFO queues for packet ingress and egress to the kernel module for each device allocated.

The KNI kernel loadable module is a standard net driver, which upon receiving the IOCTL call access the Intel® DPDK's FIFO queue to receive/transmit packets from/to the Intel® DPDK userspace application. The FIFO queues contain pointers to data packets in the Intel® DPDK. This:

- Provides a faster mechanism to interface with the kernel net stack and eliminates system calls
- Facilitates the Intel® DPDK using standard Linux* userspace net tools (`tcpdump`, `ftp`, and so on)
- Eliminate the `copy_to_user` and `copy_from_user` operations on packets.

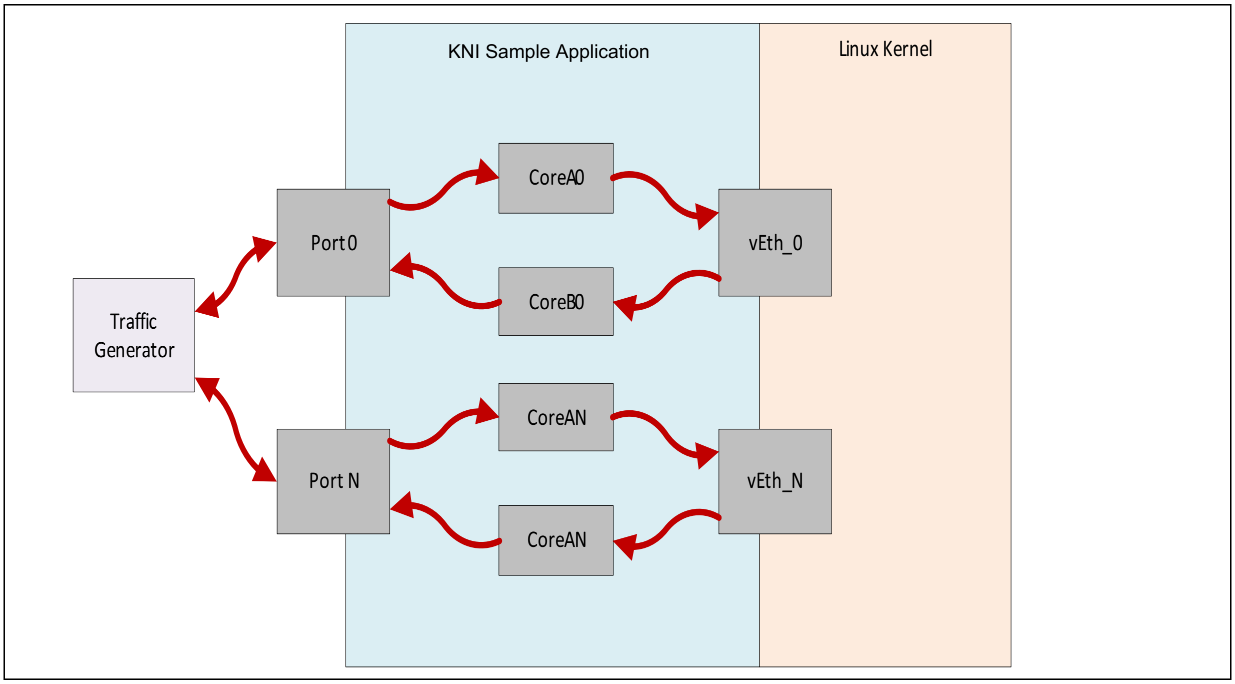
The Kernel NIC Interface sample application is a simple example that demonstrates the use of the Intel® DPDK to create a path for packets to go through the Linux* kernel. This is done by creating one or more kernel net devices for each of the Intel® DPDK ports. The application allows the use of standard Linux tools (`ethtool`, `ifconfig`, `tcpdump`) with the Intel® DPDK ports and also the exchange of packets between the Intel® DPDK application and the Linux kernel.

## 8.1 Overview

The Kernel NIC Interface sample application uses two threads in user space for each physical NIC port being used, and allocates one or more KNI device for each physical NIC port with kernel module's support. For a physical NIC port, one thread reads from the port and writes to KNI devices, and another thread reads from KNI devices and writes the data unmodified to the physical NIC port. It is recommended to configure one KNI device for each physical NIC port. If configured with more than one KNI devices for a physical NIC port, it is just for performance testing, or it can work together with VMDq support in future.

The packet flow through the Kernel NIC Interface application is as shown in the following figure.

**Figure 2. Kernel NIC Application Packet Flow**




## 8.2 Compiling the Application

Compile the application as follows:

1. Go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/kni
```

2. Set the target (a default target is used if not specified)

*Note:* This application is intended as a linuxapp only.

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

3. Build the application:

```
make
```

## 8.3 Loading the Kernel Module

Loading the KNI kernel module without any parameter is the typical way an Intel® DPDK application gets packets into and out of the kernel net stack. This way, only one kernel thread is created for all KNI devices for packet receiving in kernel side.

```
#insmod rte_kni.ko
```

Pinning the kernel thread to a specific core can be done using a taskset command such as following:

```
#taskset -p 100000 `pgrep -fl kni_thread | awk '{print $1}'`
```

This command line tries to pin the specific `kni_thread` on the 20th lcore (lcore numbering starts at 0), which means it needs to check if that lcore is available on the board. This command must be sent after the application has been launched, as `insmod` does not start the `kni` thread.

For optimum performance, the lcore in the mask must be selected to be on the same socket as the lcores used in the KNI application.

To provide flexibility of performance, the kernel module of the KNI, located in the `kmod` sub-directory of the Intel® DPDK target directory, can be loaded with parameter of `kthread_mode` as follows:

- `#insmod rte_kni.ko kthread_mode=single`

  This mode will create only one kernel thread for all KNI devices for packet receiving in kernel side. By default, it is in this single kernel thread mode. It can set core affinity for this kernel thread by using Linux command `taskset`.
- `#insmod rte_kni.ko kthread_mode =multiple`

  This mode will create a kernel thread for each KNI device for packet receiving in kernel side. The core affinity of each kernel thread is set when creating the KNI device. The lcore ID for each kernel thread is provided in the command line of launching the application. Multiple kernel thread mode can provide scalable higher performance.

To measure the throughput in a loopback mode, the kernel module of the KNI, located in the `kmod` sub-directory of the Intel® DPDK target directory, can be loaded with parameters as follows:

- `#insmod rte_kni.ko lo_mode=lo_mode_fifo`
  This loopback mode will involve ring enqueue/dequeue operations in kernel space.
- `#insmod rte_kni.ko lo_mode=lo_mode_fifo_skb`
  This loopback mode will involve ring enqueue/dequeue operations and sk buffer copies in kernel space.

## 8.4 Running the Application

The application requires a number of command line options:

```
kni [EAL options] -- -P -p PORTMASK
--config="(port,lcore_rx,lcore_tx[,lcore_kthread,...])[,port,lcore_rx,lcore_tx
[,lcore_kthread,...]]"
```

Where:

- `-P`: Set all ports to promiscuous mode so that packets are accepted regardless of the packet's Ethernet MAC destination address. Without this option, only packets with the Ethernet MAC destination address set to the Ethernet address of the port are accepted.
- `-p PORTMASK`: Hexadecimal bitmask of ports to configure.
- `--config="(port,lcore_rx, lcore_tx[,lcore_kthread,…])[, port,lcore_rx, lcore_tx[,lcore_kthread,…]]"`: Determines which lcores of RX, TX, kernel thread are mapped to which ports.

Refer to *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

The `-c coremask` parameter of the EAL options should include the lcores indicated by the `lcore_rx` and `lcore_tx`, but does not need to include lcores indicated by `lcore_kthread` as they are used to pin the kernel thread on. The `-p PORTMASK` parameter should include the ports indicated by the `port` in `--config`, neither more nor less.

The `lcore_kthread` in `--config` can be configured none, one or more lcore IDs. In multiple kernel thread mode, if configured none, a KNI device will be allocated for each port, while no specific lcore affinity will be set for its kernel thread. If configured one or more lcore IDs, one or more KNI devices will be allocated for each port, while specific lcore affinity will be set for its kernel thread. In single kernel thread mode, if configured none, a KNI device will be allocated for each port. If configured one or more lcore IDs, one or more KNI devices will be allocated for each port while no lcore affinity will be set as there is only one kernel thread for all KNI devices.

For example, to run the application with two ports served by six lcores, one lcore of RX, one lcore of TX, and one lcore of kernel thread for each port:

```
./build/kni -c 0xf0 -n 4 -- -P -p 0x3 -config="(0,4,6,8),(1,5,7,9)"
```

## 8.5 KNI Operations

Once the KNI application is started, one can use different Linux* commands to manage the net interfaces. If more than one KNI devices configured for a physical port, only the first KNI device will be paired to the physical device. Operations on other KNI devices will not affect the physical port handled in user space application.

Assigning an IP address:

```
#ifconfig vEth0_0 192.168.0.1
```

Displaying the NIC registers:

```
#ethtool -d vEth0_0
```

Dumping the network traffic:

```
#tcpdump -i vEth0_0
```

When the Intel® DPDK userspace application is closed, all the KNI devices are deleted from Linux*.

## 8.6 Explanation

The following sections provide some explanation of code.

### 8.6.1 Initialization

Setup of mbuf pool, driver and queues is similar to the setup done in the L2 Forwarding sample application (see Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for details). In addition, one or more kernel NIC interfaces are allocated for each of the configured ports according to the command line parameters.

The code for creating the kernel NIC interface for a specific port is as follows:

```
kni = rte_kni_create(port, MAX_PACKET_SZ, pktmbuf_pool, &kni_ops);
```

```
if (kni == NULL)
    rte_exit(EXIT_FAILURE, "Fail to create kni dev "
                 "for port: %d\n", port);
```

The code for allocating the kernel NIC interfaces for a specific port is as follows:

```
static int
kni_alloc(uint8_t port_id)
{
    uint8_t i;
    struct rte_kni *kni;
    struct rte_kni_conf conf;
    struct kni_port_params **params = kni_port_params_array;

    if (port_id >= RTE_MAX_ETHPORTS || !params[port_id])
        return -1;

    params[port_id]->nb_kni = params[port_id]->nb_lcore_k ?
                              params[port_id]->nb_lcore_k : 1;

    for (i = 0; i < params[port_id]->nb_kni; i++) {
        /* Clear conf at first */
        memset(&conf, 0, sizeof(conf));
        if (params[port_id]->nb_lcore_k) {
            rte_snprintf(conf.name, RTE_KNI_NAMESIZE,
                                   "vEth%u_%u", port_id, i);
            conf.core_id = params[port_id]->lcore_k[i];
            conf.force_bind = 1;
        } else
            rte_snprintf(conf.name, RTE_KNI_NAMESIZE,
                                        "vEth%u", port_id);
            conf.group_id = (uint16_t)port_id;
            conf.mbuf_size = MAX_PACKET_SZ;
            /*
             * The first KNI device associated to a port
             * is the master, for multiple kernel thread
             * environment.
             */
            if (i == 0) {
                struct rte_kni_ops ops;
                struct rte_eth_dev_info dev_info;

                memset(&dev_info, 0, sizeof(dev_info));
                rte_eth_dev_info_get(port_id, &dev_info);
                conf.addr = dev_info.pci_dev->addr;
                conf.id = dev_info.pci_dev->id;

                memset(&ops, 0, sizeof(ops));
                ops.port_id = port_id;
                ops.change_mtu = kni_change_mtu;
                ops.config_network_if = kni_config_network_interface;

                kni = rte_kni_alloc(pktmbuf_pool, &conf, &ops);
            } else
                kni = rte_kni_alloc(pktmbuf_pool, &conf, NULL);

            if (!kni)
                rte_exit(EXIT_FAILURE, "Fail to create kni for "
                                  "port: %d\n", port_id);
            params[port_id]->kni[i] = kni;
        }

    return 0;
}
```

The other step in the initialization process that is unique to this sample application is the association of each port with lcores for RX, TX and kernel threads.

- One lcore to read from the port and write to the associated one or more KNI devices
- Another lcore to read from one or more KNI devices and write to the port
- Other lcores for pinning the kernel threads on one by one

This is done by using the`kni_port_params_array[]`array, which is indexed by the port ID. The code is as follows:

```
static int
parse_config(const char *arg)
{
    const char *p, *p0 = arg;
    char s[256], *end;
    unsigned size;
    enum fieldnames {
            FLD_PORT = 0,
            FLD_LCORE_RX,
            FLD_LCORE_TX,
            _NUM_FLD = KNI_MAX_KTHREAD + 3,
    };
    int i, j, nb_token;
    char *str_fld[_NUM_FLD];
    unsigned long int_fld[_NUM_FLD];
    uint8_t port_id, nb_kni_port_params = 0;

    memset(&kni_port_params_array, 0, sizeof(kni_port_params_array));
    while (((p = strchr(p0, '(')) != NULL) &&
        nb_kni_port_params < RTE_MAX_ETHPORTS) {
        p++;
        if ((p0 = strchr(p, ')')) == NULL)
            goto fail;
        size = p0 - p;
        if (size >= sizeof(s)) {
            printf("Invalid config parameters\n");
            goto fail;
        }
        rte_snprintf(s, sizeof(s), "%.*s", size, p);
        nb_token = rte_strsplit(s, sizeof(s), str_fld, _NUM_FLD, ',');
        if (nb_token <= FLD_LCORE_TX) {
            printf("Invalid config parameters\n");
            goto fail;
        }
        for (i = 0; i < nb_token; i++) {
            errno = 0;
            int_fld[i] = strtoul(str_fld[i], &end, 0);
            if (errno != 0 || end == str_fld[i]) {
                printf("Invalid config parameters\n");
                goto fail;
            }
        }

        i = 0;
        port_id = (uint8_t)int_fld[i++];
        if (port_id >= RTE_MAX_ETHPORTS) {
            printf("Port ID %u could not exceed the maximum %u\n",
                                    port_id, RTE_MAX_ETHPORTS);
            goto fail;
        }
        if (kni_port_params_array[port_id]) {
            printf("Port %u has been configured\n", port_id);
            goto fail;
        }
```

```
        kni_port_params_array[port_id] =
                (struct kni_port_params*)rte_zmalloc("KNI_port_params",
                sizeof(struct kni_port_params), CACHE_LINE_SIZE);
        kni_port_params_array[port_id]->port_id = port_id;
        kni_port_params_array[port_id]->lcore_rx =
                                    (uint8_t)int_fld[i++];
        kni_port_params_array[port_id]->lcore_tx =
                                    (uint8_t)int_fld[i++];
        if (kni_port_params_array[port_id]->lcore_rx >= RTE_MAX_LCORE ||
        kni_port_params_array[port_id]->lcore_tx >= RTE_MAX_LCORE) {
        printf("lcore_rx %u or lcore_tx %u ID could not "
                                        "exceed the maximum %u\n",
               kni_port_params_array[port_id]->lcore_rx,
               kni_port_params_array[port_id]->lcore_tx,
                                            RTE_MAX_LCORE);
        goto fail;
    }
    for (j = 0; i < nb_token && j < KNI_MAX_KTHREAD; i++, j++)
        kni_port_params_array[port_id]->lcore_k[j] =
                                    (uint8_t)int_fld[i];
        kni_port_params_array[port_id]->nb_lcore_k = j;
    }
    print_config();

    return 0;

fail:

    for (i = 0; i < RTE_MAX_ETHPORTS; i++) {
        if (kni_port_params_array[i]) {
            rte_free(kni_port_params_array[i]);
            kni_port_params_array[i] = NULL;
        }
    }

    return -1;
}
```

### 8.6.2 Packet Forwarding

After the initialization steps are completed, the `main_loop()` function is run on each lcore. This function first checks the `lcore_id` against the user provided lcore_rx and lcore_tx to see if this lcore is reading from or writing to kernel NIC interfaces.

For the case that reads from a NIC port and writes to the kernel NIC interfaces, the packet reception is the same as in L2 Forwarding sample application (see Section 9.4.6, "Receive, Process and Transmit Packets" on page 48). The packet transmission is done by sending mbufs into the kernel NIC interfaces by `rte_kni_tx_burst()`. The KNI library automatically frees the mbufs after the kernel successfully copied the mbufs.

```
/**
 * Interface to burst rx and enqueue mbufs into rx_q
 */

static void
kni_ingress(struct kni_port_params *p)
{
    uint8_t i, nb_kni, port_id;
    unsigned nb_rx, num;
    struct rte_mbuf *pkts_burst[PKT_BURST_SZ];

    if (p == NULL)
        return;

    nb_kni = p->nb_kni;
```

```
    port_id = p->port_id;
    for (i = 0; i < nb_kni; i++) {
        /* Burst rx from eth */
        nb_rx = rte_eth_rx_burst(port_id, 0, pkts_burst, PKT_BURST_SZ);
        if (unlikely(nb_rx > PKT_BURST_SZ)) {
            RTE_LOG(ERR, APP, "Error receiving from eth\n");
            return;
        }
        /* Burst tx to kni */
        num = rte_kni_tx_burst(p->kni[i], pkts_burst, nb_rx);
        kni_stats[port_id].rx_packets += num;

        rte_kni_handle_request(p->kni[i]);
        if (unlikely(num < nb_rx)) {
            /* Free mbufs not tx to kni interface */
            kni_burst_free_mbufs(&pkts_burst[num], nb_rx - num);
            kni_stats[port_id].rx_dropped += nb_rx - num;
        }
    }
}
```

For the other case that reads from kernel NIC interfaces and writes to a physical NIC port, packets are retrieved by reading mbufs from kernel NIC interfaces by `rte_kni_rx_burst()`. The packet transmission is the same as in the L2 Forwarding sample application (see Section 9.4.6, "Receive, Process and Transmit Packets" on page 48).

```
/**
 * Interface to dequeue mbufs from tx_q and burst tx
 */
static void
kni_egress(struct kni_port_params *p)
{
    uint8_t i, nb_kni, port_id;
    unsigned nb_tx, num;
    struct rte_mbuf *pkts_burst[PKT_BURST_SZ];

    if (p == NULL)
        return;

    nb_kni = p->nb_kni;
    port_id = p->port_id;
    for (i = 0; i < nb_kni; i++) {
        /* Burst rx from kni */
        num = rte_kni_rx_burst(p->kni[i], pkts_burst, PKT_BURST_SZ);
        if (unlikely(num > PKT_BURST_SZ)) {
                RTE_LOG(ERR, APP, "Error receiving from KNI\n");
                return;
        }
        /* Burst tx to eth */
        nb_tx = rte_eth_tx_burst(port_id, 0, pkts_burst, (uint16_t)num);
        kni_stats[port_id].tx_packets += nb_tx;
        if (unlikely(nb_tx < num)) {
            /* Free mbufs not tx to NIC */
            kni_burst_free_mbufs(&pkts_burst[nb_tx], num - nb_tx);
            kni_stats[port_id].tx_dropped += num - nb_tx;
        }
    }
}
```

### 8.6.3 Callbacks for Kernel Requests

To execute specific PMD operations in user space requested by some Linux* commands, callbacks must be implemented and filled in the `struct rte_kni_ops` structure. Currently, setting a new MTU and configuring the network interface (up/down) are supported.

```
static struct rte_kni_ops kni_ops = {
    .change_mtu = kni_change_mtu,
    .config_network_if = kni_config_network_interface,
};

/* Callback for request of changing MTU */
static int
kni_change_mtu(uint8_t port_id, unsigned new_mtu)
{
    int ret;
    struct rte_eth_conf conf;

    if (port_id >= rte_eth_dev_count()) {
        RTE_LOG(ERR, APP, "Invalid port id %d\n", port_id);
        return -EINVAL;
    }

    RTE_LOG(INFO, APP, "Change MTU of port %d to %u\n", port_id, new_mtu);

    /* Stop specific port */
    rte_eth_dev_stop(port_id);

    memcpy(&conf, &port_conf, sizeof(conf));
    /* Set new MTU */
    if (new_mtu > ETHER_MAX_LEN)
        conf.rxmode.jumbo_frame = 1;
    else
        conf.rxmode.jumbo_frame = 0;

    /* mtu + length of header + length of FCS = max pkt length */
    conf.rxmode.max_rx_pkt_len = new_mtu + KNI_ENET_HEADER_SIZE +
                                KNI_ENET_FCS_SIZE;
    ret = rte_eth_dev_configure(port_id, 1, 1, &conf);
    if (ret < 0) {
        RTE_LOG(ERR, APP, "Fail to reconfigure port %d\n", port_id);
        return ret;
    }

    /* Restart specific port */
    ret = rte_eth_dev_start(port_id);
    if (ret < 0) {
        RTE_LOG(ERR, APP, "Fail to restart port %d\n", port_id);
        return ret;
    }

    return 0;
}

/* Callback for request of configuring network interface up/down */
static int
kni_config_network_interface(uint8_t port_id, uint8_t if_up)
{
    int ret = 0;

    if (port_id >= rte_eth_dev_count() || port_id >= RTE_MAX_ETHPORTS) {
        RTE_LOG(ERR, APP, "Invalid port id %d\n", port_id);
        return -EINVAL;
    }
```

```
    RTE_LOG(INFO, APP, "Configure network interface of %d %s\n",
                    port_id, if_up ? "up" : "down");

    if (if_up != 0) { /* Configure network interface up */
        rte_eth_dev_stop(port_id);
        ret = rte_eth_dev_start(port_id);
    } else /* Configure network interface down */
        rte_eth_dev_stop(port_id);

    if (ret < 0)
        RTE_LOG(ERR, APP, "Failed to start port %d\n", port_id);

    return ret;
}
```

§ §

# 9.0 L2 Forwarding Sample Application (in Real and Virtualized Environments)

The L2 Forwarding sample application is a simple example of packet processing using Intel® Data Plane Development Kit (Intel® DPDK) which also takes advantage of Single Root I/O Virtualization (SR-IOV) features in a virtualized environment.

*Note:* Please note that previously a separate L2 Forwarding in Virtualized Environments sample application was used, however, in later Intel® DPDK versions these sample applications have been merged.

## 9.1 Overview

The L2 Forwarding sample application, which can operate in real and virtualized environments, performs L2 forwarding for each packet that is received on an RX_PORT. The destination port is the adjacent port from the enabled portmask, that is, if the first four ports are enabled (portmask 0xf), ports 1 and 2 forward into each other, and ports 3 and 4 forward into each other. Also, the MAC addresses are affected as follows:

- The source MAC address is replaced by the TX_PORT MAC address
- The destination MAC address is replaced by `02:00:00:00:00:TX_PORT_ID`

This application can be used to benchmark performance using a traffic-generator, as shown in the Figure 3. The application can also be used in a virtualized environment as shown in Figure 4.

**Figure 3. Performance Benchmark Setup (Basic Environment)**

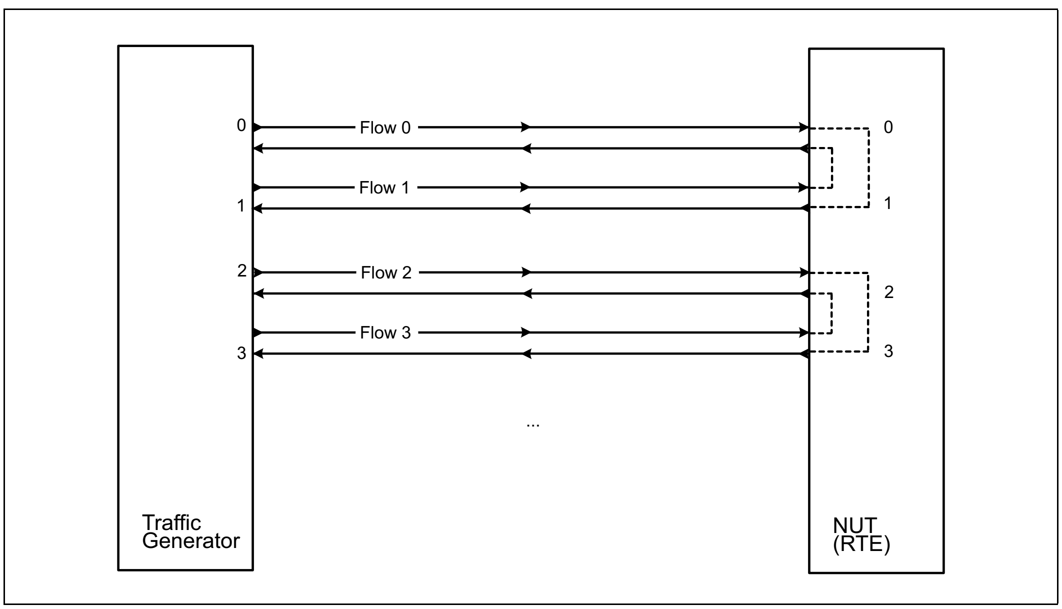
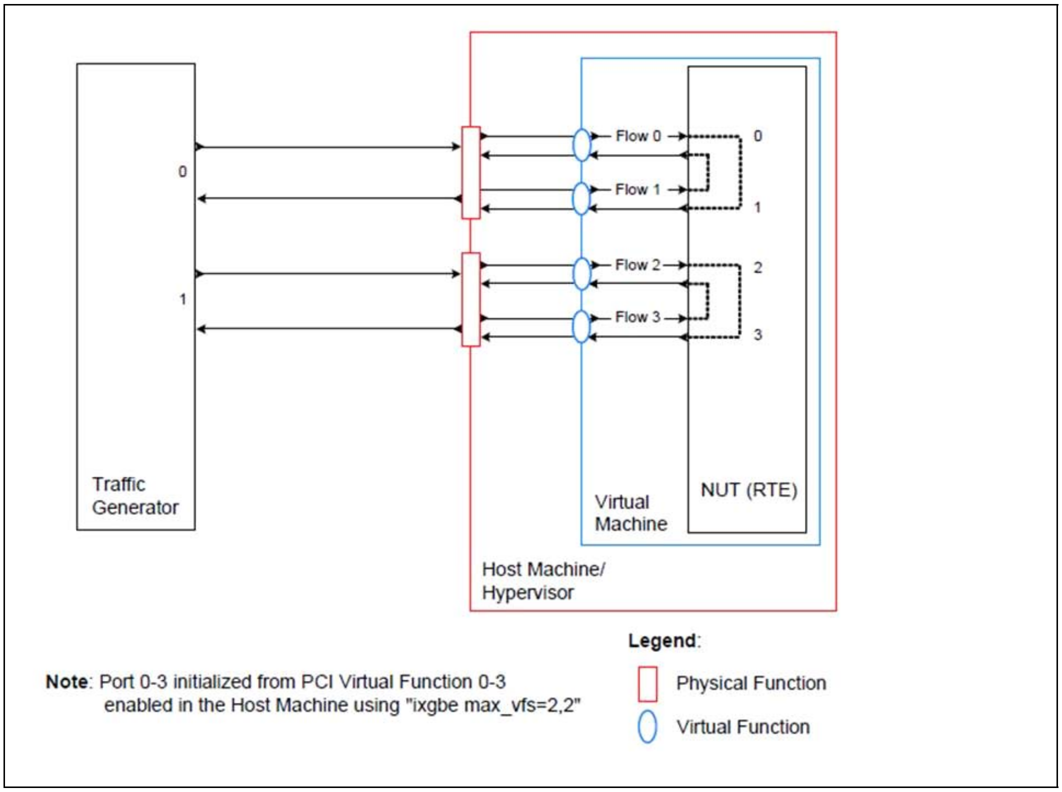


**Figure 4. Performance Benchmark Setup (Virtualized Environment)**




The L2 Forwarding application can also be used as a starting point for developing a new application based on the Intel® DPDK.

## 9.1.1 Virtual Function Setup Instructions

This application can use the virtual function available in the system and therefore can be used in a virtual machine without passing through the whole Network Device into a guest machine in a virtualized scenario. The virtual functions can be enabled in the host machine or the hypervisor with the respective physical function driver.

For example, in a Linux* host machine, it is possible to enable a virtual function using the following command:

```
modprobe ixgbe max_vfs=2,2
```

This command enables two Virtual Functions on each of Physical Function of the NIC, with two physical ports in the PCI configuration space. It is important to note that enabled Virtual Function 0 and 2 would belong to Physical Function 0 and Virtual Function 1 and 3 would belong to Physical Function 1, in this case enabling a total of four Virtual Functions.

## 9.2 Compiling the Application

1. Go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/l2fwd
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   See the *Intel® DPDK Getting Started Guide* for possible RTE_TARGET values.

3. Build the application:

```
make
```

## 9.3 Running the Application

The application requires a number of command line options:

```
./build/l2fwd [EAL options] -- -p PORTMASK [-q NQ]
```

where,

- -p PORTMASK: A hexadecimal bitmask of the ports to configure
- -q NQ: A number of queues (=ports) per lcore (default is 1)

To run the application in linuxapp environment with 4 lcores, 16 ports and 8 RX queues per lcore, issue the command:

```
$ ./build/l2fwd -c f -n 4 -- -q 8 -p ffff
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 9.4 Explanation

The following sections provide some explanation of the code.

### 9.4.1 Command Line Arguments

The L2 Forwarding sample application takes specific parameters, in addition to Environment Abstraction Layer (EAL) arguments (see Section 9.3). The preferred way to parse parameters is to use the getopt() function, since it is part of a well-defined and portable library.

The parsing of arguments is done in the l2fwd_parse_args() function. The method of argument parsing is not described here. Refer to the *glibc getopt (3)* man page for details.

EAL arguments are parsed first, then application-specific arguments. This is done at the beginning of the main() function:

```
/* init EAL */
ret = rte_eal_init(argc, argv);
if (ret < 0)
```

```
        rte_exit(EXIT_FAILURE, "Invalid EAL arguments\n");
    argc -= ret;
    argv += ret;

    /* parse application arguments (after the EAL ones) */
    ret = l2fwd_parse_args(argc, argv);
    if (ret < 0)
        rte_exit(EXIT_FAILURE, "Invalid L2FWD arguments\n");
```

### 9.4.2 Mbuf Pool Initialization

Once the arguments are parsed, the mbuf pool is created. The mbuf pool contains a set of mbuf objects that will be used by the driver and the application to store network packet data:

```
    /* create the mbuf pool */
    l2fwd_pktmbuf_pool =
        rte_mempool_create("mbuf_pool", NB_MBUF,
                           MBUF_SIZE, 32,
                           sizeof(struct rte_pktmbuf_pool_private),
                           rte_pktmbuf_pool_init, NULL,
                           rte_pktmbuf_init, NULL,
                           SOCKET0, 0);
    if (l2fwd_pktmbuf_pool == NULL)
        rte_panic("Cannot init mbuf pool\n");
```

The `rte_mempool` is a generic structure used to handle pools of objects. In this case, it is necessary to create a pool that will be used by the driver, which expects to have some reserved space in the mempool structure, `sizeof(struct rte_pktmbuf_pool_private)` bytes. The number of allocated `pktmbufs` is `NB_MBUF`, with a size of `MBUF_SIZE` each. A per-lcore cache of 32 mbufs is kept. The memory is allocated in NUMA socket 0, but it is possible to extend this code to allocate one mbuf pool per socket.

Two callback pointers are also given to the `rte_mempool_create()` function:

- The first callback pointer is to `rte_pktmbuf_pool_init()` and is used to initialize the private data of the mempool, which is needed by the driver. This function is provided by the mbuf API, but can be copied and extended by the developer.
- The second callback pointer given to `rte_mempool_create()` is the mbuf initializer. The default is used, that is, `rte_pktmbuf_init()`, which is provided in the `rte_mbuf` library. If a more complex application wants to extend the `rte_pktmbuf` structure for its own needs, a new function derived from `rte_pktmbuf_init()` can be created.

### 9.4.3 Driver Initialization

The main part of the code in the `main()` function relates to the initialization of the driver. To fully understand this code, it is recommended to study the chapters that related to the *Poll Mode Driver* in the *Intel® DPDK Programmer's Guide* - Rel 1.4 EAR and the *Intel® DPDK API Reference*.

```
    /* init driver(s) */
    if (rte_pmd_init_all() < 0)
        rte_exit(EXIT_FAILURE, "Cannot init pmd\n");

    if (rte_eal_pci_probe() < 0)
        rte_exit(EXIT_FAILURE, "Cannot probe PCI\n");

    nb_ports = rte_eth_dev_count();
```

```
    if (nb_ports == 0)
        rte_exit(EXIT_FAILURE, "No Ethernet ports - bye\n");

    if (nb_ports > RTE_MAX_ETHPORTS)
        nb_ports = RTE_MAX_ETHPORTS;

    /* reset l2fwd_dst_ports */
    for (portid = 0; portid < RTE_MAX_ETHPORTS; portid++)
        l2fwd_dst_ports[portid] = 0;
    last_port = 0;

    /*
    * Each logical core is assigned a dedicated TX queue on each port.
    */
    for (portid = 0; portid < nb_ports; portid++) {
        /* skip ports that are not enabled */
        if ((l2fwd_enabled_port_mask & (1 << portid)) == 0)
            continue;

            if (nb_ports_in_mask % 2) {
                l2fwd_dst_ports[portid] = last_port;
                l2fwd_dst_ports[last_port] = portid;
            }
            else
                last_port = portid;

            nb_ports_in_mask++;

            rte_eth_dev_info_get((uint8_t) portid, &dev_info);
        }
```

Observe that:

- `rte_igb_pmd_init_all()` simultaneously registers the driver as a PCI driver and as an Ethernet* Poll Mode Driver.
- `rte_eal_pci_probe()` parses the devices on the PCI bus and initializes recognized devices.

The next step is to configure the RX and TX queues. For each port, there is only one RX queue (only one lcore is able to poll a given port). The number of TX queues depends on the number of available lcores. The `rte_eth_dev_configure()` function is used to configure the number of queues for a port:

```
        ret = rte_eth_dev_configure((uint8_t)portid, 1, 1, &port_conf);
        if (ret < 0)
            rte_exit(EXIT_FAILURE, "Cannot configure device: "
                    "err=%d, port=%u\n",
                    ret, portid);
```

The global configuration is stored in a static structure:

```
static const struct rte_eth_conf port_conf = {
    .rxmode = {
        .split_hdr_size = 0,
        .header_split   = 0, /**< Header Split disabled */
        .hw_ip_checksum = 0, /**< IP checksum offload disabled */
        .hw_vlan_filter = 0, /**< VLAN filtering disabled */
        .jumbo_frame    = 0, /**< Jumbo Frame Support disabled */
        .hw_strip_crc   = 0, /**< CRC stripped by hardware *
    },
    .txmode = {
        .mq_mode = ETH_DCB_NONE
    },
};
```

### 9.4.4 RX Queue Initialization

The application uses one lcore to poll one or several ports, depending on the `-q` option, which specifies the number of queues per lcore.

For example, if the user specifies `-q 4`, the application is able to poll four ports with one lcore. If there are 16 ports on the target (and if the portmask argument is `-p ffff`), the application will need four lcores to poll all the ports.

```
ret = rte_eth_rx_queue_setup((uint8_t) portid, 0, nb_rxd,
                             SOCKET0, &rx_conf,
                             l2fwd_pktmbuf_pool);

if (ret < 0)
    rte_exit(EXIT_FAILURE, "rte_eth_rx_queue_setup: "
             "err=%d, port=%u\n",
             ret, portid);
```

The list of queues that must be polled for a given lcore is stored in a private structure called `struct lcore_queue_conf`.

```
struct lcore_queue_conf {
    unsigned n_rx_port;
    unsigned rx_port_list[MAX_RX_QUEUE_PER_LCORE];
    struct mbuf_table tx_mbufs[L2FWD_MAX_PORTS];

    } __rte_cache_aligned;

struct lcore_queue_conf lcore_queue_conf[RTE_MAX_LCORE];
```

The values `n_rx_port` and `rx_port_list[]` are used in the main packet processing loop (see Section 9.4.6, “Receive, Process and Transmit Packets” on page 48 later in this chapter).

The global configuration for the RX queues is stored in a static structure:

```
static const struct rte_eth_rxconf rx_conf = {
    .rx_thresh = {
        .pthresh = RX_PTHRESH,
        .hthresh = RX_HTHRESH,
        .wthresh = RX_WTHRESH,
    },
};
```

### 9.4.5 TX Queue Initialization

Each lcore should be able to transmit on any port. For every port, a single TX queue is initialized.

```
        /* init one TX queue on each port */
        fflush(stdout);
        ret = rte_eth_tx_queue_setup((uint8_t) portid, 0, nb_txd,
                    rte_eth_dev_socket_id(portid), &tx_conf);
        if (ret < 0)
            rte_exit(EXIT_FAILURE, "rte_eth_tx_queue_setup:err=%d, port=%u\n",
                    ret, (unsigned) portid);
```

The global configuration for TX queues is stored in a static structure:

```
static const struct rte_eth_txconf tx_conf = {
    .tx_thresh = {
        .pthresh = TX_PTHRESH,
        .hthresh = TX_HTHRESH,
```

```
        .wthresh = TX_WTHRESH,
    },
    .tx_free_thresh = RTE_TEST_TX_DESC_DEFAULT + 1, /* disable feature */
};
```

### 9.4.6 Receive, Process and Transmit Packets

In the `l2fwd_main_loop()` function, the main task is to read ingress packets from the RX queues. This is done using the following code:

```
/*
 * Read packet from RX queues
 */
for (i = 0; i < qconf->n_rx_port; i++) {

    portid = qconf->rx_port_list[i];
    nb_rx = rte_eth_rx_burst((uint8_t) portid, 0,
                             pkts_burst, MAX_PKT_BURST);

    for (j = 0; j < nb_rx; j++) {
        m = pkts_burst[j];
        rte_prefetch0[rte_pktmbuf_mtod(m, void *));
        l2fwd_simple_forward(m, portid);
    }
}
```

Packets are read in a burst of size `MAX_PKT_BURST`. The `rte_eth_rx_burst()` function writes the mbuf pointers in a local table and returns the number of available mbufs in the table.

Then, each mbuf in the table is processed by the `l2fwd_simple_forward()` function. The processing is very simple: process the TX port from the RX port, then replace the source and destination MAC addresses.

*Note:* In the following code, one line for getting the output port requires some explanation. During the initialization process, a static array of destination ports (`l2fwd_dst_ports[]`) is filled such that for each source port, a destination port is assigned that is either the next or previous enabled port from the portmask. Naturally, the number of ports in the portmask must be even, otherwise, the application exits.

```
static void
l2fwd_simple_forward(struct rte_mbuf *m, unsigned portid)
{
    struct ether_hdr *eth;
    void *tmp;
    unsigned dst_port;

    dst_port = l2fwd_dst_ports[portid];
    eth = rte_pktmbuf_mtod(m, struct ether_hdr *);

    /* 02:00:00:00:00:xx */
    tmp = &eth->d_addr.addr_bytes[0];
    *((uint64_t *)tmp) = 0x000000000002 + ((uint64_t) dst_port << 40);

    /* src addr */
    ether_addr_copy(&l2fwd_ports_eth_addr[dst_port], &eth->s_addr);

    l2fwd_send_packet(m, (uint8_t) dst_port);
}
```

Then, the packet is sent using the `l2fwd_send_packet(m, dst_port)` function. For this test application, the processing is exactly the same for all packets arriving on the same RX port. Therefore, it would have been possible to call the `l2fwd_send_burst()` function directly from the main loop to send all the received packets on the same TX port, using the burst-oriented send function, which is more efficient.

However, in real-life applications (such as, L3 routing), packet N is not necessarily forwarded on the same port as packet N-1. The application is implemented to illustrate that, so the same approach can be reused in a more complex application.

The `l2fwd_send_packet()` function stores the packet in a per-lcore and per-txport table. If the table is full, the whole packets table is transmitted using the `l2fwd_send_burst()` function:

```
/* Send the packet on an output interface */
static int
l2fwd_send_packet(struct rte_mbuf *m, uint8_t port)
{
    unsigned lcore_id, len;
    struct lcore_queue_conf *qconf;

    lcore_id = rte_lcore_id();

    qconf = &lcore_queue_conf[lcore_id];
    len = qconf->tx_mbufs[port].len;
    qconf->tx_mbufs[port].m_table[len] = m;
    len++;

    /* enough pkts to be sent */
    if (unlikely(len == MAX_PKT_BURST)) {
        l2fwd_send_burst(qconf, MAX_PKT_BURST, port);
        len = 0;
    }

    qconf->tx_mbufs[port].len = len;
    return 0;
}
```

To ensure that no packets remain in the tables, each lcore does a draining of TX queue in its main loop. This technique introduces some latency when there are not many packets to send, however it improves performance:

```
        cur_tsc = rte_rdtsc();

        /*
         * TX burst queue drain
         */
        diff_tsc = cur_tsc - prev_tsc;
        if (unlikely(diff_tsc > drain_tsc)) {

            for (portid = 0; portid < RTE_MAX_ETHPORTS; portid++) {
                if (qconf->tx_mbufs[portid].len == 0)
                    continue;
                l2fwd_send_burst(&lcore_queue_conf[lcore_id],
                                 qconf->tx_mbufs[portid].len,
                                 (uint8_t) portid);
                qconf->tx_mbufs[portid].len = 0;
            }

            /* if timer is enabled */
            if (timer_period > 0) {

                /* advance the timer */
```

```
            timer_tsc += diff_tsc;

            /* if timer has reached its timeout */
            if (unlikely(timer_tsc >= (uint64_t) timer_period)) {

                /* do this only on master core */
                if (lcore_id == rte_get_master_lcore()) {
                    print_stats();
                    /* reset the timer */
                    timer_tsc = 0;
                }
            }
        }

        prev_tsc = cur_tsc;
    }
```

§ §

# 10.0 L3 Forwarding Sample Application

The L3 Forwarding application is a simple example of packet processing using the Intel® DPDK. The application performs L3 forwarding.

## 10.1 Overview

The application demonstrates the use of the `hash` and `LPM` libraries in the Intel® DPDK to implement packet forwarding. The initialization and run-time paths are very similar to those of the L2 forwarding application (see Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for more information). The main difference from the L2 Forwarding sample application is that the forwarding decision is made based on information read from the input packet.

The lookup method is either hash-based or LPM-based and is selected at compile time. When the selected lookup method is hash-based, a hash object is used to emulate the flow classification stage. The hash object is used in correlation with a flow table to map each input packet to its flow at runtime.

The hash lookup key is represented by a DiffServ 5-tuple composed of the following fields read from the input packet: Source IP Address, Destination IP Address, Protocol, Source Port and Destination Port. The ID of the output interface for the input packet is read from the identified flow table entry. The set of flows used by the application is statically configured and loaded into the hash at initialization time. When the selected lookup method is LPM based, an LPM object is used to emulate the forwarding stage for IPv4 packets. The LPM object is used as the routing table to identify the next hop for each input packet at runtime.

The LPM lookup key is represented by the Destination IP Address field read from the input packet. The ID of the output interface for the input packet is the next hop returned by the LPM lookup. The set of LPM rules used by the application is statically configured and loaded into the LPM object at initialization time.

In the sample application, hash-based forwarding supports IPv4 and IPv6. LPM-based forwarding supports IPv4 only.

## 10.2 Compiling the Application

To compile the application:

1. Go to the sample application directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/l3fwd
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 10.3 Running the Application

The application has a number of command line options:

```
./build/l3fwd [EAL options] -- -p PORTMASK [-P]
--config(port,queue,lcore)[,(port,queue,lcore)]
```

where,

- `-p PORTMASK`: Hexadecimal bitmask of ports to configure
- `-P`: Sets all ports to promiscuous mode so that packets are accepted regardless of the packet's Ethernet MAC destination address. Without this option, only packets with the Ethernet MAC destination address set to the Ethernet address of the port are accepted.
- `--config (port,queue,lcore)[,(port,queue,lcore]`: determines which queues from which ports are mapped to which cores

For example, consider a dual processor socket platform where cores 0-7 and 16-23 appear on socket 0, while cores 8-15 and 24-31 appear on socket 1. Let's say that the programmer wants to use memory from both NUMA nodes, the platform has only two ports, one connected to each NUMA node, and the programmer wants to use two cores from each processor socket to do the packet processing.

To enable L3 forwarding between two ports, using two cores, cores 1 and 2, from each processor, while also taking advantage of local memory access by optimizing around NUMA, the programmer must enable two queues from each port, pin to the appropriate cores and allocate memory from the appropriate NUMA node. This is achieved using the following command:

```
./build/l3fwd -c 606 -n 4 -- -p 0x3 --config="(0,0,1),(0,1,2),(1,0,9),(1,1,10)"
```

In this command:

- The `-c` option enables cores 0, 1, 2, 3
- The `-p` option enables ports 0 and 1
- The `--config` option enables two queues on each port and maps each (port,queue) pair to a specific core. Logic to enable multiple RX queues using RSS and to allocate memory from the correct NUMA nodes is included in the application and is done transparently. The following table shows the mapping in this example:

| Port | Queue | lcore | Description |
|---|---|---|---|
| 0 | 0 | 0 | Map queue 0 from port 0 to lcore 0. |
| 0 | 1 | 2 | Map queue 1 from port 0 to lcore 2. |
| 1 | 0 | 1 | Map queue 0 from port 1 to lcore 1. |
| 1 | 1 | 3 | Map queue 1 from port 1 to lcore 3. |

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Envrionment Abstraction Layer (EAL) options.

## 10.4 Explanation

The following sections provide some explanation of the sample application code. As mentioned in the overview section, the initialization and run-time paths are very similar to those of the L2 forwarding application (see Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for more information). The following sections describe aspects that are specific to the L3 Forwarding sample application.

### 10.4.1 Hash Initialization

The hash object is created and loaded with the pre-configured entries read from a global array, and then generate the expected 5-tuple as key to keep consistence with those of real flow for the convenience to execute hash performance test on 4M/8M/16M flows.

*Note:* The Hash initialization will setup both ipv4 and ipv6 hash table, and populate the either table depending on the value of variable ipv6. To support the hash performance test with up to 8M single direction flows/16M bi-direction flows, `populate_ipv4_many_flow_into_table()` function will populate the hash table with specified hash table entry number(default 4M).

*Note:* Value of global variable `ipv6` can be specified with `--ipv6` in the command line. Value of global variable `hash_entry_number`, which is used to specify the total hash entry number for all used ports in hash performance test, can be specified with `--hash-entry-num VALUE` in command line, being its default value 4.

```
#if (APP_LOOKUP_METHOD == APP_LOOKUP_EXACT_MATCH)
static void
setup_hash(int socketid)
{
    // ...
if (hash_entry_number != HASH_ENTRY_NUMBER_DEFAULT)
    if (ipv6 == 0) {
        /* populate the ipv4 hash */
        populate_ipv4_many_flow_into_table(
            ipv4_l3fwd_lookup_struct[socketid], hash_entry_number);
    } else {
        /* populate the ipv6 hash */
        populate_ipv6_many_flow_into_table(
            ipv6_l3fwd_lookup_struct[socketid], hash_entry_number);
    }
} else
    if (ipv6 == 0) {
        /* populate the ipv4 hash */
        populate_ipv4_few_flow_into_table(ipv4_l3fwd_lookup_struct[socketid]);
    } else {
        /* populate the ipv6 hash */
        populate_ipv6_few_flow_into_table(ipv6_l3fwd_lookup_struct[socketid]);
    }
}
}
#endif
```

### 10.4.2 LPM Initialization

The LPM object is created and loaded with the pre-configured entries read from a global array.

```
#if (APP_LOOKUP_METHOD == APP_LOOKUP_LPM)
static void
setup_lpm(int socketid)
    {
        unsigned i;
        int ret;
        char s[64];

    /* create the LPM table */
    rte_snprintf(s, sizeof(s), "IPV4_L3FWD_LPM_%d", socketid);
    ipv4_l3fwd_lookup_struct[socketid] = rte_lpm_create(s, socketid,
                IPV4_L3FWD_LPM_MAX_RULES, 0);
    if (ipv4_l3fwd_lookup_struct[socketid] == NULL)
        rte_exit(EXIT_FAILURE, "Unable to create the l3fwd LPM table"
                " on socket %d\n", socketid);

    /* populate the LPM table */
    for (i = 0; i < IPV4_L3FWD_NUM_ROUTES; i++) {
        ret = rte_lpm_add(ipv4_l3fwd_lookup_struct[socketid],
            ipv4_l3fwd_route_array[i].ip,
            ipv4_l3fwd_route_array[i].depth,
            ipv4_l3fwd_route_array[i].if_out);

        if (ret < 0) {
            rte_exit(EXIT_FAILURE, "Unable to add entry %u to the "
                "l3fwd LPM table on socket %d\n",
                i, socketid);
        }

        printf("LPM: Adding route 0x%08x / %d (%d)\n",
            (unsigned)ipv4_l3fwd_route_array[i].ip,
            ipv4_l3fwd_route_array[i].depth,
            ipv4_l3fwd_route_array[i].if_out);
    }
}
#endif
```

### 10.4.3 Packet Forwarding for Hash-based Lookups

For each input packet, the packet forwarding operation is done by the `l3fwd_simple_forward()` or `simple_ipv4_fwd_4pkts()` function for IPv4 packets or the `simple_ipv6_fwd_4pkts()` function for IPv6 packets. The `l3fwd_simple_forward()` function provides the basic functionality for both IPv4 and IPv6 packet forwarding for any number of burst packets received, and the packet forwarding decision (that is, the identification of the output interface for the packet) for hash-based lookups is done by the `get_ipv4_dst_port()` or `get_ipv6_dst_port()` function. The `get_ipv4_dst_port()` function is shown below:

```
    static inline uint8_t
    get_ipv4_dst_port(void *ipv4_hdr, uint8_t portid,
                      lookup_struct_t *ipv4_l3fwd_lookup_struct)
    {
        int ret = 0;
        union ipv4_5tuple_host key;

        ipv4_hdr = (uint8_t *)ipv4_hdr + offsetof(struct ipv4_hdr, time_to_live);
        __m128i data = _mm_loadu_si128((__m128i*)(ipv4_hdr));
        /* Get 5 tuple: dst port, src port, dst IP address, src IP address and
```

```
        protocol */
        key.xmm = _mm_and_si128(data, mask0);
        /* Find destination port */
        ret = rte_hash_lookup(ipv4_l3fwd_lookup_struct, (const void *)&key);
        return (uint8_t)((ret < 0)? portid : ipv4_l3fwd_out_if[ret]);
    }
```

The `get_ipv6_dst_port()` function is similar to the `get_ipv4_dst_port()` function.

The `simple_ipv4_fwd_4pkts()` and `simple_ipv6_fwd_4pkts()` function are optimized for continuous 4 valid ipv4 and ipv6 packets, they leverage the multiple buffer optimization to boost the performance of forwarding packets with the exact match on hash table. The key code snippet of `simple_ipv4_fwd_4pkts()` is shown below:

```
static inline void
simple_ipv4_fwd_4pkts(struct rte_mbuf* m[4], uint8_t portid,
                      struct lcore_conf *qconf)
{
    // ...
    data[0] = _mm_loadu_si128((__m128i*)(rte_pktmbuf_mtod(m[0], unsigned char *) +
        sizeof(struct ether_hdr) + offsetof(struct ipv4_hdr, time_to_live)));
    data[1] = _mm_loadu_si128((__m128i*)(rte_pktmbuf_mtod(m[1], unsigned char *) +
        sizeof(struct ether_hdr) + offsetof(struct ipv4_hdr, time_to_live)));
    data[2] = _mm_loadu_si128((__m128i*)(rte_pktmbuf_mtod(m[2], unsigned char *) +
       sizeof(struct ether_hdr) + offsetof(struct ipv4_hdr, time_to_live)));
    data[3] = _mm_loadu_si128((__m128i*)(rte_pktmbuf_mtod(m[3], unsigned char *) +
        sizeof(struct ether_hdr) + offsetof(struct ipv4_hdr, time_to_live)));
    key[0].xmm = _mm_and_si128(data[0], mask0);
    key[1].xmm = _mm_and_si128(data[1], mask0);
    key[2].xmm = _mm_and_si128(data[2], mask0);
    key[3].xmm = _mm_and_si128(data[3], mask0);
    const void *key_array[4] = {&key[0], &key[1], &key[2],&key[3]};
    rte_hash_lookup_multi(qconf->ipv4_lookup_struct, &key_array[0], 4, ret);
   dst_port[0] = (ret[0] < 0)? portid:ipv4_l3fwd_out_if[ret[0]];
    dst_port[1] = (ret[1] < 0)? portid:ipv4_l3fwd_out_if[ret[1]];
    dst_port[2] = (ret[2] < 0)? portid:ipv4_l3fwd_out_if[ret[2]];
    dst_port[3] = (ret[3] < 0)? portid:ipv4_l3fwd_out_if[ret[3]];

    // ...
}
```

The `simple_ipv6_fwd_4pkts()` function is similar to the `simple_ipv4_fwd_4pkts()` function.

### 10.4.4 Packet Forwarding for LPM-based Lookups

For each input packet, the packet forwarding operation is done by the `l3fwd_simple_forward()` function, but the packet forwarding decision (that is, the identification of the output interface for the packet) for LPM-based lookups is done by the `get_ipv4_dst_port()` function below:

```
static inline uint8_t
get_ipv4_dst_port(struct ipv4_hdr *ipv4_hdr,  uint8_t portid, lookup_struct_t *
ipv4_l3fwd_lookup_struct)
{
    uint8_t next_hop;

    return (uint8_t) ((rte_lpm_lookup(ipv4_l3fwd_lookup_struct,
            rte_be_to_cpu_32(ipv4_hdr->dst_addr), &next_hop) == 0)?
            next_hop : portid);
}
```

# 11.0 L3 Forwarding with Power Management Sample Application

## 11.1 Introduction

The L3 Forwarding with Power Management application is an example of power-aware packet processing using the Intel® DPDK. The application is based on existing L3 Forwarding sample application, with the power management algorithms to control the P-states and C-states of the Intel processor via a power management library.

## 11.2 Overview

The application demonstrates the use of the Power libraries in the Intel® DPDK to implement packet forwarding. The initialization and run-time paths are very similar to those of the L3 forwarding sample application (see Chapter 10.0, "L3 Forwarding Sample Application" for more information). The main difference from the L3 Forwarding sample application is that this application introduces power-aware optimization algorithms by leveraging the Power library to control P-state and C-state of processor based on packet load.

The Intel® DPDK includes poll-mode drivers to configure Intel NIC devices and their receive (Rx) and transmit (Tx) queues. The design principle of this PMD is to access the Rx and Tx descriptors directly without any interrupts to quickly receive, process and deliver packets in the user space.

In general, the Intel® DPDK executes an endless packet processing loop on dedicated IA cores that include the following steps:

- Retrieve input packets through the PMD to poll Rx queue
- Process each received packet or provide received packets to other processing cores through software queues
- Send pending output packets to Tx queue through the PMD

In this way, the PMD achieves better performance than a traditional interrupt-mode driver, at the cost of keeping cores active and running at the highest frequency, hence consuming the maximum power all the time. However, during the period of processing light network traffic, which happens regularly in communication infrastructure systems due to well-known "tidal effect", the PMD is still busy waiting for network packets, which wastes a lot of power.

Processor performance states (P-states) are the capability of an Intel processor to switch between different supported operating frequencies and voltages. If configured correctly, according to system workload, this feature provides power savings. CPUFreq is the infrastructure provided by the Linux* kernel to control the processor performance state capability. CPUFreq supports a user space governor that enables setting frequency via manipulating the virtual file device from a user space application. The Power library in the Intel® DPDK provides a set of APIs for manipulating a virtual file device to allow user space application to set the CPUFreq governor and set the frequency of specific cores.

This application includes a P-state power management algorithm to generate a frequency hint to be sent to CPUFreq. The algorithm uses the number of received and available Rx packets on recent polls to make a heuristic decision to scale frequency up/down. Specifically, some thresholds are checked to see whether a specific core running an Intel® DPDK polling thread needs to increase frequency a step up based on the near to full trend of polled Rx queues. Also, it decreases frequency a step if packet processed per loop is far less than the expected threshold or the thread's sleeping time exceeds a threshold.

C-States are also known as sleep states. They allow software to put an Intel core into a low power idle state from which it is possible to exit via an event, such as an interrupt. However, there is a tradeoff between the power consumed in the idle state and the time required to wake up from the idle state (exit latency). Therefore, as you go into deeper C-states, the power consumed is lower but the exit latency is increased. Each C-state has a target residency. It is essential that when entering into a C-state, the core remains in this C-state for at least as long as the target residency in order to fully realize the benefits of entering the C-state. CPUIdle is the infrastructure provide by the Linux kernel to control the processor C-state capability. Unlike CPUFreq, CPUIdle does not provide a mechanism that allows the application to change C-state. It actually has its own heuristic algorithms in kernel space to select target C-state to enter by executing privileged instructions like `HLT` and `MWAIT`, based on the speculative sleep duration of the core. In this application, we introduce a heuristic algorithm that allows packet processing cores to sleep for a short period if there is no Rx packet received on recent polls. In this way, CPUIdle automatically forces the corresponding cores to enter deeper C-states instead of always running to the C0 state waiting for packets**.**

*Note:* To fully demonstrate the power saving capability of using C-states, it is recommended to enable deeper C3 and C6 states in the BIOS during system boot up.

## 11.3 Compiling the Application

The application has a number of command line options:

```
./build/l3fwd_power [EAL options] -- -p PORTMASK [-P]
[--config(port,queue,lcore)[,(port,queue,lcore]]
```

where,

- `-p PORTMASK`: Hexadecimal bitmask of ports to configure
- `-P`: Sets all ports to promiscuous mode so that packets are accepted regardless of the packet's Ethernet MAC destination address. Without this option, only packets with the Ethernet MAC destination address set to the Ethernet address of the port are accepted.
- `--config (port,queue,lcore)[,(port,queue,lcore]`: determines which queues from which ports are mapped to which cores.

See Chapter 10.0, "L3 Forwarding Sample Application" for details. The `L3fwd-power` example reuses the `L3fwd` command line options.

## 11.4 Explanation

The following sections provide some explanation of the sample application code. As mentioned in the overview section, the initialization and run-time paths are identical to those of the L3 forwarding application. The following sections describe aspects that are specific to the L3 Forwarding with Power Management sample application.

### 11.4.1 Power Library Initialization

The Power library is initialized in the MAIN routine. It changes the P-state governor to userspace for specific cores that are under control. The Timer library is also initialized and several timers are created later on, responsible for checking if it needs to scale down frequency at run time by checking CPU utilization statistics.

*Note:* Only the power management related initialization is shown.

```
int MAIN(int argc, char **argv)
{
    struct lcore_conf *qconf;
    int ret;
    unsigned nb_ports;
    uint16_t queueid;
    unsigned lcore_id;
    uint64_t hz;
    uint32_t n_tx_queue, nb_lcores;
    uint8_t portid, nb_rx_queue, queue, socketid;

    // ...

    /* init RTE timer library to be used to initialize per-core timers */
    rte_timer_subsystem_init();
    // ...

    /* per-core initialization */
    for (lcore_id = 0; lcore_id < RTE_MAX_LCORE; lcore_id++) {
        if (rte_lcore_is_enabled(lcore_id) == 0)
            continue;

        /* init power management library for a specified core */
        ret = rte_power_init(lcore_id);
        if (ret)
            rte_exit(EXIT_FAILURE, "Power management library "
               "initialization failed on core%d\n", lcore_id);

        /* init timer structures for each enabled lcore */
        rte_timer_init(&power_timers[lcore_id]);
        hz = rte_get_hpet_hz();
        rte_timer_reset(&power_timers[lcore_id],
                hz/TIMER_NUMBER_PER_SECOND, SINGLE, lcore_id,
                            power_timer_cb, NULL);

        // ...
    }

    // ...
}
```

### 11.4.2 Monitoring Loads of Rx Queues

In general, the polling nature of the Intel® DPDK prevents the OS power management subsystem from knowing if the network load is actually heavy or light. In this sample, sampling network load work is done by monitoring received and available descriptors on NIC Rx queues in recent polls. Based on the number of returned and available Rx descriptors, this example implements algorithms to generate frequency scaling hints and speculative sleep duration, and use them to control P-state and C-state of processors via the power management library. Frequency (P-state) control and sleep state (C-state) control work individually for each logical core, and the combination of them contributes to a power efficient packet processing solution when serving light network loads.

The `rte_eth_rx_burst()` function and the newly-added `rte_eth_rx_queue_count()` function are used in the endless packet processing loop to return the number of received and available Rx descriptors. And those numbers of specific queue are passed to P-state and C-state heuristic algorithms to generate hints based on recent network load trends.

*Note:* Only power control related code is shown.

```
static __attribute__((noreturn)) int
main_loop(__attribute__((unused)) void *dummy)
{
    // ...
    while (1) {
        // ...

        /**
         * Read packet from RX queues
         */
        lcore_scaleup_hint = FREQ_CURRENT;
        lcore_rx_idle_count = 0;

        for (i = 0; i < qconf->n_rx_queue; ++i) {
            rx_queue = &(qconf->rx_queue_list[i]);
            rx_queue->idle_hint = 0;
            portid = rx_queue->port_id;
            queueid = rx_queue->queue_id;

            nb_rx = rte_eth_rx_burst(portid, queueid, pkts_burst,
                                    MAX_PKT_BURST);
            stats[lcore_id].nb_rx_processed += nb_rx;

            if (unlikely(nb_rx == 0)) {
                /**
                 * no packet received from rx queue, try to
                 * sleep for a while forcing CPU enter deeper
                 * C states.
                 */
                rx_queue->zero_rx_packet_count++;

                if (rx_queue->zero_rx_packet_count <=
                            MIN_ZERO_POLL_COUNT)
                    continue;

                rx_queue->idle_hint = power_idle_heuristic(\
                    rx_queue->zero_rx_packet_count);
                lcore_rx_idle_count++;
            } else {
                rx_ring_length = rte_eth_rx_queue_count(portid,
                                    queueid);
                rx_queue->zero_rx_packet_count = 0;

                /**
                 * do not scale up frequency immediately as
                 * user to kernel space communication is costly
                 * which might impact packet I/O for received
                 * packets.
                 */
                rx_queue->freq_up_hint =
                    power_freq_scaleup_heuristic(lcore_id,
                            rx_ring_length);
            }

            /* Prefetch and forward packets */
           // ...
        }
```

```
            if (likely(lcore_rx_idle_count != qconf->n_rx_queue)) {
                for (i = 1, lcore_scaleup_hint =
                    qconf->rx_queue_list[0].freq_up_hint;
                        i < qconf->n_rx_queue; ++i) {
                    rx_queue = &(qconf->rx_queue_list[i]);
                    if (rx_queue->freq_up_hint > lcore_scaleup_hint)
                        lcore_scaleup_hint = rx_queue->freq_up_hint;
                }

                if (lcore_scaleup_hint == FREQ_HIGHEST)
                    rte_power_freq_max(lcore_id);
                else if (lcore_scaleup_hint == FREQ_HIGHER)
                    rte_power_freq_up(lcore_id);
            } else {
                /**
                 * All Rx queues empty in recent consecutive polls,
                 * sleep in a conservative manner, meaning sleep as
                 * less as possible.
                 */
                for (i = 1, lcore_idle_hint =
                    qconf->rx_queue_list[0].idle_hint;
                        i < qconf->n_rx_queue; ++i) {
                    rx_queue = &(qconf->rx_queue_list[i]);
                    if (rx_queue->idle_hint < lcore_idle_hint)
                        lcore_idle_hint = rx_queue->idle_hint;
                }

                if ( lcore_idle_hint < SLEEP_GEAR1_THRESHOLD)
                    /**
                     * execute "pause" instruction to avoid context
                     * switch for short sleep.
                     */
                    rte_delay_us(lcore_idle_hint);
                else
                    /* long sleep force runing thread to suspend */
                    usleep(lcore_idle_hint);

                stats[lcore_id].sleep_time += lcore_idle_hint;

            }
        }
    }
```

### 11.4.3 P-State Heuristic Algorithm

The `power_freq_scaleup_heuristic()` function is responsible for generating a frequency hint for the specified logical core according to available descriptor number returned from `rte_eth_rx_queue_count()`. On every poll for new packets, the length of available descriptor on an Rx queue is evaluated, and the algorithm used for frequency hinting is as follows:

- If the size of available descriptors exceeds 96, the maximum frequency is hinted.
- If the size of available descriptors exceeds 64, a `trend` counter is incremented by 100.
- If the length of the ring exceeds 32, the `trend` counter is incremented by 1.
- When the `trend` counter reached 10000 the frequency hint is changed to the next higher frequency.

*Note:* The assumption is that the Rx queue size is 128 and the thresholds specified above must be adjusted accordingly based on actual hardware Rx queue size, which are configured via the `rte_eth_rx_queue_setup()` function.

In general, a thread needs to poll packets from multiple Rx queues. Most likely, different queue have different load, so they would return different frequency hints. The algorithm evaluates all the hints and then scales up frequency in an aggressive manner by scaling up to highest frequency as long as one Rx queue requires. In this way, we can minimize any negative performance impact.

On the other hand, frequency scaling down is controlled in the timer callback function. Specifically, if the sleep times of a logical core indicate that it is sleeping more than 25% of the sampling period, or if the average packet per iteration is less than expectation, the frequency is decreased by one step.

### 11.4.4 C-State Heuristic Algorithm

Whenever recent `rte_eth_rx_burst()` polls return 5 consecutive zero packets, an idle counter begins incrementing for each successive zero poll. At the same time, the function `power_idle_heuristic()` is called to generate speculative sleep duration in order to force logical to enter deeper sleeping C-state. There is no way to control C-state directly, and the CPUIdle subsystem in OS is intelligent enough to select C-state to enter based on actual sleep period time of giving logical core. The algorithm has the following sleeping behavior depending on the idle counter:

- If idle count less than 100, the counter value is used as a microsecond sleep value through `rte_delay_us()` which execute `pause` instructions to avoid costly context switch but saving power at the same time.
- If idle count is between 100 and 999, a fixed sleep interval of 100 μs is used. A 100 μs sleep interval allows the core to enter the C1 state while keeping a fast response time in case new traffic arrives.
- If idle count is greater than 1000, a fixed sleep value of 1 ms is used until the next timer expiration is used. This allows the core to enter the C3/C6 states.

*Note:* The thresholds specified above need to be adjusted for different Intel processors and traffic profiles.

If a thread polls multiple Rx queues and different queue returns different sleep duration values, the algorithm controls the sleep time in a conservative manner by sleeping for the least possible time in order to avoid a potential performance impact.

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# 12.0 L3 Forwarding in a Virtualization Environment Sample Application

The L3 Forwarding in a Virtualization Environment sample application is a simple example of packet processing using the Intel® DPDK. The application performs L3 forwarding that takes advantage of Single Root I/O Virtualization (SR-IOV) features in a virtualized environment.

## 12.1 Overview

The application demonstrates the use of the `hash` and `LPM` libraries in the Intel® DPDK to implement packet forwarding. The initialization and run-time paths are very similar to those of the L3 forwarding application (see Chapter 10.0, "L3 Forwarding Sample Application" for more information). The forwarding decision is taken based on information read from the input packet.

The lookup method is either hash-based or LPM-based and is selected at compile time. When the selected lookup method is hash-based, a hash object is used to emulate the flow classification stage. The hash object is used in correlation with the flow table to map each input packet to its flow at runtime.

The hash lookup key is represented by the DiffServ 5-tuple composed of the following fields read from the input packet: Source IP Address, Destination IP Address, Protocol, Source Port and Destination Port. The ID of the output interface for the input packet is read from the identified flow table entry. The set of flows used by the application is statically configured and loaded into the hash at initialization time. When the selected lookup method is LPM based, an LPM object is used to emulate the forwarding stage for IPv4 packets. The LPM object is used as the routing table to identify the next hop for each input packet at runtime.

The LPM lookup key is represented by the Destination IP Address field read from the input packet. The ID of the output interface for the input packet is the next hop returned by the LPM lookup. The set of LPM rules used by the application is statically configured and loaded into the LPM object at the initialization time.

*Note:* Please refer to Section 9.1.1, "Virtual Function Setup Instructions" on page 43 for virtualized test case setup.

## 12.2 Compiling the Application

To compile the application:

1. Go to the sample application directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/l3fwd-vf
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

*Note:* The compiled application is written to the `build` subdirectory. To have the application written to a different location, the `O=/path/to/build/directory` option may be specified in the `make` command.

## 12.3 Running the Application

The application has a number of command line options:

```
./build/l3fwd-vf [EAL options] -- -p PORTMASK
--config(port,queue,lcore)[,(port,queue,lcore)]
```

where,

- `--p PORTMASK`: Hexadecimal bitmask of ports to configure
- `--config (port,queue,lcore)[,(port,queue,lcore]`: determines which queues from which ports are mapped to which cores

For example, consider a dual processor socket platform where cores 0,2,4,6, 8, and 10 appear on socket 0, while cores 1,3,5,7,9, and 11 appear on socket 1. Let's say that the programmer wants to use memory from both NUMA nodes, the platform has only two ports and the programmer wants to use one core from each processor socket to do the packet processing since only one Rx/Tx queue pair can be used in virtualization mode.

To enable L3 forwarding between two ports, using one core from each processor, while also taking advantage of local memory accesses by optimizing around NUMA, the programmer can pin to the appropriate cores and allocate memory from the appropriate NUMA node. This is achieved using the following command:

```
./build/l3fwd-vf -c 0x03 -n 3 -- -p 0x3 --config="(0,0,0),(1,0,1)"
```

In this command:

- The `-c` option enables cores 0 and 1
- The `-p` option enables ports 0 and 1
- The `--config` option enables one queue on each port and maps each (port,queue) pair to a specific core. Logic to enable multiple RX queues using RSS and to allocate memory from the correct NUMA nodes is included in the application and is done transparently. The following table shows the mapping in this example:

| Port | Queue | lcore | Description |
|---|---|---|---|
| 0 | 0 | 0 | Map queue 0 from port 0 to lcore 0. |
| 1 | 0 | 1 | Map queue 0 from port 1 to lcore 1. |

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 12.4 Explanation

The operation of this application is similar to that of the basic L3 Forwarding Sample Application. See Section 10.4, “Explanation” on page 53 for more information.

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# 13.0 Link Status Interrupt Sample Application

The Link Status Interrupt sample application is a simple example of packet processing using the Intel® Data Plane Development Kit (Intel® DPDK) that demonstrates how network link status changes for a network port can be captured and used by an Intel® DPDK application.

## 13.1 Overview

The Link Status Interrupt sample application registers a user space callback for the link status interrupt of each port and performs L2 forwarding for each packet that is received on an RX_PORT. The following operations are performed:

- RX_PORT and TX_PORT are paired with available ports one-by-one according to the core mask
- The source MAC address is replaced by the TX_PORT MAC address
- The destination MAC address is replaced by 02:00:00:00:00:TX_PORT_ID

This application can be used to demonstrate the usage of link status interrupt and its user space callbacks and the behavior of L2 forwarding each time the link status changes.

## 13.2 Compiling the Application

1. Go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/link_status_interrupt
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

*Note:* The compiled application is written to the `build` subdirectory. To have the application written to a different location, the `O=/path/to/build/directory` option may be specified on the `make` command line.

## 13.3 Running the Application

The application requires a number of command line options:

```
./build/link_status_interrupt [EAL options] -- -p PORTMASK [-q NQ]
```

where,

- `-p PORTMASK`: A hexadecimal bitmask of the ports to configure
- `-q NQ`: A number of queues (=ports) per lcore (default is 1)

To run the application in a linuxapp environment with 4 lcores, 4 memory channels, 16 ports and 8 RX queues per lcore, issue the command:

```
$ ./build/link_status_interrupt -c f -n 4-- -q 8 -p ffff
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 13.4 Explanation

The following sections provide some explanation of the code.

### 13.4.1 Command Line Arguments

The Link Status Interrupt sample application takes specific parameters, in addition to Environment Abstraction Layer (EAL) arguments (see Section 13.3).

Command line parsing is done in the same way as it is done in the L2 Forwarding Sample Application. See Section 9.4.1, "Command Line Arguments" on page 44 for more information.

### 13.4.2 Mbuf Pool Initialization

Mbuf pool initialization is done in the same way as it is done in the L2 Forwarding Sample Application. See Section 9.4.2, "Mbuf Pool Initialization" on page 45 for more information.

### 13.4.3 Driver Initialization

The main part of the code in the `main()` function relates to the initialization of the driver. To fully understand this code, it is recommended to study the chapters that related to the Poll Mode Driver in the *Intel® DPDK Programmer's Guide* - Rel 1.4 EAR and the *Intel® DPDK API Reference*.

```
/* init driver(s) */
if (rte_pmd_init_all() < 0)
    rte_exit(EXIT_FAILURE, "Cannot init pmd\n");

if (rte_eal_pci_probe() < 0)
    rte_exit(EXIT_FAILURE, "Cannot probe PCI\n");

nb_ports = rte_eth_dev_count();
if (nb_ports == 0)
    rte_exit(EXIT_FAILURE, "No Ethernet ports - bye\n");

if (nb_ports > RTE_MAX_ETHPORTS)
    nb_ports = RTE_MAX_ETHPORTS;

/*
* Each logical core is assigned a dedicated TX queue on each port.
*/
for (portid = 0; portid < nb_ports; portid++) {
    /* skip ports that are not enabled */
    if ((lsi_enabled_port_mask & (1 << portid)) == 0)
        continue;
```

```
            /* save the destination port id */
            if (nb_ports_in_mask % 2) {
                lsi_dst_ports[portid] = portid_last;
                lsi_dst_ports[portid_last] = portid;
            }
            else
                portid_last = portid;

            nb_ports_in_mask++;

            rte_eth_dev_info_get((uint8_t) portid, &dev_info);
        }
```

Observe that:

- `rte_igb_pmd_init_all()` or `rte_ixgbe_pmd_init()` simultaneously registers the driver as a PCI driver and as an Ethernet* poll mode driver.
- `rte_eal_pci_probe()` parses the devices on the PCI bus and initializes recognized devices.

The next step is to configure the RX and TX queues. For each port, there is only one RX queue (only one lcore is able to poll a given port). The number of TX queues depends on the number of available lcores. The `rte_eth_dev_configure()` function is used to configure the number of queues for a port:

```
    ret = rte_eth_dev_configure((uint8_t) portid, 1, 1, &port_conf);
    if (ret < 0)
    rte_exit(EXIT_FAILURE, "Cannot configure device: err=%d, port=%u\n",
             ret, portid);
```

The global configuration is stored in a static structure:

```
static const struct rte_eth_conf port_conf = {
    .rxmode = {
        .split_hdr_size = 0,
        .header_split   = 0, /**< Header Split disabled */
        .hw_ip_checksum = 0, /**< IP checksum offload disabled */
        .hw_vlan_filter = 0, /**< VLAN filtering disabled */
        .hw_strip_crc   = 0, /**< CRC stripped by hardware *
    },
    .txmode = {
    },
    .intr_conf = {
        .lsc = 1, /**< link status interrupt feature enabled */
    },
};
```

Configuring `lsc` to 0 (the default) disables the generation of any link status change interrupts in kernel space and no user space interrupt event is received. The public interface `rte_eth_link_get()` accesses the NIC registers directly to update the link status. Configuring `lsc` to non-zero enables the generation of link status change interrupts in kernel space when a link status change is present and calls the user space callbacks registered by the application. The public interface `rte_eth_link_get()` just reads the link status in a global structure that would be updated in the interrupt host thread only.

### 13.4.4 Interrupt Callback Registration

The application can register one or more callbacks to a specific port and interrupt event. An example callback function that has been written as indicated below.

```
static void
```

```
lsi_event_callback(uint8_t port_id, enum rte_eth_event_type type, void *param)
{
    struct rte_eth_link link;
        RTE_SET_USED(param);
        printf("\n\nIn registered callback...\n");
        printf("Event type: %s\n", type == RTE_ETH_EVENT_INTR_LSC ? "LSC interrupt"
: "unknown event");
        rte_eth_link_get_nowait(port_id, &link);
        if (link.link_status) {
            printf("Port %d Link Up - speed %u Mbps - %s\n\n",
                    port_id, (unsigned)link.link_speed,
                    (link.link_duplex == ETH_LINK_FULL_DUPLEX) ?
                    ("full-duplex") : ("half-duplex"));
        } else
            printf("Port %d Link Down\n\n", port_id);
}
```

This function is called when a link status interrupt is present for the right port. The `port_id` indicates which port the interrupt applies to. The `type` parameter identifies the interrupt event type, which currently can be `RTE_ETH_EVENT_INTR_LSC` only, but other types can be added in the future. The `param` parameter is the address of the parameter for the callback. This function should be implemented with care since it will be called in the interrupt host thread, which is different from the main thread of its caller.

The application registers the `lsi_event_callback` and a `NULL` parameter to the link status interrupt event on each port:

```
    rte_eth_dev_callback_register((uint8_t)portid,
        RTE_ETH_EVENT_INTR_LSC, lsi_event_callback, NULL);
```

This registration can be done only after calling the `rte_eth_dev_configure()` function and before calling any other function. If `lsc` is initialized with 0, the callback is never called since no interrupt event would ever be present.

### 13.4.5 RX Queue Initialization

The application uses one lcore to poll one or several ports, depending on the `-q` option, which specifies the number of queues per lcore.

For example, if the user specifies `-q 4`, the application is able to poll four ports with one lcore. If there are 16 ports on the target (and if the `portmask` argument is `-p ffff`), the application will need four lcores to poll all the ports.

```
    ret = rte_eth_rx_queue_setup((uint8_t) portid, 0, nb_rxd,
                                 SOCKET0, &rx_conf,
                                 lsi_pktmbuf_pool);
    if (ret < 0)
        rte_exit(EXIT_FAILURE, "rte_eth_rx_queue_setup: err=%d, port=%u\n",
                 ret, portid);
```

The list of queues that must be polled for a given lcore is stored in a private structure called `struct lcore_queue_conf`.

```
struct lcore_queue_conf {
    unsigned n_rx_port;
    unsigned rx_port_list[MAX_RX_QUEUE_PER_LCORE];
    unsigned tx_queue_id;
    struct mbuf_table tx_mbufs[LSI_MAX_PORTS];

    } __rte_cache_aligned;
```

```
struct lcore_queue_conf lcore_queue_conf[RTE_MAX_LCORE];
```

The `n_rx_port` and `rx_port_list[]` fields are used in the main packet processing loop (see Section 13.4.7, "Receive, Process and Transmit Packets" on page 69 later in this chapter).

The global configuration for the RX queues is stored in a static structure:

```
static const struct rte_eth_rxconf rx_conf = {
    .rx_thresh = {
        .pthresh = RX_PTHRESH,
        .hthresh = RX_HTHRESH,
        .wthresh = RX_WTHRESH,
    },
};
```

### 13.4.6 TX Queue Initialization

Each lcore should be able to transmit on any port. For every port, a single TX queue is initialized.

```
    /* init one TX queue logical core on each port */
    fflush(stdout);
    ret = rte_eth_tx_queue_setup(portid, 0, nb_txd,
                                 rte_eth_dev_socket_id(portid), &tx_conf);
    if (ret < 0)
        rte_exit(EXIT_FAILURE, "rte_eth_tx_queue_setup: err=%d,port=%u\n",
                 ret, (unsigned) portid);
```

The global configuration for TX queues is stored in a static structure:

```
static const struct rte_eth_txconf tx_conf = {
    .tx_thresh = {
        .pthresh = TX_PTHRESH,
        .hthresh = TX_HTHRESH,
        .wthresh = TX_WTHRESH,
        },
    .tx_free_thresh = RTE_TEST_TX_DESC_DEFAULT + 1, /* disable feature */
};
```

### 13.4.7 Receive, Process and Transmit Packets

In the `lsi_main_loop()` function, the main task is to read ingress packets from the RX queues. This is done using the following code:

```
    /*
     * Read packet from RX queues
     */
    for (i = 0; i < qconf->n_rx_port; i++) {

        portid = qconf->rx_port_list[i];
        nb_rx = rte_eth_rx_burst((uint8_t) portid, 0,
                                 pkts_burst, MAX_PKT_BURST);

        port_statistics[portid].rx += nb_rx;

        for (j = 0; j < nb_rx; j++) {
            m = pkts_burst[j];
            rte_prefetch0(rte_pktmbuf_mtod(m, void *));
            lsi_simple_forward(m, portid);
        }
```

```
}
```

Packets are read in a burst of size MAX_PKT_BURST. The `rte_eth_rx_burst()` function writes the mbuf pointers in a local table and returns the number of available mbufs in the table.

Then, each mbuf in the table is processed by the `lsi_simple_forward()` function. The processing is very simple: processes the TX port from the RX port and then replaces the source and destination MAC addresses.

*Note:* In the following code, the two lines for calculating the output port require some explanation. If `portId` is even, the first line does nothing (as `portid` & 1 will be 0), and the second line adds 1. If `portId` is odd, the first line subtracts one and the second line does nothing. Therefore, 0 goes to 1, and 1 to 0, 2 goes to 3 and 3 to 2, and so on.

```
static void
lsi_simple_forward(struct rte_mbuf *m, unsigned portid)
{
    struct ether_hdr *eth;
    void *tmp;
    unsigned dst_port = lsi_dst_ports[portid];

    eth = rte_pktmbuf_mtod(m, struct ether_hdr *);

    /* 02:00:00:00:00:xx */
    tmp = &eth->d_addr.addr_bytes[0];
    *((uint64_t *)tmp) = 0x000000000002 + (dst_port << 40);

    /* src addr */
    ether_addr_copy(&lsi_ports_eth_addr[dst_port], &eth->s_addr);

    lsi_send_packet(m, dst_port);
}
```

Then, the packet is sent using the `lsi_send_packet(m, dst_port)` function. For this test application, the processing is exactly the same for all packets arriving on the same RX port. Therefore, it would have been possible to call the `lsi_send_burst()` function directly from the main loop to send all the received packets on the same TX port using the burst-oriented send function, which is more efficient.

However, in real-life applications (such as, L3 routing), packet N is not necessarily forwarded on the same port as packet N-1. The application is implemented to illustrate that so the same approach can be reused in a more complex application.

The `lsi_send_packet()` function stores the packet in a per-lcore and per-txport table. If the table is full, the whole packets table is transmitted using the `lsi_send_burst()` function:

```
/* Send the packet on an output interface */
static int
lsi_send_packet(struct rte_mbuf *m, uint8_t port)
{
    unsigned lcore_id, len;
    struct lcore_queue_conf *qconf;

    lcore_id = rte_lcore_id();

    qconf = &lcore_queue_conf[lcore_id];
    len = qconf->tx_mbufs[port].len;
    qconf->tx_mbufs[port].m_table[len] = m;
    len++;
```

```
        /* enough pkts to be sent */
        if (unlikely(len == MAX_PKT_BURST)) {
            lsi_send_burst(qconf, MAX_PKT_BURST, port);
            len = 0;
        }

        qconf->tx_mbufs[port].len = len;
        return 0;
    }
```

To ensure that no packets remain in the tables, each lcore does a draining of the TX queue in its main loop. This technique introduces some latency when there are not many packets to send. However, it improves performance:

```
    cur_tsc = rte_rdtsc();
    /*
     * TX burst queue drain
     */
    diff_tsc = cur_tsc - prev_tsc;
    if (unlikely(diff_tsc > drain_tsc)) {

        /* this could be optimized (use queueid instead of
        * portid), but it is not called so often */

        for (portid = 0; portid < RTE_MAX_ETHPORTS; portid++) {
            if (qconf->tx_mbufs[portid].len == 0)
                continue;
            lsi_send_burst(&lcore_queue_conf[lcore_id],
                           qconf->tx_mbufs[portid].len,
                           (uint8_t) portid);
            qconf->tx_mbufs[portid].len = 0;
        }

        /* if timer is enabled */
        if (timer_period > 0) {

            /* advance the timer */
            timer_tsc += diff_tsc;

            /* if timer has reached its timeout */
            if (unlikely(timer_tsc >= (uint64_t) timer_period)) {

                /* do this only on master core */
                if (lcore_id == rte_get_master_lcore()) {
                    print_stats();
                    /* reset the timer */
                    timer_tsc = 0;
                }
            }
        }

        prev_tsc = cur_tsc;
    }
```

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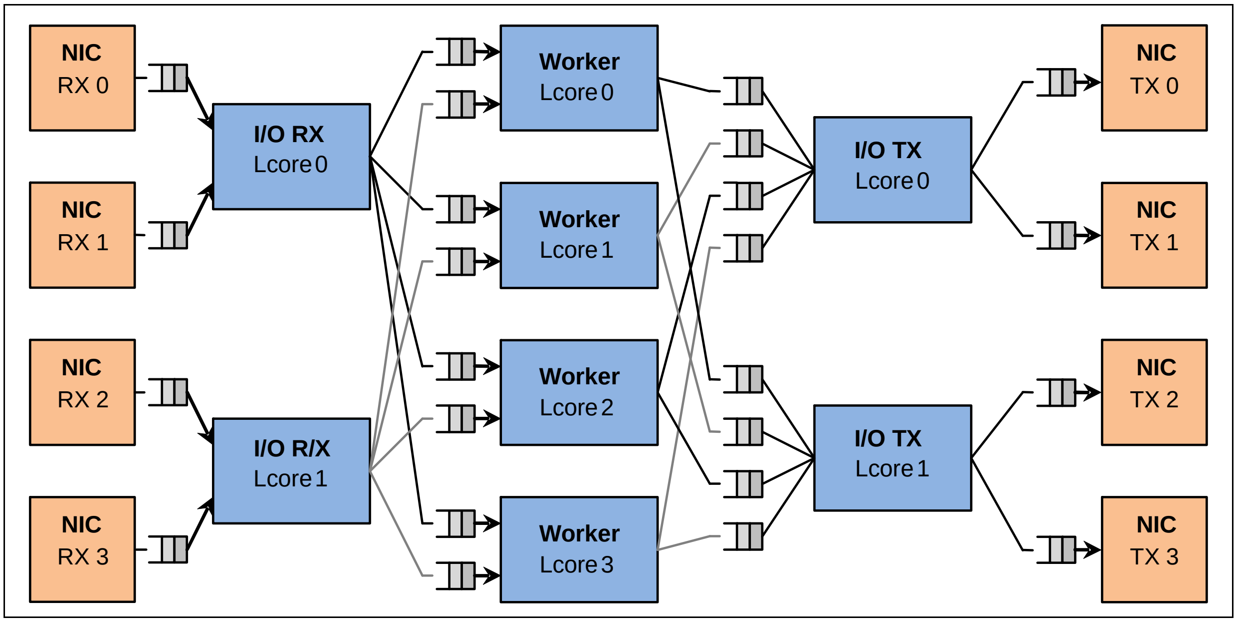
# 14.0 Load Balancer Sample Application

The Load Balancer sample application demonstrates the concept of isolating the packet I/O task from the application-specific workload. Depending on the performance target, a number of logical cores (lcores) are dedicated to handle the interaction with the NIC ports (I/O lcores), while the rest of the lcores are dedicated to performing the application processing (worker lcores). The worker lcores are totally oblivious to the intricacies of the packet I/O activity and use the NIC-agnostic interface provided by software rings to exchange packets with the I/O cores.

## 14.1 Overview

The architecture of the Load Balance application is presented in the following figure.

**Figure 5. Load Balancer Application Architecture**




For the sake of simplicity, the diagram illustrates a specific case of two I/O RX and two I/O TX lcores off loading the packet I/O overhead incurred by four NIC ports from four worker cores, with each I/O lcore handling RX/TX for two NIC ports.

### 14.1.1 I/O RX Logical Cores

Each I/O RX lcore performs packet RX from its assigned NIC RX rings and then distributes the received packets to the worker threads. The application allows each I/O RX lcore to communicate with any of the worker threads, therefore each (I/O RX lcore, worker lcore) pair is connected through a dedicated single producer – single consumer software ring.

The worker lcore to handle the current packet is determined by reading a predefined 1-byte field from the input packet:

```
worker_id = packet[load_balancing_field] % n_workers
```

Since all the packets that are part of the same traffic flow are expected to have the same value for the load balancing field, this scheme also ensures that all the packets that are part of the same traffic flow are directed to the same worker lcore (flow affinity) in the same order they enter the system (packet ordering).

### 14.1.2 I/O TX Logical Cores

Each I/O lcore owns the packet TX for a predefined set of NIC ports. To enable each worker thread to send packets to any NIC TX port, the application creates a software ring for each (worker lcore, NIC TX port) pair, with each I/O TX core handling those software rings that are associated with NIC ports that it handles.

### 14.1.3 Worker Logical Cores

Each worker lcore reads packets from its set of input software rings and routes them to the NIC ports for transmission by dispatching them to output software rings. The routing logic is LPM based, with all the worker threads sharing the same LPM rules.

## 14.2 Compiling the Application

The sequence of steps used to build the application is:

1. Export the required environment variables:

```
export RTE_SDK=<Path to the Intel DPDK installation folder>
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

2. Build the application executable file:

```
cd ${RTE_SDK}/examples/load_balancer
make
```

For more details on how to build the Intel® DPDK libraries and sample applications, please refer to the *Intel® DPDK Getting Started Guide*.

## 14.3 Running the Application

To successfully run the application, the command line used to start the application has to be in sync with the traffic flows configured on the traffic generator side.

For examples of application command lines and traffic generator flows, please refer to the *Intel® DPDK Test Report*. For more details on how to set up and run the sample applications provided with Intel DPDK package, please refer to the *Intel® DPDK Getting Started Guide*.

## 14.4 Explanation

### 14.4.1 Application Configuration

The application run-time configuration is done through the application command line parameters. Any parameter that is not specified as mandatory is optional, with the default value hard-coded in the `main.h` header file from the application folder.

The list of application command line parameters is listed below:

1. `--rx "(PORT, QUEUE, LCORE), ..."`: The list of NIC RX ports and queues handled by the I/O RX lcores. This parameter also implicitly defines the list of I/O RX lcores. This is a mandatory parameter.
2. `--tx "(PORT, LCORE), ..."`: The list of NIC TX ports handled by the I/O TX lcores. This parameter also implicitly defines the list of I/O TX lcores. This is a mandatory parameter.
3. `--w "LCORE, ..."`: The list of the worker lcores. This is a mandatory parameter.
4. `--lpm "IP / PREFIX => PORT; ..."`: The list of LPM rules used by the worker lcores for packet forwarding. This is a mandatory parameter.
5. `--rsz "A, B, C, D"`: Ring sizes:
    a. `A` = The size (in number of buffer descriptors) of each of the NIC RX rings read by the I/O RX lcores.
    b. `B` = The size (in number of elements) of each of the software rings used by the I/O RX lcores to send packets to worker lcores.
    c. `C` = The size (in number of elements) of each of the software rings used by the worker lcores to send packets to I/O TX lcores.
    d. `D` = The size (in number of buffer descriptors) of each of the NIC TX rings written by I/O TX lcores.
6. `--bsz "(A, B), (C, D), (E, F)"`: Burst sizes:
    a. `A` = The I/O RX lcore read burst size from NIC RX.
    b. `B` = The I/O RX lcore write burst size to the output software rings.
    c. `C` = The worker lcore read burst size from the input software rings.
    d. `D` = The worker lcore write burst size to the output software rings.
    e. `E` = The I/O TX lcore read burst size from the input software rings.
    f. `F` = The I/O TX lcore write burst size to the NIC TX.
7. `--pos-lb POS`: The position of the 1-byte field within the input packet used by the I/O RX lcores to identify the worker lcore for the current packet. This field needs to be within the first 64 bytes of the input packet.

The infrastructure of software rings connecting I/O lcores and worker lcores is built by the application as a result of the application configuration provided by the user through the application command line parameters.

A specific lcore performing the I/O RX role for a specific set of NIC ports can also perform the I/O TX role for the same or a different set of NIC ports. A specific lcore cannot perform both the I/O role (either RX or TX) and the worker role during the same session.

**Example:**

```
./load_balancer -c 0xf8 -n 4 -- --rx "(0,0,3),(1,0,3)" --tx "(0,3),(1,3)" --w
"4,5,6,7" --lpm "1.0.0.0/24=>0; 1.0.1.0/24=>1;" --pos-lb 29
```

There is a single I/O lcore (lcore 3) that handles RX and TX for two NIC ports (ports 0 and 1) that handles packets to/from four worker lcores (lcores 4, 5, 6 and 7) that are assigned worker IDs 0 to 3 (worker ID for lcore 4 is 0, for lcore 5 is 1, for lcore 6 is 2 and for lcore 7 is 3).

Assuming that all the input packets are IPv4 packets with no VLAN label and the source IP address of the current packet is A.B.C.D, the worker lcore for the current packet is determined by byte D (which is byte 29). There are two LPM rules that are used by each worker lcore to route packets to the output NIC ports.

The following table illustrates the packet flow through the system for several possible traffic flows:

| Flow # | Source IP Address | Destination IP Address | Worker ID (Worker lcore) | Output NIC Port |
|---|---|---|---|---|
| 1 | 0.0.0.0 | 1.0.0.1 | 0 (4) | 0 |
| 2 | 0.0.0.1 | 1.0.1.2 | 1 (5) | 1 |
| 3 | 0.0.0.14 | 1.0.0.3 | 2 (6) | 0 |
| 4 | 0.0.0.15 | 1.0.1.4 | 3 (7) | 1 |

### 14.4.2 NUMA Support

The application has built-in performance enhancements for the NUMA case:

1. One buffer pool per each CPU socket.
2. One LPM table per each CPU socket.
3. Memory for the NIC RX or TX rings is allocated on the same socket with the lcore handling the respective ring.

In the case where multiple CPU sockets are used in the system, it is recommended to enable at least one lcore to fulfil the I/O role for the NIC ports that are directly attached to that CPU socket through the PCI Express* bus. It is always recommended to handle the packet I/O with lcores from the same CPU socket as the NICs.

Depending on whether the I/O RX lcore (same CPU socket as NIC RX), the worker lcore and the I/O TX lcore (same CPU socket as NIC TX) handling a specific input packet, are on the same or different CPU sockets, the following run-time scenarios are possible:

1. AAA: The packet is received, processed and transmitted without going across CPU sockets.
2. AAB: The packet is received and processed on socket A, but as it has to be transmitted on a NIC port connected to socket B, the packet is sent to socket B through software rings.
3. ABB: The packet is received on socket A, but as it has to be processed by a worker lcore on socket B, the packet is sent to socket B through software rings. The packet is transmitted by a NIC port connected to the same CPU socket as the worker lcore that processed it.
4. ABC: The packet is received on socket A, it is processed by an lcore on socket B, then it has to be transmitted out by a NIC connected to socket C. The performance price for crossing the CPU socket boundary is paid twice for this packet.

§ §

# 15.0 Multi-process Sample Application

This chapter describes the example applications for multi-processing that are included in the Intel® DPDK.

## 15.1 Example Applications

### 15.1.1 Building the Sample Applications

The multi-process example applications are built in the same way as other sample applications, and as documented in the *Intel® DPDK Getting Started Guide*. To build all the example applications:

1. Set RTE_SDK and go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/multi_process
```

2. Set the target (a default target will be used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the applications:

```
make
```

*Note:* If just a specific multi-process application needs to be built, the final make command can be run just in that application's directory, rather than at the top-level multi-process directory.

### 15.1.2 Basic Multi-process Example

The `examples/simple_mp` folder in the Intel® DPDK release contains a basic example application to demonstrate how two Intel® DPDK processes can work together using queues and memory pools to share information.

#### 15.1.2.1 Running the Application

To run the application, start one copy of the `simple_mp` binary in one terminal, passing at least two cores in the coremask, as follows:

```
./build/simple_mp -c 3 -n 4 --proc-type=primary
```

For the first Intel® DPDK process run, the `proc-type` flag can be omitted or set to `auto`, since all Intel® DPDK processes will default to being a primary instance, meaning they have control over the hugepage shared memory regions. The process should start successfully and display a command prompt as follows:

```
$ ./build/simple_mp -c 3 -n 4 --proc-type=primary
EAL: coremask set to 3
EAL: Detected lcore 0 on socket 0
EAL: Detected lcore 1 on socket 0
EAL: Detected lcore 2 on socket 0
EAL: Detected lcore 3 on socket 0
...
EAL: Requesting 2 pages of size 1073741824
EAL: Requesting 768 pages of size 2097152
EAL: Ask a virtual area of 0x40000000 bytes
EAL: Virtual area found at 0x7ff200000000 (size = 0x40000000)
...
EAL: check igb_uio module
EAL: check module finished
EAL: Master core 0 is ready (tid=54e41820)
EAL: Core 1 is ready (tid=53b32700)
Starting core 1

simple_mp >
```

To run the secondary process to communicate with the primary process, again run the same binary setting at least two cores in the coremask.

```
./build/simple_mp -c C -n 4 --proc-type=secondary
```

When running a secondary process such as that shown above, the `proc-type` parameter can again be specified as `auto`. However, omitting the parameter altogether will cause the process to try and start as a primary rather than secondary process.

Once the process type is specified correctly, the process starts up, displaying largely similar status messages to the primary instance as it initializes. Once again, you will be presented with a command prompt.

Once both processes are running, messages can be sent between them using the `send` command. At any stage, either process can be terminated using the `quit` command.

```
EAL: Master core 10 is ready (tid=b5f89820)      EAL: Master core 8 is ready (tid=864a3820)
EAL: Core 11 is ready (tid=84ffe700)             EAL: Core 9 is ready (tid=85995700)
Starting core 11                                 Starting core 9

simple_mp > send hello_secondary                 simple_mp > core 9: Received 'hello_secondary'

simple_mp > core 11: Received 'hello_primary'
                                                 simple_mp > send hello_primary

simple_mp > quit                                 simple_mp > quit
```

*Note:* If the primary instance is terminated, the secondary instance must also be shut-down and restarted after the primary. This is necessary because the primary instance will clear and reset the shared memory regions on startup, invalidating the secondary process's pointers. The secondary process can be stopped and restarted without affecting the primary process.

### 15.1.2.2 How the Application Works

The core of this example application is based on using two queues and a single memory pool in shared memory. These three objects are created at startup by the primary process, since the secondary process cannot create objects in memory as it cannot reserve memory zones, and the secondary process then uses lookup functions to attach to these objects as it starts up.

```
if (rte_eal_process_type() == RTE_PROC_PRIMARY){
    send_ring = rte_ring_create(_PRI_2_SEC, ring_size, SOCKET0, flags);
    recv_ring = rte_ring_create(_SEC_2_PRI, ring_size, SOCKET0, flags);
    message_pool = rte_mempool_create(_MSG_POOL, pool_size,
            string_size, pool_cache, priv_data_sz,
            NULL, NULL, NULL, NULL,
            SOCKET0, flags);
} else {
    recv_ring = rte_ring_lookup(_PRI_2_SEC);
    send_ring = rte_ring_lookup(_SEC_2_PRI);
    message_pool = rte_mempool_lookup(_MSG_POOL);
}
```

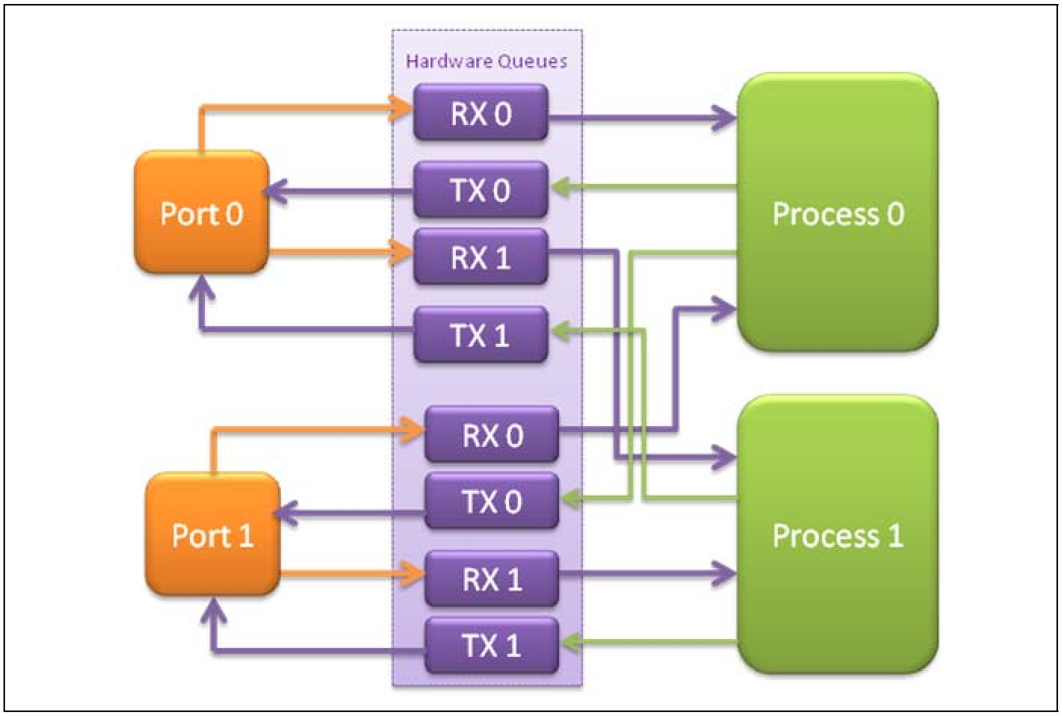
Note, however, that the named ring structure used as `send_ring` in the primary process is the `recv_ring` in the secondary process.

Once the rings and memory pools are all available in both the primary and secondary processes, the application simply dedicates two threads to sending and receiving messages respectively. The receive thread simply dequeues any messages on the receive ring, prints them, and frees the buffer space used by the messages back to the memory pool. The send thread makes use of the command-prompt library to interactively request user input for messages to send. Once a `send` command is issued by the user, a buffer is allocated from the memory pool, filled in with the message contents, then enqueued on the appropriate rte_ring.

### 15.1.3 Symmetric Multi-process Example

The second example of Intel® DPDK multi-process support demonstrates how a set of processes can run in parallel, with each process performing the same set of packet-processing operations. (Since each process is identical in functionality to the others, we refer to this as symmetric multi-processing, to differentiate it from asymmetric multi-processing - such as a client-server mode of operation seen in the next example, where different processes perform different tasks, yet co-operate to form a packet-processing system.) The following diagram shows the data-flow through the application, using two processes.

**Figure 6. Example Data Flow in a Symmetric Multi-process Application**




As the diagram shows, each process reads packets from each of the network ports in use. RSS is used to distribute incoming packets on each port to different hardware RX queues. Each process reads a different RX queue on each port and so does not contend with any other process for that queue access. Similarly, each process writes outgoing packets to a different TX queue on each port.

### 15.1.3.1 Running the Application

As with the `simple_mp` example, the first instance of the `symmetric_mp` process must be run as the primary instance, though with a number of other application-specific parameters also provided after the EAL arguments. These additional parameters are:

- `-p <portmask>`, where `portmask` is a hexadecimal bitmask of what ports on the system are to be used. For example: `-p 3` to use ports 0 and 1 only.
- `--num-procs <N>`, where `N` is the total number of `symmetric_mp` instances that will be run side-by-side to perform packet processing. This parameter is used to configure the appropriate number of receive queues on each network port.
- `--proc-id <n>`, where `n` is a numeric value in the range 0 <= n < N (number of processes, specified above). This identifies which `symmetric_mp` instance is being run, so that each process can read a unique receive queue on each network port.

The secondary `symmetric_mp` instances must also have these parameters specified, and the first two must be the same as those passed to the primary instance, or errors result.

For example, to run a set of four `symmetric_mp` instances, running on lcores 1-4, all performing level-2 forwarding of packets between ports 0 and 1, the following commands can be used (assuming run as root):

```
# ./build/symmetric_mp -c 2 -n 4 --proc-type=auto -- -p 3 --num-procs=4 --proc-id=0
# ./build/symmetric_mp -c 4 -n 4 --proc-type=auto -- -p 3 --num-procs=4 --proc-id=1
# ./build/symmetric_mp -c 8 -n 4 --proc-type=auto -- -p 3 --num-procs=4 --proc-id=2
# ./build/symmetric_mp -c 10 -n 4 --proc-type=auto -- -p 3 --num-procs=4 --proc-id=3
```

*Note:* In the above example, the process type can be explicitly specified as `primary` or `secondary`, rather than `auto`. When using `auto`, the first process run creates all the memory structures needed for all processes - irrespective of whether it has a `proc-id` of 0, 1, 2 or 3.

*Note:* For the symmetric multi-process example, since all processes work in the same manner, once the hugepage shared memory and the network ports are initialized, it is not necessary to restart all processes if the primary instance dies. Instead, that process can be restarted as a secondary, by explicitly setting the `proc-type` to `secondary` on the command line. (All subsequent instances launched will also need this explicitly specified, as auto-detection will detect no primary processes running and therefore attempt to re-initialize shared memory.)

#### 15.1.3.2 How the Application Works

The initialization calls in both the primary and secondary instances are the same for the most part, calling the `rte_eal_init()`, 1G and 10 G driver initialization and then `rte_eal_pci_probe()` functions. Thereafter, the initialization done depends on whether the process is configured as a primary or secondary instance.

In the primary instance, a memory pool is created for the packet `mbufs` and the network ports to be used are initialized - the number of RX and TX queues per port being determined by the `num-procs` parameter passed on the command-line. The structures for the initialized network ports are stored in shared memory and therefore will be accessible by the secondary process as it initializes.

```
if (num_ports & 1)
    rte_exit(EXIT_FAILURE, "Application must use an even number of ports\n");
for(i = 0; i < num_ports; i++){
    if(proc_type == RTE_PROC_PRIMARY)
        if (smp_port_init(ports[i], mp, (uint16_t)num_procs) < 0)
            rte_exit(EXIT_FAILURE, "Error initialising ports\n");
}
```

In the secondary instance, rather than initializing the network ports, the port information exported by the primary process is used, giving the secondary process access to the hardware and software rings for each network port. Similarly, the memory pool of `mbufs` is accessed by doing a lookup for it by name:

```
mp = (proc_type == RTE_PROC_SECONDARY) ?
        rte_mempool_lookup(_SMP_MBUF_POOL) :
        rte_mempool_create(_SMP_MBUF_POOL, NB_MBUFS, MBUF_SIZE, ... )
```

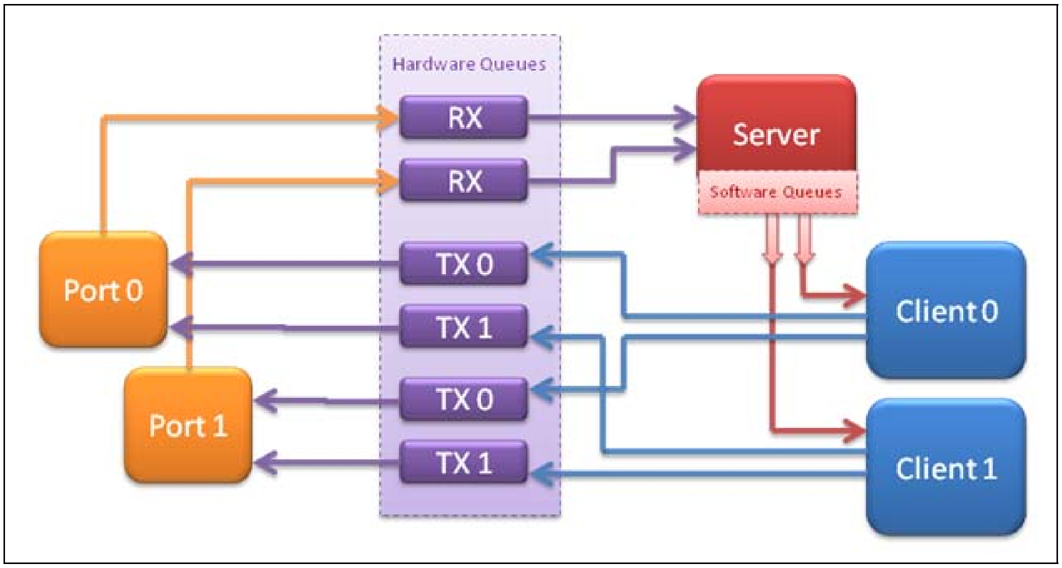
Once this initialization is complete, the main loop of each process, both primary and secondary, is exactly the same - each process reads from each port using the queue corresponding to its `proc-id` parameter, and writes to the corresponding transmit queue on the output port.

### 15.1.4 Client-Server Multi-process Example

The third example multi-process application included with the Intel® DPDK shows how one can use a client-server type multi-process design to do packet processing. In this example, a single server process performs the packet reception from the ports being used and distributes these packets using round-robin ordering among a set of client processes, which perform the actual packet processing. In this case, the client applications just perform level-2 forwarding of packets by sending each packet out on a different network port.

The following diagram shows the data-flow through the application, using two client processes.

**Figure 7. Example Data Flow in a Client-Server Symmetric Multi-process Application**




### 15.1.4.1 Running the Application

The server process must be run initially as the primary process to set up all memory structures for use by the clients. In addition to the EAL parameters, the application-specific parameters are:

- `-p <portmask>`, where `portmask` is a hexadecimal bitmask of what ports on the system are to be used. For example: `-p 3` to use ports 0 and 1 only.
- `-n <num-clients>`, where the `num-clients` parameter is the number of client processes that will process the packets received by the server application.

*Note:* In the server process, a single thread, the master thread, that is, the lowest numbered lcore in the coremask, performs all packet I/O. If a coremask is specified with more than a single lcore bit set in it, an additional lcore will be used for a thread to periodically print packet count statistics.

Since the server application stores configuration data in shared memory, including the network ports to be used, the only application parameter needed by a client process is its client instance ID. Therefore, to run a server application on lcore 1 (with lcore 2 printing statistics) along with two client processes running on lcores 3 and 4, the following commands could be used:

```
# ./mp_server/build/mp_server -c 6 -n 4 -- -p 3 -n 2
# ./mp_client/build/mp_client -c 8 -n 4 --proc-type=auto -- -n 0
# ./mp_client/build/mp_client -c 10 -n 4 --proc-type=auto -- -n 1
```

*Note:* If the server application dies and needs to be restarted, all client applications also need to be restarted, as there is no support in the server application for it to run as a secondary process. Any client processes that need restarting can be restarted without affecting the server process.

#### 15.1.4.2 How the Application Works

The server process performs the network port and data structure initialization much as the symmetric multi-process application does when run as primary. One additional enhancement in this sample application is that the server process stores its port configuration data in a memory zone in hugepage shared memory. This eliminates the need for the client processes to have the `portmask` parameter passed into them on the command line, as is done for the symmetric multi-process application, and therefore eliminates mismatched parameters as a potential source of errors.

In the same way that the server process is designed to be run as a primary process instance only, the client processes are designed to be run as secondary instances only. They have no code to attempt to create shared memory objects. Instead, handles to all needed rings and memory pools are obtained via calls to `rte_ring_lookup()` and `rte_mempool_lookup()`. The network ports for use by the processes are obtained by loading the network port drivers and probing the PCI bus, which will, as in the symmetric multi-process example, automatically get access to the network ports using the settings already configured by the primary/server process.

Once all applications are initialized, the server operates by reading packets from each network port in turn and distributing those packets to the client queues (software rings, one for each client process) in round-robin order. On the client side, the packets are read from the rings in as big of bursts as possible, then routed out to a different network port. The routing used is very simple. All packets received on the first NIC port are transmitted back out on the second port and vice versa. Similarly, packets are routed between the 3rd and 4th network ports and so on. The sending of packets is done by writing the packets directly to the network ports; they are not transferred back via the server process.

In both the server and the client processes, outgoing packets are buffered before being sent, so as to allow the sending of multiple packets in a single burst to improve efficiency. For example, the client process will buffer packets to send, until either the buffer is full or until we receive no further packets from the server.

### 15.1.5 Master-slave Multi-process Example

The fourth example of Intel® DPDK multi-process support demonstrates a master-slave model that provide the capability of application recovery if a slave process crashes or meets unexpected conditions. In addition, it also demonstrates the floating process, which can run among different cores in contrast to the traditional way of binding a process/thread to a specific CPU core, using the local cache mechanism of `mempool` structures.

This application performs the same functionality as the L2 Forwarding sample application, therefore this chapter does not cover that part but describes functionality that is introduced in this multi-process example only. Please refer to Chapter 9.0, “L2 Forwarding Sample Application (in Real and Virtualized Environments)” for more information.

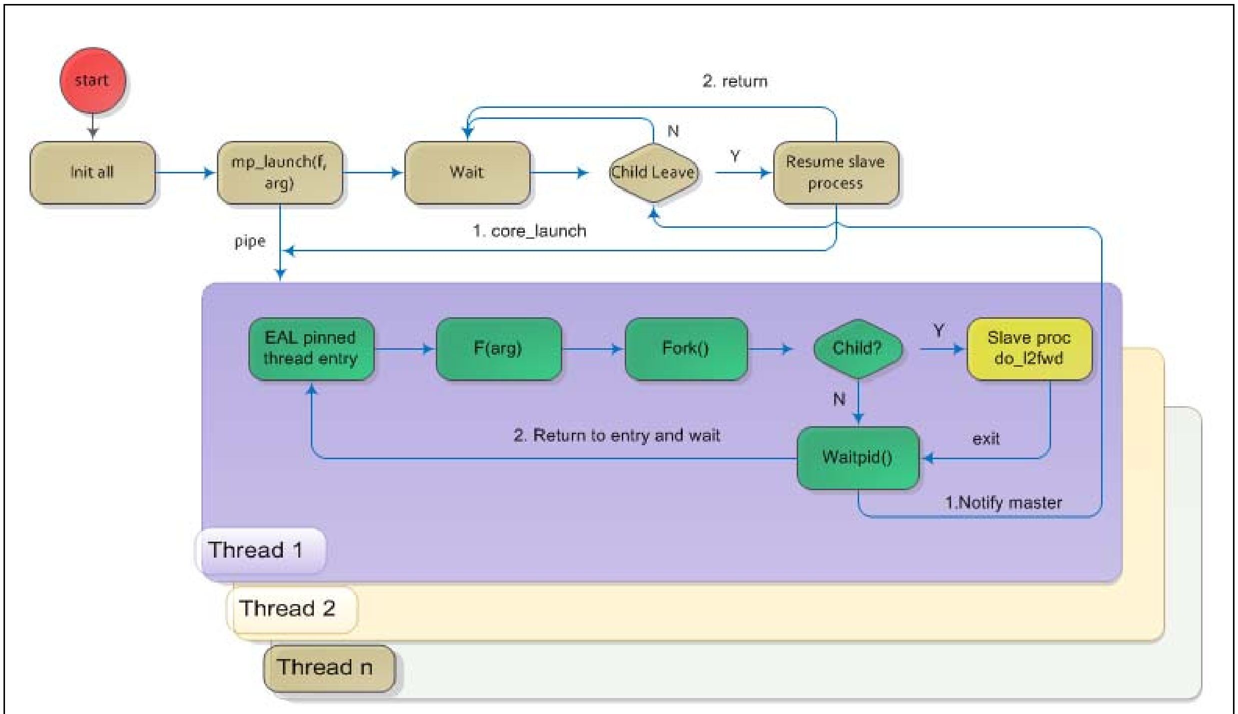
Unlike previous examples where all processes are started from the command line with input arguments, in this example, only one process is spawned from the command line and that process creates other processes. The following section describe this in more detail.

### 15.1.5.1 Master-slave Process Models

The process spawned from the command line is called the *master* process in this document. A process created by the master is called a *slave* process. The application has only one master process, but could have multiple slave processes.

Once the master process begins to run, it tries to initialize all the resources such as memory, CPU cores, driver, ports, and so on, as the other examples do. Thereafter, it creates slave processes, as shown in the following figure.

**Figure 8. Master-slave Process Workflow**




The master process calls the `rte_eal_mp_remote_launch()` EAL function to launch an application function for each pinned thread through the pipe. Then, it waits to check if any slave processes have exited. If so, the process tries to re-initialize the resources that belong to that slave and launch them in the pinned thread entry again. The following section describes the recovery procedures in more detail.

For each pinned thread in EAL, after reading any data from the pipe, it tries to call the function that the application specified. In this master specified function, a `fork()` call creates a slave process that performs the L2 forwarding task. Then, the function waits until the slave exits, is killed or crashes. Thereafter, it notifies the master of this event and returns. Finally, the EAL pinned thread waits until the new function is launched.

After discussing the master-slave model, it is necessary to mention another issue, global and static variables.

For multiple-thread cases, all global and static variables have only one copy and they can be accessed by any thread if applicable. So, they can be used to sync or share data among threads.

In the previous examples, each process has separate global and static variables in memory and are independent of each other. If it is necessary to share the knowledge, some communication mechanism should be deployed, such as, memzone, ring, shared memory, and so on. The global or static variables are not a valid approach to share data among processes. For variables in this example, on the one hand, the slave process inherits all the knowledge of these variables after being created by the master. On the other hand, other processes cannot know if one or more processes modifies them after slave creation since that is the nature of a multiple process address space. But this does not mean that these variables cannot be used to share or sync data; it depends on the use case. The following are the possible use cases:

1. The master process starts and initializes a variable and it will never be changed after slave processes created. This case is OK.
2. After the slave processes are created, the master or slave cores need to change a variable, but other processes do not need to know the change. This case is also OK.
3. After the slave processes are created, the master or a slave needs to change a variable. In the meantime, one or more other process needs to be aware of the change. In this case, global and static variables cannot be used to share knowledge. Another communication mechanism is needed. A simple approach without lock protection can be a heap buffer allocated by `rte_malloc` or `memzone`.

### 15.1.5.2 Slave Process Recovery Mechanism

Before talking about the recovery mechanism, it is necessary to know what is needed before a new slave instance can run if a previous one exited.

When a slave process exits, the system returns all the resources allocated for this process automatically. However, this does not include the resources that were allocated by the Intel® DPDK. All the hardware resources are shared among the processes, which include memzone, mempool, ring, a heap buffer allocated by the `rte_malloc` library, and so on. If the new instance runs and the allocated resource is not returned, either resource allocation failed or the hardware resource is lost forever.

When a slave process runs, it may have dependencies on other processes. They could have execution sequence orders; they could share the ring to communicate; they could share the same port for reception and forwarding; they could use lock structures to do exclusive access in some critical path. What happens to the dependent process(es) if the peer leaves? The consequence are varied since the dependency cases are complex. It depends on what the processed had shared. However, it is necessary to notify the peer(s) if one slave exited. Then, the peer(s) will be aware of that and wait until the new instance begins to run.

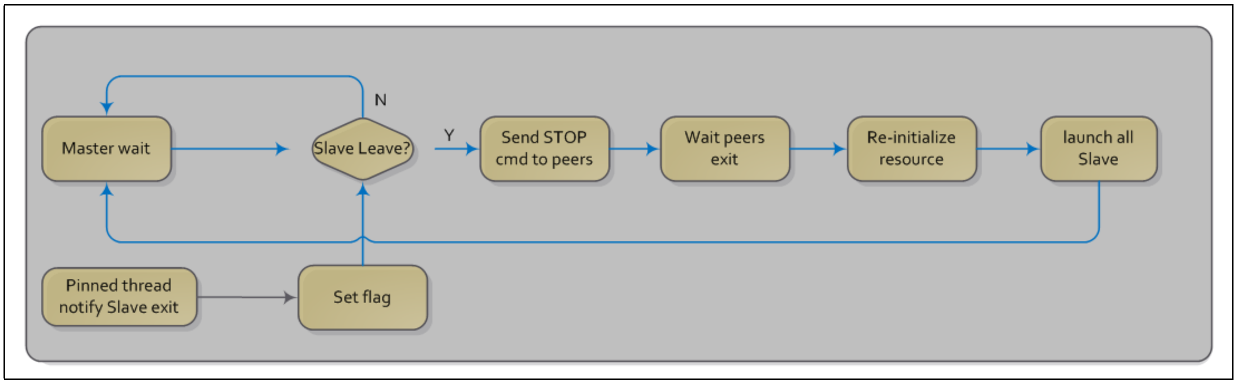
Therefore, to provide the capability to resume the new slave instance if the previous one exited, it is necessary to provide several mechanisms:

1. Keep a resource list for each slave process. Before a slave process run, the master should prepare a resource list. After it exits, the master could either delete the allocated resources and create new ones, or re-initialize those for use by the new instance.
2. Set up a notification mechanism for slave process exit cases. After the specific slave leaves, the master should be notified and then help to create a new instance. This mechanism is provided in Section 15.1.5.1, "Master-slave Process Models" on page 83.
3. Use a synchronization mechanism among dependent processes. The master should have the capability to stop or kill slave processes that have a dependency on the one that has exited. Then, after the new instance of exited slave process begins to run, the dependency ones could resume or run from the start. The example sends a

STOP command to slave processes dependent on the exited one, then they will exit. Thereafter, the master creates new instances for the exited slave processes.

The following diagram describes slave process recovery.

**Figure 9. Slave Process Recovery Process Flow**




### 15.1.5.3 Floating Process Support

When the Intel® DPDK application runs, there is always a `-c` option passed in to indicate the cores that are enabled. Then, the Intel® DPDK creates a thread for each enabled core. By doing so, it creates a 1:1 mapping between the enabled core and each thread. The enabled core always has an ID, therefore, each thread has a unique core ID in the Intel® DPDK execution environment. With the ID, each thread can easily access the structures or resources exclusively belonging to it without using function parameter passing. It can easily use the `rte_lcore_id()` function to get the value in every function that is called.

For threads/processes not created in that way, either pinned to a core or not, they will not own a unique ID and the `rte_lcore_id()` function will not work in the correct way. However, sometimes these threads/processes still need the unique ID mechanism to do easy access on structures or resources. For example, the Intel® DPDK `mempool` library provides a local cache mechanism (refer to *Intel® DPDK Programmer's Guide* - Rel 1.4 EAR, Section 6.4, "Local Cache") for fast element allocation and freeing. If using a non-unique ID or a fake one, a race condition occurs if two or more threads/ processes with the same core ID try to use the local cache.

Therefore, unused core IDs from the passing of parameters with the `-c` option are used to organize the core ID allocation array. Once the floating process is spawned, it tries to allocate a unique core ID from the array and release it on exit.

A natural way to spawn a floating process is to use the `fork()` function and allocate a unique core ID from the unused core ID array. However, it is necessary to write new code to provide a notification mechanism for slave exit and make sure the process recovery mechanism can work with it.

To avoid producing redundant code, the Master-Slave process model is still used to spawn floating processes, then cancel the affinity to specific cores. Besides that, clear the core ID assigned to the Intel® DPDK spawning a thread that has a 1:1 mapping with the core mask. Thereafter, get a new core ID from the unused core ID allocation array.

### 15.1.5.4 Run the Application

This example has a command line similar to the L2 Forwarding sample application with a few differences.

To run the application, start one copy of the l2fwd_fork binary in one terminal. Unlike the L2 Forwarding example, this example requires at least three cores since the master process will wait and be accountable for slave process recovery. The command is as follows:

```
#./build/l2fwd_fork -c 1c -n 4 -- -p 3 -f
```

This example provides another -f option to specify the use of floating process. If not specified, the example will use a pinned process to perform the L2 forwarding task.

To verify the recovery mechanism, proceed as follows:

First, check the PID of the slave processes:

```
#ps -fe | grep l2fwd_fork
root        5136   4843 29 11:11 pts/1    00:00:05 ./build/l2fwd_fork
root        5145   5136 98 11:11 pts/1    00:00:11 ./build/l2fwd_fork
root        5146   5136 98 11:11 pts/1    00:00:11 ./build/l2fwd_fork
```

Then, kill one of the slaves.

```
#kill -9 5145
```

After 1 or 2 seconds, check whether the slave has resumed:

```
#ps -fe | grep l2fwd_fork
root        5136   4843  3 11:11 pts/1    00:00:06 ./build/l2fwd_fork
root        5247   5136 99 11:14 pts/1    00:00:01 ./build/l2fwd_fork
root        5248   5136 99 11:14 pts/1    00:00:01 ./build/l2fwd_fork
```

It can also monitor the traffic generator statics to see whether slave processes have resumed.

#### 15.1.5.5 Explanation

As described in previous sections, not all global and static variables need to change to be accessible in multiple processes; it depends on how they are used. In this example, the statics info on packets dropped/forwarded/received count needs to be updated by the slave process, and the master needs to see the update and print them out. So, it needs to allocate a heap buffer using rte_zmalloc. In addition, if the -f option is specified, an array is needed to store the allocated core ID for the floating process so that the master can return it after a slave has exited accidently.

```
static int
l2fwd_malloc_shared_struct(void)
{
    port_statistics = rte_zmalloc("port_stat",
                sizeof(struct l2fwd_port_statistics) * RTE_MAX_ETHPORTS, 0);
    if (port_statistics == NULL)
        return -1;
    /* allocate  mapping_id array */
    if (float_proc) {
        int i;
        mapping_id = rte_malloc("mapping_id", sizeof(unsigned) *
                     RTE_MAX_LCORE, 0);
        if (mapping_id == NULL)
            return -1;
        for (i = 0 ;i < RTE_MAX_LCORE; i++)
            mapping_id[i] = INVALID_MAPPING_ID;
    }
    return 0;
}
```

For each slave process, packets are received from one port and forwarded to another port that another slave is operating on. If the other slave exits accidentally, the port it is operating on may not work normally, so the first slave cannot forward packets to that port. There is a dependency on the port in this case. So, the master should recognize the dependency. The following is the code to detect this dependency:

```
for (portid = 0; portid < nb_ports; portid++) {
    /* skip ports that are not enabled */
    if ((l2fwd_enabled_port_mask & (1 << portid)) == 0)
        continue;
    /* Find pair ports' lcores */
    find_lcore = find_pair_lcore = 0;
    pair_port = l2fwd_dst_ports[portid];
    for (i = 0; i < RTE_MAX_LCORE; i++) {
        if (!rte_lcore_is_enabled(i))
            continue;
        for (j = 0; j < lcore_queue_conf[i].n_rx_port;j++) {
            if (lcore_queue_conf[i].rx_port_list[j] == portid) {
                lcore = i;
                find_lcore = 1;
                break;
            }
            if (lcore_queue_conf[i].rx_port_list[j] == pair_port) {
                pair_lcore = i;
                find_pair_lcore = 1;
                break;
            }
        }
        if (find_lcore && find_pair_lcore)
            break;
    }
    if (!find_lcore || !find_pair_lcore)
        rte_exit(EXIT_FAILURE, "Not find port=%d pair\n", portid);
    printf("lcore %u and %u paired\n", lcore, pair_lcore);
    lcore_resource[lcore].pair_id = pair_lcore;
    lcore_resource[pair_lcore].pair_id = lcore;
}
```

Before launching the slave process, it is necessary to set up the communication channel between the master and slave so that the master can notify the slave if its peer process with the dependency exited. In addition, the master needs to register a callback function in the case where a specific slave exited.

```
for (i = 0; i < RTE_MAX_LCORE; i++) {
    if (lcore_resource[i].enabled) {
        /* Create ring for master and slave communication */
        ret = create_ms_ring(i);
        if (ret != 0)
            rte_exit(EXIT_FAILURE, "Create ring for lcore=%u failed",i);
        if (flib_register_slave_exit_notify(i,slave_exit_cb) != 0)
            rte_exit(EXIT_FAILURE, "Register master_trace_slave_exit failed");
        }
    }
```

After launching the slave process, the master waits and prints out the port statics periodically. If an event indicating that a slave process exited is detected, it sends the STOP command to the peer and waits until it has also exited. Then, it tries to clean up the execution environment and prepare new resources. Finally, the new slave instance is launched.

```
    while (1) {
        sleep(1);
        cur_tsc = rte_rdtsc();
        diff_tsc = cur_tsc - prev_tsc;
        /* if timer is enabled */
```

```
        if (timer_period > 0) {
        /* advance the timer */
        timer_tsc += diff_tsc;
        /* if timer has reached its timeout */
        if (unlikely(timer_tsc >= (uint64_t) timer_period)) {
            print_stats();
            /* reset the timer */
            timer_tsc = 0;
        }
    }
    prev_tsc = cur_tsc;
    /* Check any slave need restart or recreate */
    rte_spinlock_lock(&res_lock);
    for (i = 0; i < RTE_MAX_LCORE; i++) {
        struct lcore_resource_struct *res  = &lcore_resource[i];
        struct lcore_resource_struct *pair = &lcore_resource[res->pair_id];
        /* If find slave exited, try to reset pair */
        if (res->enabled && res->flags && pair->enabled) {
            if (!pair->flags) {
                master_sendcmd_with_ack(pair->lcore_id, CMD_STOP);
                rte_spinlock_unlock(&res_lock);
                sleep(1);
                rte_spinlock_lock(&res_lock);
                if (pair->flags)
                    continue;
            }
            if (reset_pair(res->lcore_id, pair->lcore_id) != 0)
                rte_exit(EXIT_FAILURE, "failed to reset slave");
            res->flags  = 0;
            pair->flags = 0;
        }
    }
    rte_spinlock_unlock(&res_lock);
}
```

When the slave process is spawned and starts to run, it checks whether the floating process option is applied. If so, it clears the affinity to a specific core and also sets the unique core ID to 0. Then, it tries to allocate a new core ID. Since the core ID has changed, the resource allocated by the master cannot work, so it remaps the resource to the new core ID slot.

```
static int
l2fwd_launch_one_lcore(__attribute__((unused)) void *dummy)
{
    unsigned lcore_id = rte_lcore_id();
    if (float_proc) {
        unsigned flcore_id;
        /* Change it to floating process, also change it's lcore_id */
        clear_cpu_affinity();
        RTE_PER_LCORE(_lcore_id) = 0;
        /* Get a lcore_id */
        if (flib_assign_lcore_id() < 0 ) {
            printf("flib_assign_lcore_id failed\n");
            return -1;
        }
        flcore_id = rte_lcore_id();
        /* Set mapping id, so master can return it after slave exited */
        mapping_id[lcore_id] = flcore_id;
        printf("Org lcore_id = %u, cur lcore_id = %u\n",lcore_id, flcore_id);
        remapping_slave_resource(lcore_id, flcore_id);
    }
    l2fwd_main_loop();
    /* return lcore_id before return */
    if (float_proc) {
        flib_free_lcore_id(rte_lcore_id());
        mapping_id[lcore_id] = INVALID_MAPPING_ID;
```

```
        }
        return 0;
}
```

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# 16.0 QoS Metering Sample Application

The QoS meter sample application is an example that demonstrates the use of Intel® DPDK to provide QoS marking and metering, as defined by RFC2697 for Single Rate Three Color Marker (srTCM) and RFC 2698 for Two Rate Three Color Marker (trTCM) algorithm.

## 16.1 Overview

The application uses a single thread for reading the packets from the RX port, metering, marking them with the appropriate color (green, yellow or red) and writing them to the TX port.

A policing scheme can be applied before writing the packets to the TX port by dropping or changing the color of the packet in a static manner depending on both the input and output colors of the packets that are processed by the meter.

The operation mode can be selected as compile time out of the following options:

- Simple forwarding
- srTCM color blind
- srTCM color aware
- srTCM color blind
- srTCM color aware

Please refer to RFC2697 and RFC2698 for details about the srTCM and trTCM configurable parameters (CIR, CBS and EBS for srTCM; CIR, PIR, CBS and PBS for trTCM).

The color blind modes are functionally equivalent with the color-aware modes when all the incoming packets are colored as green.

## 16.2 Compiling the Application

1. Go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/qos_meter
```

2. Set the target(a default target is used if not specified)

*Note:* This application is intended as a linuxapp only.

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

3. Build the application

```
make
```

## 16.3 Running the Application

The application execution command line is as below:

```
./qos_meter [EAL options] -- -p PORTMASK
```

The application is constrained to use a single core in the EAL core mask and 2 ports only in the application port mask (first port from the port mask is used for RX and the other port in the core mask is used for TX).

Refer to *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 16.4 Explanation

Selecting one of the metering modes is done with these defines:

```
#define APP_MODE_FWD                    0
#define APP_MODE_SRTCM_COLOR_BLIND      1
#define APP_MODE_SRTCM_COLOR_AWARE      2
#define APP_MODE_TRTCM_COLOR_BLIND      3
#define APP_MODE_TRTCM_COLOR_AWARE      4

#define APP_MODE       APP_MODE_SRTCM_COLOR_BLIND
```

To simplify debugging (e.g. by using the traffic generator RX side MAC address based packet filtering feature), the color is defined as the LSB byte of the destination MAC address.

The traffic meter parameters are configured in the application source code with following default values:

```
struct rte_meter_srtcm_params app_srtcm_params[] = {
    {.cir = 1000000 * 46, .cbs = 2048, .ebs = 2048},
};

struct rte_meter_trtcm_params app_trtcm_params[] = {
    {.cir = 1000000 * 46, .pir = 1500000 * 46, .cbs = 2048, .pbs = 2048},
};
```

Assuming the input traffic is generated at line rate and all packets are 64 bytes Ethernet frames (IPv4 packet size of 46 bytes) and green, the expected output traffic should be marked as shown in the following table:

### Table 1. Output Traffic Marking

| Mode | Green (Mpps) | Yellow (Mpps) | Red (Mpps) |
|---|---|---|---|
| srTCM blind | 1 | 1 | 12.88 |
| srTCM color | 1 | 1 | 12.88 |
| trTCM blind | 1 | 0.5 | 13.38 |
| trTCM color | 1 | 0.5 | 13.38 |
| FWD | 14.88 | 0 | 0 |

In order to set up the policing scheme as desired, it is necessary to modify the *main.h* source file, where this policy is implemented as a static structure, as follows:

```
int policer_table[e_RTE_METER_COLORS][e_RTE_METER_COLORS] =
{
    { GREEN, RED, RED},
    { DROP, YELLOW, RED},
    { DROP, DROP, RED}
};
```

Where rows indicate the input color, columns indicate the output color, and the value that is stored in the table indicates the action to be taken for that particular case.

There are four different actions:

- GREEN: The packet's color is changed to green.
- YELLOW: The packet's color is changed to yellow.
- RED: The packet's color is changed to red.
- DROP: The packet is dropped.

In this particular case:

- Every packet which input and output color are the same, keeps the same color.
- Every packet which color has improved is dropped (this particular case can't happen, so these values will not be used).
- For the rest of the cases, the color is changed to red.

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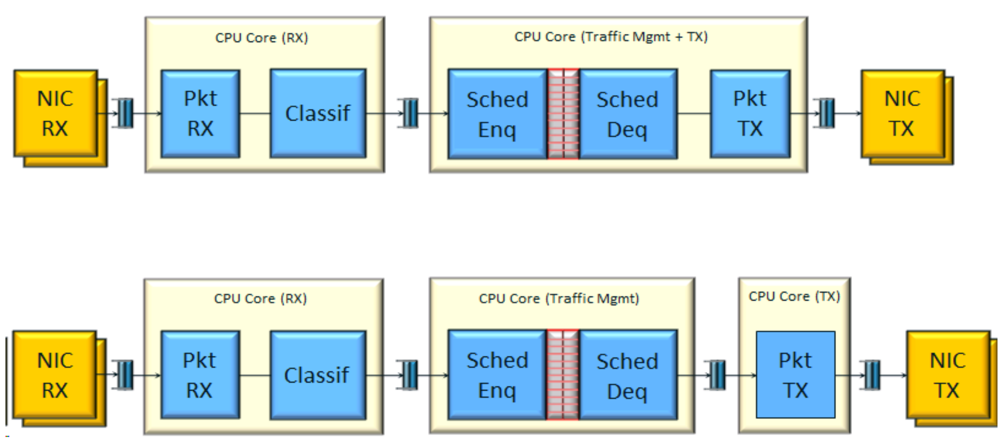
# 17.0 QoS Scheduler Sample Application

The QoS sample application demonstrates the use of the Intel® DPDK to provide QoS scheduling.

## 17.1 Overview

The architecture of the QoS scheduler application is shown in the following figure.

**Figure 10. QoS Scheduler Application Architecture**




There are two flavors of the runtime execution for this application, with two or three threads per each packet flow configuration being used. The RX thread reads packets from the RX port, classifies the packets based on the double VLAN (outer and inner) and the lower two bytes of the IP destination address and puts them into the ring queue. The worker thread dequeues the packets from the ring and calls the QoS scheduler enqueue/dequeue functions. If a separate TX core is used, these are sent to the TX ring. Otherwise, they are sent directly to the TX port. The TX thread, if present, reads from the TX ring and write the packets to the TX port.

## 17.2 Compiling the Application

To compile the application:

1. Go to the sample application directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/qos_sched
```

2. Set the target (a default target is used if not specified). For example:
   **Note**: This application is intended as a linuxapp only.

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

3. Build the application:

```
make
```

*Note:* In order to get statistics on the sample app using the command line interface as described in the next section, DPDK must be compiled defining *CONFIG_RTE_SCHED_COLLECT_STATS*, which can be done by changing the configuration file for the specific target to be compiled.

## 17.3 Running the Application

*Note:* In order to run the application, a total of at least 4G of huge pages must be set up for each of the used sockets (depending on the cores in use).

The application has a number of command line options:

```
./qos_sched [EAL options] -- <APP PARAMS>
```

Mandatory application parameters include:

- `--pfc "RX PORT, TX PORT, RX LCORE, WT LCORE, TX CORE"`: Packet flow configuration. Multiple `pfc` entities can be configured in the command line, having 4 or 5 items (if TX core defined or not).

Optional application parameters include:

- `-i`: It makes the application to start in the interactive mode. In this mode, the application shows a command line that can be used for obtaining statistics while scheduling is taking place (see interactive mode below for more information).
- `--mst n`: Master core index (the default value is 1).
- `--rsz "A, B, C"`: Ring sizes:
  — `A` = Size (in number of buffer descriptors) of each of the NIC RX rings read by the I/O RX lcores (the default value is 128).
  — `B` = Size (in number of elements) of each of the software rings used by the I/O RX lcores to send packets to worker lcores (the default value is 8192).
  — `C` = Size (in number of buffer descriptors) of each of the NIC TX rings written by worker lcores (the default value is 256)
- `--bsz "A, B, C, D"`: Burst sizes
  — `A` = I/O RX lcore read burst size from the NIC RX (the default value is 64)

  - B = I/O RX lcore write burst size to the output software rings, worker lcore read burst size from input software rings, QoS enqueue size (the default value is 64)
  - C = QoS dequeue size (the default value is 32)
  - D = Worker lcore write burst size to the NIC TX (the default value is 64)
- `--msz M`: Mempool size (in number of mbufs) for each pfc (default 2097152)
- `--rth "A, B, C"`: The RX queue threshold parameters
  - A = RX prefetch threshold (the default value is 8)
  - B = RX host threshold (the default value is 8)
  - C = RX write-back threshold (the default value is 4)
- `--tth "A, B, C"`: TX queue threshold parameters
  - A = TX prefetch threshold (the default value is 36)
  - B = TX host threshold (the default value is 0)
  - C = TX write-back threshold (the default value is 0)
- `--cfg FILE`: Profile configuration to load

Refer to *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

The profile configuration file defines all the port/subport/pipe/traffic class/queue parameters needed for the QoS scheduler configuration.

The profile file has the following format:

```
; port configuration
[port]
frame overhead = 24
number of subports per port = 1
number of pipes per subport = 4096
queue sizes = 64 64 64 64

; Subport configuration
[subport 0]
tb rate = 1250000000           ; Bytes per second
tb size = 1000000              ; Bytes

tc 0 rate = 1250000000         ; Bytes per second
tc 1 rate = 1250000000         ; Bytes per second
tc 2 rate = 1250000000         ; Bytes per second
tc 3 rate = 1250000000         ; Bytes per second
tc period = 10                 ; Milliseconds
tc oversubscription period = 10; Milliseconds

pipe 0-4095 = 0               ; These pipes are configured with pipe profile 0

; Pipe configuration
[pipe profile 0]
tb rate = 305175               ; Bytes per second
tb size = 1000000              ; Bytes

tc 0 rate = 305175             ; Bytes per second
tc 1 rate = 305175             ; Bytes per second
tc 2 rate = 305175             ; Bytes per second
tc 3 rate = 305175             ; Bytes per second
tc period = 40                 ; Milliseconds

tc 0 oversubscription weight = 1
tc 1 oversubscription weight = 1
```

```
tc 2 oversubscription weight = 1
tc 3 oversubscription weight = 1

tc 0 wrr weights = 1 1 1 1
tc 1 wrr weights = 1 1 1 1
tc 2 wrr weights = 1 1 1 1
tc 3 wrr weights = 1 1 1 1

; RED params per traffic class and color (Green / Yellow / Red)
[red]
tc 0 wred min = 48 40 32
tc 0 wred max = 64 64 64
tc 0 wred inv prob = 10 10 10
tc 0 wred weight = 9 9 9

tc 1 wred min = 48 40 32
tc 1 wred max = 64 64 64
tc 1 wred inv prob = 10 10 10
tc 1 wred weight = 9 9 9

tc 2 wred min = 48 40 32
tc 2 wred max = 64 64 64
tc 2 wred inv prob = 10 10 10
tc 2 wred weight = 9 9 9

tc 3 wred min = 48 40 32
tc 3 wred max = 64 64 64
tc 3 wred inv prob = 10 10 10
tc 3 wred weight = 9 9 9
```

### 17.3.1 Interactive mode

These are the commands that are currently working under the command line interface:

- ***Control commands***
  - `quit:` Quits the application.
- ***General Statistics***
  - `stats app:` Shows a table with in-app calculated statistics.
  - `stats port X subport Y:` For a specific subport, it shows the number of packets that went through the scheduler properly and the number of packets that were dropped. The same information is shown in bytes. The information is displayed in a table separating it in different traffic classes.
  - `stats port X subport Y pipe Z:` For a specific pipe, it shows the number of packets that went through the scheduler properly and the number of packets that were dropped. The same information is shown in bytes. This information is displayed in a table separating it in individual queues.
- ***Average queue size***

All of these commands work the same way, averaging the number of packets throughout a specific subset of queues.

Two parameters can be configured for this prior to calling any of these commands:

- `qavg n X:` *n* is the number of times that the calculation will take place. Bigger numbers provide higher accuracy. The default value is 10.

— `qavg period X`: *period* is the number of microseconds that will be allowed between each calculation. The default value is 100.

The commands that can be used for measuring average queue size are:

— `qavg port X subport Y`: Show average queue size per subport.

— `qavg port X subport Y tc Z`: Show average queue size per subport for a specific traffic class.

— `qavg port X subport Y pipe Z`: Show average queue size per pipe.

— `qavg port X subport Y pipe Z tc A`: Show average queue size per pipe for a specific traffic class.

— `qavg port X subport Y pipe Z tc A q B`: Show average queue size of a specific queue.

### 17.3.2 Example

The following is an example command with a single packet flow configuration:

```
./qos_sched -c a2 -n 4 -- --pfc "3,2,5,7" --cfg ./profile.cfg
```

This example uses a single packet flow configuration which creates one RX thread on lcore 5 reading from port 3 and a worker thread on lcore 7 writing to port 2.

Another example with 2 packet flow configurations using different ports but sharing the same core for QoS scheduler is given below:

```
./qos_sched -c c6 -n 4 -- --pfc "3,2,2,6,7" --pfc "1,0,2,6,7"  --cfg ./profile.cfg
```

Note that independent cores for the packet flow configurations for each of the RX, WT and TX thread are also supported, providing flexibility to balance the work.

The EAL coremask is constrained to contain the default mastercore 1 and the RX, WT and TX cores only.

## 17.4 Explanation

The Port/Subport/Pipe/Traffic Class/Queue are the hierarchical entities in a typical QoS application:

- A subport represents a predefined group of users.
- A pipe represents an individual user/subscriber.
- A traffic class is the representation of a different traffic type with a specific loss rate, delay and jitter requirements; such as data voice, video or data transfers.
- A queue hosts packets from one or multiple connections of the same type belonging to the same user.

The traffic flows that need to be configured are application dependent. This application classifies based on the QinQ double VLAN tags and the IP destination address as indicated in the following table.

**Table 2. Entity Types**

| Level Name | Siblings per Parent | QoS Functional Description | Selected By |
|---|---|---|---|
| Port | - | Ethernet port | Physical port |
| Subport | Config (8) | Traffic shaped (token bucket) | Outer VLAN tag |
| Pipe | Config (4k) | Traffic shaped (token bucket) | Inner VLAN tag |
| Traffic class (TC) | 4 | TCs of the same pipe services in strict priority | Destination IP address (0.0.X.0) |
| Queue | 4 | Queue of the same TC serviced in WRR | Destination IP address (0.0.0.X) |

Please refer to the "QoS Scheduler" chapter in the *Intel® DPDK Programmer's Guide - Rel 1.4 EAR* for more information about this parameters.

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# 18.0 Intel® QuickAssist Technology Sample Application

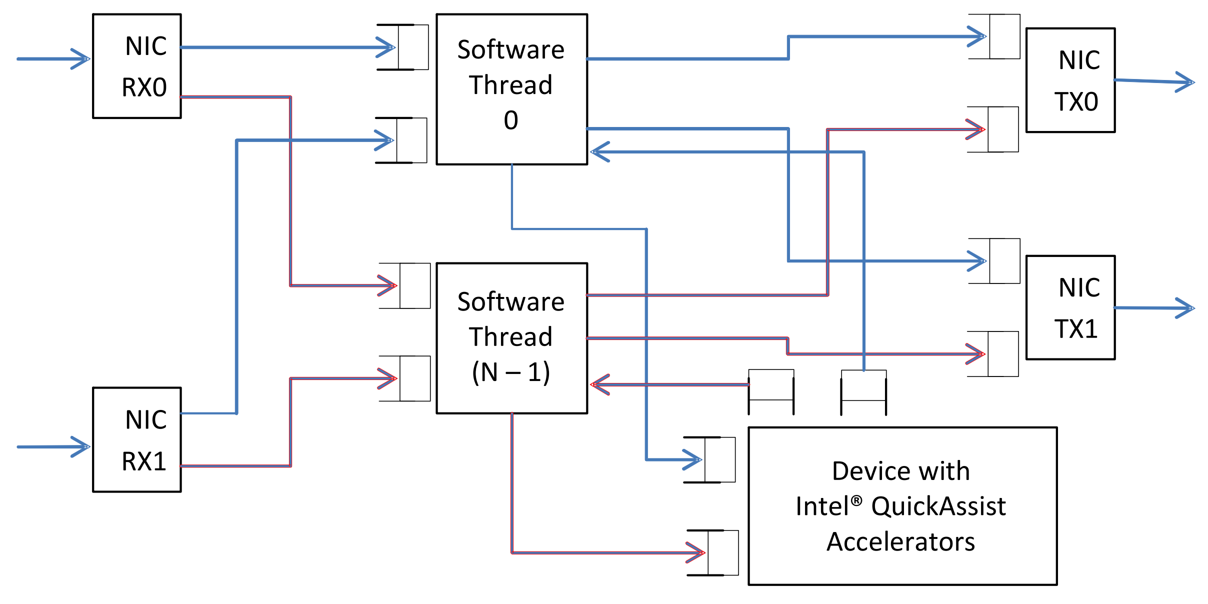
This sample application demonstrates the use of the cryptographic operations provided by the Intel® QuickAssist Technology from within the Intel® DPDK environment. Therefore, building and running this application requires having both the Intel® DPDK and the QuickAssist Technology Software Library installed, as well as at least one Intel® QuickAssist Technology hardware device present in the system.

For this sample application, there is a dependency on the Intel® Communications Chipset 89xx Series Software for Linux* package. See the *Intel® Communications Chipset 89xx Series Software for Linux* and Gettting Started Guide - Download Instructions* (document number 494547).

## 18.1 Overview

An overview of the application is provided in Figure 11. For simplicity, only two NIC ports and one Intel® QuickAssist Technology device are shown in this diagram, although the number of NIC ports and Intel® QuickAssist Technology devices can be different.

**Figure 11. Intel® QuickAssist Technology Application Block Diagram**




**Note**: Lines in blue show the packet flow for Software Thread 0, and lines in red show the packet flow for Software Thread (N – 1).

The application allows the configuration of the following items:

- Number of NIC ports
- Number of logical cores (lcores)
- Mapping of NIC RX queues to logical cores

Each lcore communicates with every cryptographic acceleration engine in the system through a pair of dedicated input – output queues. Each lcore has a dedicated NIC TX queue with every NIC port in the system. Therefore, each lcore reads packets from its NIC RX queues and cryptographic accelerator output queues and writes packets to its NIC TX queues and cryptographic accelerator input queues.

Each incoming packet that is read from a NIC RX queue is either directly forwarded to its destination NIC TX port (forwarding path) or first sent to one of the Intel® QuickAssist Technology devices for either encryption or decryption before being sent out on its destination NIC TX port (cryptographic path).

The application supports IPv4 input packets only. For each input packet, the decision between the forwarding path and the cryptographic path is taken at the classification stage based on the value of the IP source address field read from the input packet. Assuming that the IP source address is A.B.C.D, then if:

- D = 0: the forwarding path is selected (the packet is forwarded out directly)
- D = 1: the cryptographic path for encryption is selected (the packet is first encrypted and then forwarded out)
- D = 2: the cryptographic path for decryption is selected (the packet is first decrypted and then forwarded out)

For the cryptographic path cases (D = 1 or D = 2), byte C specifies the cipher algorithm and byte B the cryptographic hash algorithm to be used for the current packet. Byte A is not used and can be any value. The cipher and cryptographic hash algorithms supported by this application are listed in the `crypto.h` header file.

For each input packet, the destination NIC TX port is decided at the forwarding stage (executed after the cryptographic stage, if enabled for the packet) by looking at the RX port index of the `dst_ports[ ]` array, which was initialized at startup, being the outport the adjacent enabled port. For example, if ports 1,3,5 and 6 are enabled, for input port 1, outport port will be 3 and vice versa, and for input port 5, output port will be 6 and vice versa.

For the cryptographic path, it is the payload of the IPv4 packet that is encrypted or decrypted.

### 18.1.1 Setup

Building and running this application requires having both the Intel® DPDK package and the QuickAssist Technology Software Library installed, as well as at least one Intel® QuickAssist Technology hardware device present in the system.

For more details on how to build and run Intel® DPDK and Intel® QuickAssist Technology applications, please refer to the following documents:

- *Intel® DPDK Getting Started Guide*
- *Intel® Communications Chipset 89xx Series Software for Linux* and Gettting Started Guide - Download Instructions* (document number 494547)
- *Intel® Communications Chipset 89xx Series Software for Linux* Getting Started Guide* (440005)

For more details on the actual platforms used to validate this application, as well as performance numbers, please refer to the Test Report, which is accessible by contacting your Intel representative.

## 18.2 Building the Application

Steps to build the application:

1. Set up the following environment variables:

```
export RTE_SDK=<Absolute path to the Intel DPDK installation folder>
export ICP_ROOT=<Absolute path to the Intel QAT installation folder>
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   Refer to the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
cd ${RTE_SDK}/examples/dpdk_qat
make
```

## 18.3 Running the Application

### 18.3.1 Intel® QuickAssist Technology Configuration Files

The Intel® QuickAssist Technology configuration files used by the application are located in the `config_files` folder in the application folder. There are two sets of configuration files available for different Intel Customer Reference Boards (CRBs):

- Stargo CRB (single CPU socket): located in the `stargo` folder
  - `dh89xxcc_qa_dev0.conf`
- Shumway CRB (dual CPU socket): located in the `shumway` folder.
  - `dh89xxcc_qa_dev0.conf`
  - `dh89xxcc_qa_dev1.conf`

*Note:* The configuration files mentioned above are intended for CRBs with on-board accelerators only. For CRBs with plug-in cards (CPICs) that contain additional Intel® QuickAssist Technology accelerators, additional configuration files are required. See the *Cave Creek Plug-in Card (CPIC) User's Guide*.

The relevant configuration file(s) must be copied to the `/etc/` directory.

Please note that any change to these configuration files requires restarting the Intel® QuickAssist Technology driver using the following command:

```
# service qat_service restart
```

Refer to the *Intel® Communications Chipset 89xx Series Software Programmer's Guide* and the *Intel® Communications Chipset 89xx Series Software for Linux* Getting Started Guide* for information on the Intel® QuickAssist Technology configuration files.

### 18.3.2 Traffic Generator Setup and Application Startup

The application has a number of command line options:

```
dpdk_qat [EAL options] -- -p PORTMASK [--no-promisc]
         [--config '(port,queue,lcore)[,(port,queue,lcore)]']
```

where,

- `-p PORTMASK`: Hexadecimal bitmask of ports to configure
- `--no-promisc`: Disables promiscuous mode for all ports, so that only packets with the Ethernet MAC destination address set to the Ethernet address of the port are accepted. By default promiscuous mode is enabled so that packets are accepted regardless of the packet's Ethernet MAC destination address.
- `--config'(port,queue,lcore)[,(port,queue,lcore)]'`: determines which queues from which ports are mapped to which cores.

Refer to the *L3 Forwarding Sample Application User Guide* (482251) for more detailed descriptions of the '--config' command line option.

As an example, to run the application with two ports and two cores, which are using different Intel® QuickAssist Technology execution engines, performing AES-CBC-128 encryption with AES-XCBC-MAC-96 hash, the following settings can be used:

- Traffic generator source IP address: 0.9.6.1
- Command line:

```
./build/dpdk_qat -c 0xff -n 2 -- -p 0x3 --config '(0,0,1),(1,0,2)'
```

Refer to the *Intel® DPDK Test Report* (450257) for more examples of traffic generator setup and the application startup command lines. If no errors are generated in response to the startup commands, the application is running correctly.

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# 19.0 Quota and Watermark Sample Application

The Quota and Watermark sample application is a simple example of packet processing using Intel® Data Plane Development Kit (Intel® DPDK) that showcases the use of a quota as the maximum number of packets enqueue/dequeue at a time and low and high watermarks to signal low and high ring usage respectively.

Additionally, it shows how ring watermarks can be used to feedback congestion notifications to data producers by temporarily stopping processing overloaded rings and sending Ethernet flow control frames.

This sample application is split in two parts:

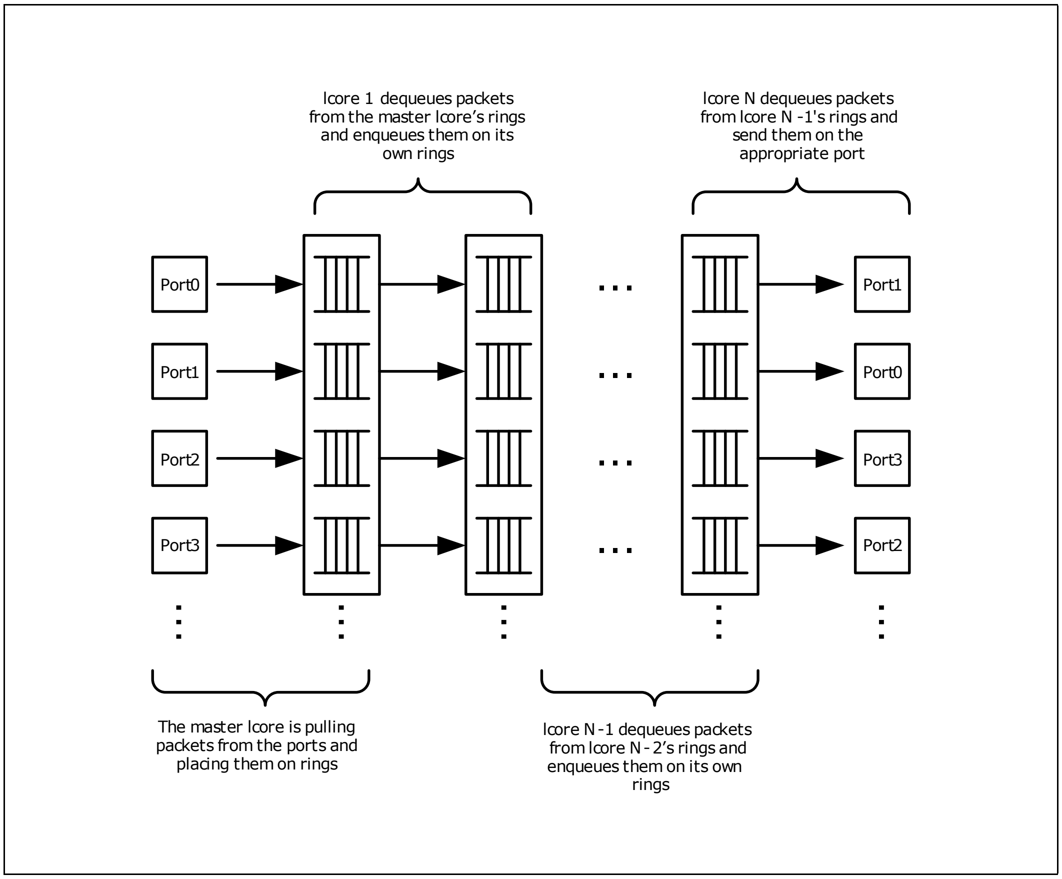
- qw - The core quota and watermark sample application
- qwctl - A command line tool to alter quota and watermarks while qw is running

## 19.1 Overview

The Quota and Watermark sample application performs forwarding for each packet that is received on a given port. The destination port is the adjacent port from the enabled port mask, that is, if the first four ports are enabled (port mask 0xf), ports 0 and 1 forward into each other, and ports 2 and 3 forward into each other. The MAC addresses of the forwarded Ethernet frames are not affected.

Internally, packets are pulled from the ports by the master logical core and put on a variable length processing pipeline, each stage of which being connected by rings, as shown in Figure 12.

## Figure 12. Pipeline Overview



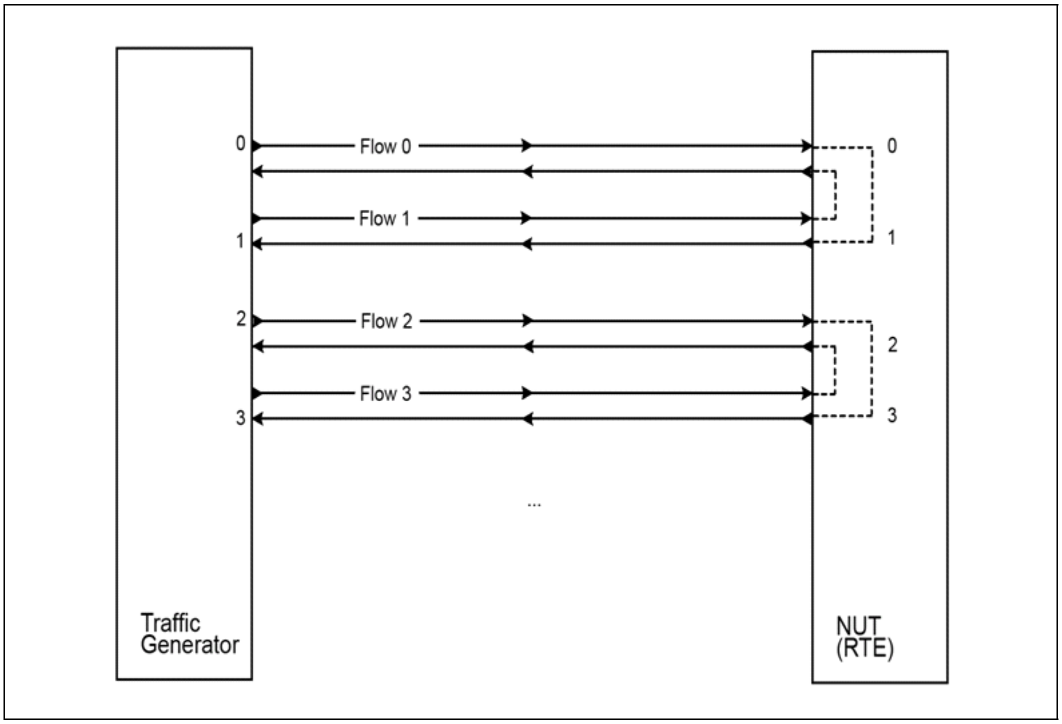

An adjustable quota value controls how many packets are being moved through the pipeline per enqueue and dequeue. Adjustable watermark values associated with the rings control a back-off mechanism that tries to prevent the pipeline from being overloaded by:

- Stopping enqueuing on rings for which the usage has crossed the high watermark threshold
- Sending Ethernet pause frames
- Only resuming enqueuing on a ring once its usage goes below a global low watermark threshold

This mechanism allows congestion notifications to go up the ring pipeline and eventually lead to an Ethernet flow control frame being send to the source.

On top of serving as an example of quota and watermark usage, this application can be used to benchmark ring based processing pipelines performance using a traffic-generator, as shown in Figure 13.

**Figure 13. Ring-based Processing Pipeline Performance Setup**




## 19.2 Compiling the Application

1. Go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/quota_watermark
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 19.3 Running the Application

The core application, `qw`, has to be started first.

Once it is up and running, one can alter quota and watermarks while it runs using the control application, `qwctl`.

### 19.3.1 Running the Core Application

The application requires a single command line option:

```
./qw/build/qw [EAL options] -- -p PORTMASK
```

where,

`-p PORTMASK`: A hexadecimal bitmask of the ports to configure

To run the application in a linuxapp environment with four logical cores and ports 0 and 2, issue the following command:

```
./qw/build/qw -c f -n 4 -- -p 5
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

### 19.3.2 Running the Control Application

The control application requires a number of command line options:

```
./qwctl/build/qwctl [EAL options] --proc-type=secondary
```

The `--proc-type=secondary` option is necessary for the EAL to properly initialize the control application to use the same huge pages as the core application and thus be able to access its rings.

To run the application in a linuxapp environment on logical core 0, issue the following command:

```
./qwctl/build/qwctl -c 1 -n 4 --proc-type=secondary
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

`qwctl` is an interactive command line that let the user change variables in a running instance of `qw`. The help command gives a list of available commands.

```
$ qwctl> help
```

## 19.4 Code Overview

The following sections provide a quick guide to the application's source code.

### 19.4.1 Core Application - qw

#### 19.4.1.1 EAL and Drivers Setup

The EAL arguments are parsed at the beginning of the `MAIN()` function:

```
ret = rte_eal_init(argc, argv);
if (ret < 0)
    rte_exit(EXIT_FAILURE, "Cannot initialize EAL\n");

argc -= ret;
argv += ret;
```

Then, a call to `init_dpdk()`, defined in `init.c`, is made to initialize the poll mode drivers:

```
void
init_dpdk(void)
{
    int ret;

    /* Initialize the PMD */
    ret = rte_pmd_init_all();
    if (ret < 0)
        rte_exit(EXIT_FAILURE, "Failed to initialize poll mode
                 drivers (error %d)\n", ret);

    /* Bind the drivers to usable devices */
    ret = rte_eal_pci_probe();
    if (ret < 0)
        rte_exit(EXIT_FAILURE, "rte_eal_pci_probe(): error
                 %d\n", ret);

    if (rte_eth_dev_count() < 2)
        rte_exit(EXIT_FAILURE, "Not enough ethernet port
                 available\n");
}
```

To fully understand this code, it is recommended to study the chapters that relate to the *Poll Mode Driver* in the *Intel® DPDK Getting Started Guide* and the *Intel® DPDK API Reference*.

### 19.4.1.2 Shared Variables Setup

The `quota` and `low_watermark` shared variables are put into an `rte_memzone` using a call to `setup_shared_variables()`:

```
void
setup_shared_variables(void)
{
    const struct rte_memzone *qw_memzone;

    qw_memzone = rte_memzone_reserve(QUOTA_WATERMARK_MEMZONE_NAME,
                                     2 * sizeof(int), rte_socket_id(),
                                     RTE_MEMZONE_2MB);
    if (qw_memzone == NULL)
        rte_exit(EXIT_FAILURE, "%s\n", rte_strerror(rte_errno));

    quota = qw_memzone->addr;
    low_watermark = (unsigned int *) qw_memzone->addr + sizeof(int);
}
```

These two variables are initialized to a default value in `MAIN()` and can be changed while `qw` is running using the `qwctl` control program.

### 19.4.1.3 Application Arguments

The `qw` application only takes one argument: a port mask that specifies which ports should be used by the application. At least two ports are needed to run the application and there should be an even number of ports given in the port mask.

The port mask parsing is done in `parse_qw_args()`, defined in `args.c`.

### 19.4.1.4 Mbuf Pool Initialization

Once the application's arguments are parsed, an mbuf pool is created. It contains a set of mbuf objects that are used by the driver and the application to store network packets:

```
/* Create a pool of mbuf to store packets */
mbuf_pool = rte_mempool_create("mbuf_pool", MBUF_PER_POOL, MBUF_SIZE, 32,
                               sizeof(struct rte_pktmbuf_pool_private),
                               rte_pktmbuf_pool_init, NULL,
                               rte_pktmbuf_init, NULL,
                               rte_socket_id(), 0);
if (mbuf_pool == NULL)
rte_panic("%s\n", rte_strerror(rte_errno));
```

The `rte_mempool` is a generic structure used to handle pools of objects. In this case, it is necessary to create a pool that will be used by the driver, which expects to have some reserved space in the `mempool` structure, `sizeof(struct rte_pktmbuf_pool_private)` bytes.

The number of allocated `pktmbufs` is `MBUF_PER_POOL`, with a size of `MBUF_SIZE` each. A per-lcore cache of 32 mbufs is kept. The memory is allocated in on the master lcore's socket, but it is possible to extend this code to allocate one mbuf pool per socket.

Two callback pointers are also given to the `rte_mempool_create()` function:

- The first callback pointer is to `rte_pktmbuf_pool_init()` and is used to initialize the private data of the mempool, which is needed by the driver. This function is provided by the mbuf API, but can be copied and extended by the developer.
- The second callback pointer given to rte_mempool_create() is the mbuf initializer.

The default is used, that is, `rte_pktmbuf_init()`, which is provided in the `rte_mbuf` library. If a more complex application wants to extend the `rte_pktmbuf` structure for its own needs, a new function derived from `rte_pktmbuf_init()` can be created.

### 19.4.1.5 Ports Configuration and Pairing

Each port in the port mask is configured and a corresponding ring is created in the master lcore's array of rings. This ring is the first in the pipeline and will hold the packets directly coming from the port.

```
for (port_id = 0; port_id < RTE_MAX_ETHPORTS; port_id++)
    if (is_bit_set(port_id, portmask)) {
        configure_eth_port(port_id);
        init_ring(master_lcore_id, port_id);
    }
pair_ports();
```

The `configure_eth_port()` and `init_ring()` functions are used to configure a port and a ring respectively and are defined in `init.c`. They make use of the Intel® DPDK APIs defined in `rte_eth.h` and `rte_ring.h`.

`pair_ports()` builds the `port_pairs[]` array so that its key-value pairs are a mapping between reception and transmission ports. It is defined in `init.c`.

### 19.4.1.6 Logical Cores Assignment

The application uses the master logical core to poll all the ports for new packets and enqueue them on a ring associated with the port.

Each logical core except the last runs `pipeline_stage()` after a ring for each used port is initialized on that core. `pipeline_stage()` on core X dequeues packets from core X-1's rings and enqueue them on its own rings. See Figure 14.

```
    /* Start pipeline_stage() on all the available slave lcore but the last */
    for (lcore_id = 0 ; lcore_id < last_lcore_id; lcore_id++) {
        if (rte_lcore_is_enabled(lcore_id) && lcore_id != master_lcore_id) {

            for (port_id = 0; port_id < RTE_MAX_ETHPORTS; port_id++)
                if (is_bit_set(port_id, portmask))
                    init_ring(lcore_id, port_id);

            rte_eal_remote_launch(pipeline_stage, NULL, lcore_id);
        }
}
```

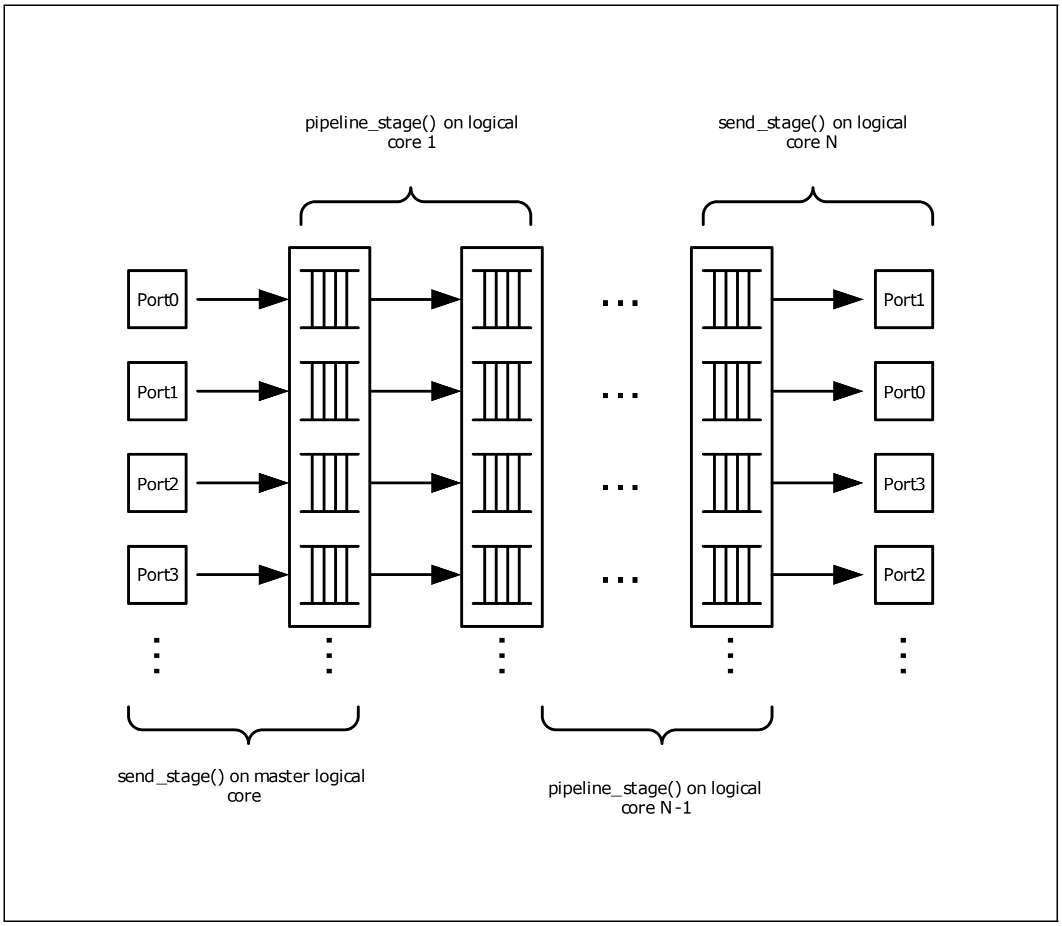
The last available logical core runs `send_stage()`, which is the last stage of the pipeline dequeuing packets from the last ring in the pipeline and sending them out on the destination port setup by `pair_ports()`.

```
    /* Start send_stage() on the last slave core */
    rte_eal_remote_launch(send_stage, NULL, last_lcore_id);
```

#### 19.4.1.7 Receive, Process and Transmit Packets

Figure 14 shows where each thread in the pipeline is. It should be used as a reference while reading the rest of this section.

**Figure 14. Threads and Pipelines**



In the `receive_stage()` function running on the master logical core, the main task is to read ingress packets from the RX ports and enqueue them on the port's corresponding first ring in the pipeline. This is done using the following code:

```
lcore_id = rte_lcore_id();

/* Process each port round robin style */
for (port_id = 0; port_id < RTE_MAX_ETHPORTS; port_id++) {

    if (!is_bit_set(port_id, portmask))
        continue;

    ring = rings[lcore_id][port_id];

    if (ring_state[port_id] != RING_READY) {
        if (rte_ring_count(ring) > *low_watermark)
            continue;
        else
            ring_state[port_id] = RING_READY;
    }

    /* Enqueue received packets on the RX ring */
    nb_rx_pkts = rte_eth_rx_burst(port_id, 0, pkts, *quota);
    ret = rte_ring_enqueue_bulk(ring, (void *) pkts, nb_rx_pkts);
    if (ret == -EDQUOT) {
        ring_state[port_id] = RING_OVERLOADED;
        send_pause_frame(port_id, 1337);
    }
}
```

For each port in the port mask, the corresponding ring's pointer is fetched into ring and that ring's state is checked:

- If it is in the RING_READY state, *quota packets are grabbed from the port and put on the ring. Should this operation make the ring's usage cross its high watermark, the ring is marked as overloaded and an Ethernet flow control frame is sent to the source.
- If it is not in the RING_READY state, this port is ignored until the ring's usage crosses the *low_watermark value.

The `pipeline_stage()` function's task is to process and move packets from the preceding pipeline stage. This thread is running on most of the logical cores to create and arbitrarily long pipeline.

```
lcore_id = rte_lcore_id();
previous_lcore_id = get_previous_lcore_id(lcore_id);

for (port_id = 0; port_id < RTE_MAX_ETHPORTS; port_id++) {

    if (!is_bit_set(port_id, portmask))
        continue;

    tx = rings[lcore_id][port_id];
    rx = rings[previous_lcore_id][port_id];

    if (ring_state[port_id] != RING_READY) {
        if (rte_ring_count(tx) > *low_watermark)
            continue;
        else
            ring_state[port_id] = RING_READY;
    }

    /* Dequeue up to quota mbuf from rx */
    nb_dq_pkts = rte_ring_dequeue_burst(rx, pkts, *quota);
    if (unlikely(nb_dq_pkts < 0))
        continue;
```

```
        /* Enqueue them on tx */
        ret = rte_ring_enqueue_bulk(tx, pkts, nb_dq_pkts);
        if (ret == -EDQUOT)
            ring_state[port_id] = RING_OVERLOADED;
    }
```

The thread's logic works mostly like `receive_stage()`, except that packets are moved from ring to ring instead of port to ring.

In this example, no actual processing is done on the packets, but `pipeline_stage()` is an ideal place to perform any processing required by the application.

Finally, the `send_stage()` function's task is to read packets from the last ring in a pipeline and send them on the destination port defined in the `port_pairs[]` array. It is running on the last available logical core only.

```
    lcore_id = rte_lcore_id();
    previous_lcore_id = get_previous_lcore_id(lcore_id);

    for (port_id = 0; port_id < RTE_MAX_ETHPORTS; port_id++) {

        if (!is_bit_set(port_id, portmask))
            continue;

        dest_port_id = port_pairs[port_id];
        tx = rings[previous_lcore_id][port_id];

        if (rte_ring_empty(tx))
            continue;

        /* Dequeue packets from tx and send them */
        nb_dq_pkts = rte_ring_dequeue_burst(tx, (void *) tx_pkts, *quota);
        nb_tx_pkts = rte_eth_tx_burst(dest_port_id, 0, tx_pkts, nb_dq_pkts);
    }
```

For each port in the port mask, up to `*quota` packets are pulled from the last ring in its pipeline and sent on the destination port paired with the current port.

## 19.4.2 Control Application - qwctl

The `qwctl` application uses the `rte_cmdline` library to provide the user with an interactive command line that can be used to modify and inspect parameters in a running qw application. Those parameters are the global quota and `low_watermark` value as well as each ring's built-in high watermark.

### 19.4.2.1 Command Definitions

The available commands are defined in `commands.c`.

It is advised to use the `cmdline` sample application user guide as a reference for everything related to the `rte_cmdline` library.

### 19.4.2.2 Accessing Shared Variables

The `setup_shared_variables()` function retrieves the shared variables quota and `low_watermark` from the `rte_memzone` previously created by `qw`.

```
    static void
    setup_shared_variables(void)
    {
        const struct rte_memzone *qw_memzone;
```

```
    qw_memzone = rte_memzone_lookup(QUOTA_WATERMARK_MEMZONE_NAME);
    if (qw_memzone == NULL)
        rte_exit(EXIT_FAILURE, "Couldn't find memzone\n");

    quota = qw_memzone->addr;
    low_watermark = (unsigned int *) qw_memzone->addr + sizeof(int);
}
```

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# 20.0 Timer Sample Application

The Timer sample application is a simple application that demonstrates the use of a timer in an Intel® DPDK application. This application prints some messages from different lcores regularly, demonstrating the use of timers.

## 20.1 Compiling the Application

1. Go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/timer
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

   See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 20.2 Running the Application

To run the example in linuxapp environment:

```
$ ./build/timer -c f -n 4
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 20.3 Explanation

The following sections provide some explanation of the code.

### 20.3.1 Initialization and Main Loop

In addition to EAL initialization, the timer subsystem must be initialized, by calling the `rte_timer_subsystem_init()` function.

```
/* init EAL */
ret = rte_eal_init(argc, argv);
if (ret < 0)
    rte_panic("Cannot init EAL\n");

/* init RTE timer library */
rte_timer_subsystem_init();
```

After timer creation (see the next paragraph), the main loop is executed on each slave lcore using the well-known `rte_eal_remote_launch()` and also on the master.

```
/* call lcore_mainloop() on every slave lcore */
RTE_LCORE_FOREACH_SLAVE(lcore_id) {
rte_eal_remote_launch(lcore_mainloop, NULL, lcore_id);
}

/* call it on master lcore too */
(void) lcore_mainloop(NULL);
```

The main loop is very simple in this example:

```
while (1) {
    /*
     * Call the timer handler on each core: as we don't
     * need a very precise timer, so only call
     * rte_timer_manage() every ~10ms (at 2 Ghz). In a real
     * application, this will enhance performances as
     * reading the HPET timer is not efficient.
     */
    cur_tsc = rte_rdtsc();
    diff_tsc = cur_tsc - prev_tsc;
    if (diff_tsc > TIMER_RESOLUTION_CYCLES) {
        rte_timer_manage();
        prev_tsc = cur_tsc;
    }
}
```

As explained in the comment, it is better to use the *TSC* register (as it is a per-lcore register) to check if the `rte_timer_manage()` function must be called or not. In this example, the resolution of the timer is 10 milliseconds.

### 20.3.2 Managing Timers

In the `main()` function, the two timers are initialized. This call to `rte_timer_init()` is necessary before doing any other operation on the timer structure.

```
/* init timer structures */
rte_timer_init(&timer0);
rte_timer_init(&timer1);
```

Then, the two timers are configured:

- The first timer (`timer0`) is loaded on the master lcore and expires every second. Since the `PERIODICAL` flag is provided, the timer is reloaded automatically by the timer subsystem. The callback function is `timer0_cb()`.
- The second timer (`timer1`) is loaded on the next available lcore every 333 ms. The `SINGLE` flag means that the timer expires only once and must be reloaded manually if required. The callback function is `timer1_cb()`.

```
/* load timer0, every second, on master lcore, reloaded automatically */
hz = rte_get_hpet_hz();
lcore_id = rte_lcore_id();
rte_timer_reset(&timer0, hz, PERIODICAL, lcore_id, timer0_cb, NULL);

/* load timer1, every second/3, on next lcore, reloaded manually */
lcore_id = rte_get_next_lcore(lcore_id, 0, 1);
rte_timer_reset(&timer1, hz/3, SINGLE, lcore_id, timer1_cb, NULL);
```

The callback for the first timer (`timer0`) only displays a message until a global counter reaches 20 (after 20 seconds). In this case, the timer is stopped using the `rte_timer_stop()` function.

```
/* timer0 callback */
static void
timer0_cb(__attribute__((unused)) struct rte_timer *tim,
          __attribute__((unused)) void *arg)
{
    static unsigned counter = 0;
    unsigned lcore_id = rte_lcore_id();

    printf("%s() on lcore %u\n", __FUNCTION__, lcore_id);

    /* this timer is automatically reloaded until we decide to
     * stop it, when counter reaches 20. */
    if ((counter ++) == 20)
        rte_timer_stop(tim);
}
```

The callback for the second timer (`timer1`) displays a message and reloads the timer on the next lcore, using the `rte_timer_reset()` function:

```
/* timer1 callback */
static void
timer1_cb(__attribute__((unused)) struct rte_timer *tim,
          __attribute__((unused)) void *arg)
{
    unsigned lcore_id = rte_lcore_id();
    uint64_t hz;

    printf("%s() on lcore %u\n", __FUNCTION__, lcore_id);

    /* reload it on another lcore */
    hz = rte_get_hpet_hz();
    lcore_id = rte_get_next_lcore(lcore_id, 0, 1);
    rte_timer_reset(&timer1, hz/3, SINGLE, lcore_id, timer1_cb, NULL);
}
```

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# 21.0 VMDQ and DCB Forwarding Sample Application

The VMDQ and DCB Forwarding sample application is a simple example of packet processing using the Intel® DPDK. The application performs L2 forwarding using VMDQ and DCB to divide the incoming traffic into 128 queues. The traffic splitting is performed in hardware by the VMDQ and DCB features of the Intel® 82599 10 Gigabit Ethernet Controller.

## 21.1 Overview

This sample application can be used as a starting point for developing a new application that is based on the Intel® DPDK and uses VMDQ and DCB for traffic partitioning.

The VMDQ and DCB filters work on VLAN traffic to divide the traffic into 128 input queues on the basis of the VLAN ID field and VLAN user priority field. VMDQ filters split the traffic into 16 or 32 groups based on the VLAN ID. Then, DCB places each packet into one of either 4 or 8 queues within that group, based upon the VLAN user priority field.

In either case, 16 groups of 8 queues, or 32 groups of 4 queues, the traffic can be split into 128 hardware queues on the NIC, each of which can be polled individually by an Intel® DPDK application.

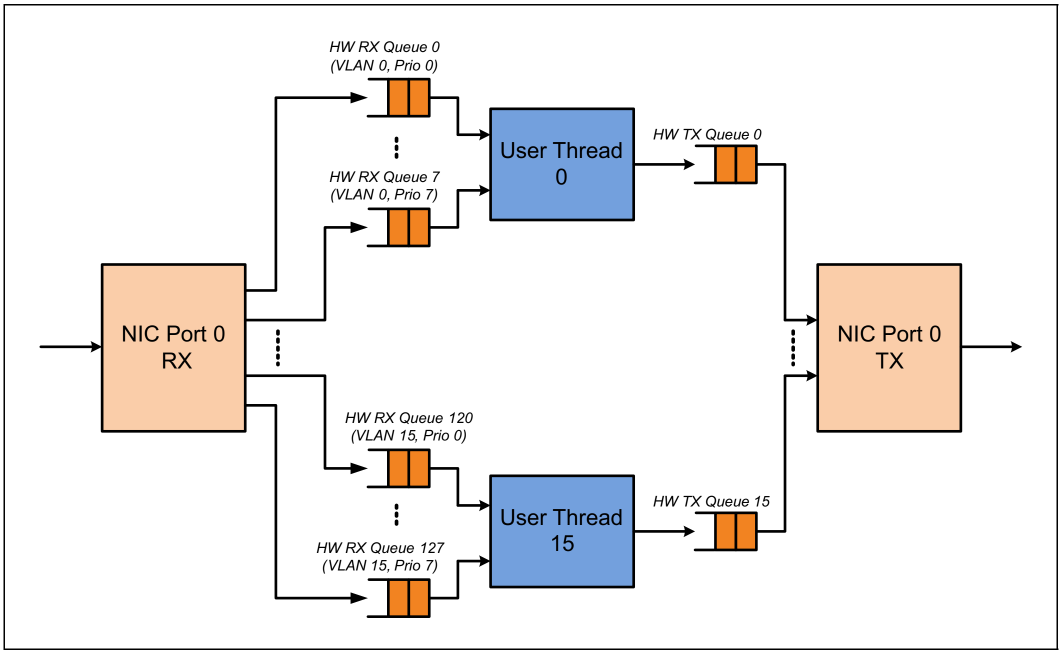
All traffic is read from a single incoming port (port 0) and output on port 1, without any processing being performed. The traffic is split into 128 queues on input, where each thread of the application reads from multiple queues. For example, when run with 8 threads, that is, with the `-c FF` option, each thread receives and forwards packets from 16 queues.

As supplied, the sample application configures the VMDQ feature to have 16 pools with 8 queues each as indicated in Figure 15. The Intel® 82599 10 Gigabit Ethernet Controller NIC also supports the splitting of traffic into 32 pools of 4 queues each and this can be used by changing the `NUM_POOLS` parameter in the supplied code. The `NUM_POOLS` parameter can be passed on the command line, after the EAL parameters:

```
./build/vmdq_dcb [EAL options] -- -p PORTMASK --nb-pools NP
```

where, NP can be 16 or 32.

**Figure 15. Packet Flow Through the VMDQ and DCB Sample Application**




In Linux* user space, the application can display statistics with the number of packets received on each queue. To have the application display the statistics, send a `SIGHUP` signal to the running application process, as follows:

```
kill -HUP <pid>
```

where, `<pid>` is the process id of the application process.

The VMDQ and DCB Forwarding sample application is in many ways simpler than the L2 Forwarding application (see Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)") as it performs unidirectional L2 forwarding of packets from one port to a second port. No command-line options are taken by this application apart from the standard EAL command-line options.

*Note:* Since VMD queues are being used for VMM, this application works correctly when VTd is disabled in the BIOS or Linux* kernel (`intel_iommu=off`).

## 21.2 Compiling the Application

1. Go to the examples directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/examples/vmdq_dcb
```

2. Set the target (a default target is used if not specified). For example:

```
export RTE_TARGET=x86_64-default-linuxapp-gcc
```

See the *Intel® DPDK Getting Started Guide* for possible `RTE_TARGET` values.

3. Build the application:

```
make
```

## 21.3 Running the Application

To run the example in a linuxapp environment:

```
user@target:~$ ./build/vmdq_dcb -c f -n 4 -- -p 0x3 --nb-pools 16
```

Refer to the *Intel® DPDK Getting Started Guide* for general information on running applications and the Environment Abstraction Layer (EAL) options.

## 21.4 Explanation

The following sections provide some explanation of the code.

### 21.4.1 Initialization

The EAL, driver and PCI configuration is performed largely as in the L2 Forwarding sample application, as is the creation of the mbuf pool. See Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)". Where this example application differs is in the configuration of the NIC port for RX.

The VMDQ and DCB hardware feature is configured at port initialization time by setting the appropriate values in the `rte_eth_conf` structure passed to the `rte_eth_dev_configure()` API. Initially in the application, a default structure is provided for VMDQ and DCB configuration to be filled in later by the application.

```
/* empty vmdq+dcb configuration structure. Filled in programatically */
static const struct rte_eth_conf vmdq_dcb_conf_default = {
    .rxmode = {
        .mq_mode        = ETH_VMDQ_DCB,
        .split_hdr_size = 0,
        .header_split   = 0, /**< Header Split disabled */
        .hw_ip_checksum = 0, /**< IP checksum offload disabled */
        .hw_vlan_filter = 0, /**< VLAN filtering disabled */
        .jumbo_frame    = 0, /**< Jumbo Frame Support disabled */
    },
    .txmode = {
        .mq_mode = ETH_DCB_NONE,
         },
    .rx_adv_conf = {
        /*
         * should be overridden separately in code with
         * appropriate values
         */
    .vmdq_dcb_conf = {
        .nb_queue_pools = ETH_16_POOLS,
        .enable_default_pool = 0,
        .default_pool = 0,
        .nb_pool_maps = 0,
        .pool_map = {{0, 0},},
        .dcb_queue = {0},
        },
    },
};
```

The `get_eth_conf()` function fills in an `rte_eth_conf` structure with the appropriate values, based on the global `vlan_tags` array, and dividing up the possible user priority values equally among the individual queues (also referred to as *traffic classes*) within each pool, that is, if the number of pools is 32, then the user priority fields are allocated two to a queue. If 16 pools are used, then each of the 8 user priority fields is allocated to its own queue within the pool. For the VLAN IDs, each one can be allocated to possibly multiple pools of queues, so the `pools` parameter in the `rte_eth_vmdq_dcb_conf` structure is specified as a bitmask value.

```
const uint16_t vlan_tags[] = {
    0,  1,  2,  3,  4,  5,  6,  7,
    8,  9, 10, 11,  12, 13, 14, 15,
    16, 17, 18, 19, 20, 21, 22, 23,
    24, 25, 26, 27, 28, 29, 30, 31
};

    /* Builds up the correct configuration for vmdq+dcb based on the vlan tags array
     * given above, and the number of traffic classes available for use. */

static inline int
get_eth_conf(struct rte_eth_conf *eth_conf, enum rte_eth_nb_pools num_pools)
{
    struct rte_eth_vmdq_dcb_conf conf;
    unsigned i;

    if (num_pools != ETH_16_POOLS && num_pools != ETH_32_POOLS ) return -1;

        conf.nb_queue_pools = num_pools;
        conf.enable_default_pool = 0;
        conf.default_pool = 0; /* set explicit value, even if not used */
        conf.nb_pool_maps = sizeof( vlan_tags )/sizeof( vlan_tags[ 0 ]);
        for (i = 0; i < conf.nb_pool_maps; i++){
            conf.pool_map[i].vlan_id = vlan_tags[ i ];
            conf.pool_map[i].pools = 1 << (i % num_pools);
        }
        for (i = 0; i < ETH_DCB_NUM_USER_PRIORITIES; i++){
             conf.dcb_queue[i] = (uint8_t)(i % (NUM_QUEUES/num_pools));
        }
        (void) rte_memcpy(eth_conf, &vmdq_dcb_conf_default, sizeof(*eth_conf));
        (void) rte_memcpy(&eth_conf->rx_adv_conf.vmdq_dcb_conf, &conf,
                   sizeof(eth_conf->rx_adv_conf.vmdq_dcb_conf));
    return 0;
}
```

Once the network port has been initialized using the correct VMDQ and DCB values, the initialization of the port's RX and TX hardware rings is performed similarly to that in the L2 Forwarding sample application. See Chapter 9.0, "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for more information.

### 21.4.2 Statistics Display

When run in a linuxapp environment, the VMDQ and DCB Forwarding sample application can display statistics showing the number of packets read from each RX queue. This is provided by way of a signal handler for the `SIGHUP` signal, which simply prints to standard output the packet counts in grid form. Each row of the output is a single pool with the columns being the queue number within that pool.

To generate the statistics output, use the following command:

```
user@host$ sudo killall -HUP vmdq_dcb_app
```

Please note that the statistics output will appear on the terminal where the `vmdq_dcb_app` is running, rather than the terminal from which the `HUP` signal was sent.

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