DPDK

DATA PLANE DEVELOPMENT KIT

Sample Applications User Guide

Release 2.2.0

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CHAPTER

ONE

INTRODUCTION

This document describes the sample applications that are included in the Data Plane Development Kit (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 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 Guides** : Describes how to install and configure the DPDK software for your operating system; 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 DPDK, the build system (including the commands that can be used in the root 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 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.

CHAPTER

TWO

COMMAND LINE SAMPLE APPLICATION

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

2.1 Overview

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

Note: 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-native-linuxapp-gcc
   ```

   Refer to the *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 *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 cmd line_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 ((unusec
{
   /* ... */
}

cmdline_parse_token_string_t cmd_obj_action = TOKEN_STRING_INITIALIZER(struct cmd_obj_del_show_

parse_token_obj_list_t cmd_obj_obj = TOKEN_OBJ_LIST_INITIALIZER(struct cmd_obj_del_show_result,

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.

CHAPTER

THREE

ETHTOOL SAMPLE APPLICATION

The Ethtool sample application shows an implementation of an ethtool-like API and provides a console environment that allows its use to query and change Ethernet card parameters. The sample is based upon a simple L2 frame reflector.

3.1 Compiling the Application

To compile the application:

1. Go to the sample application directory:

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

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

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

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

3. Build the application:

   ```
   make
   ```

3.2 Running the Application

The application requires an available core for each port, plus one. The only available options are the standard ones for the EAL:

```
./ethtool-app/ethtool-app/${RTE_TARGET}/ethtool [EAL options]
```

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

3.3 Using the application

The application is console-driven using the cmdline DPDK interface:

```
EthApp>
```

From this interface the available commands and descriptions of what they do as as follows:

- `drvinfo`: Print driver info

- `eeprom`: Dump EEPROM to file
- `link`: Print port link states
- `macaddr`: Gets/sets MAC address
- `mtu`: Set NIC MTU
- `open`: Open port
- `pause`: Get/set port pause state
- `portstats`: Print port statistics
- `regs`: Dump port register(s) to file
- `ringparam`: Get/set ring parameters
- `rxmode`: Toggle port Rx mode
- `stop`: Stop port
- `validate`: Check that given MAC address is valid unicast address
- `vlan`: Add/remove VLAN id
- `quit`: Exit program

3.4 Explanation

The sample program has two parts: A background *packet reflector* that runs on a slave core, and a foreground *Ethtool Shell* that runs on the master core. These are described below.

3.4.1 Packet Reflector

The background packet reflector is intended to demonstrate basic packet processing on NIC ports controlled by the Ethtool shim. Each incoming MAC frame is rewritten so that it is returned to the sender, using the port in question's own MAC address as the source address, and is then sent out on the same port.

3.4.2 Ethtool Shell

The foreground part of the Ethtool sample is a console-based interface that accepts commands as described in *using the application*. Individual call-back functions handle the detail associated with each command, which make use of the functions defined in the *Ethtool interface* to the DPDK functions.

3.5 Ethtool interface

The Ethtool interface is built as a separate library, and implements the following functions:

- `rte_ethtool_get_drvinfo()`
- `rte_ethtool_get_regs_len()`

- `rte_ethtool_get_regs()`
- `rte_ethtool_get_link()`
- `rte_ethtool_get_eeprom_len()`
- `rte_ethtool_get_eeprom()`
- `rte_ethtool_set_eeprom()`
- `rte_ethtool_get_pauseparam()`
- `rte_ethtool_set_pauseparam()`
- `rte_ethtool_net_open()`
- `rte_ethtool_net_stop()`
- `rte_ethtool_net_get_mac_addr()`
- `rte_ethtool_net_set_mac_addr()`
- `rte_ethtool_net_validate_addr()`
- `rte_ethtool_net_change_mtu()`
- `rte_ethtool_net_get_stats64()`
- `rte_ethtool_net_vlan_rx_add_vid()`
- `rte_ethtool_net_vlan_rx_kill_vid()`
- `rte_ethtool_net_set_rx_mode()`
- `rte_ethtool_get_ringparam()`
- `rte_ethtool_set_ringparam()`

CHAPTER

FOUR

EXCEPTION PATH SAMPLE APPLICATION

The Exception Path sample application is a simple example that demonstrates the use of the 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 DPDK application and appear to the kernel as a standard network interface.

4.1 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.

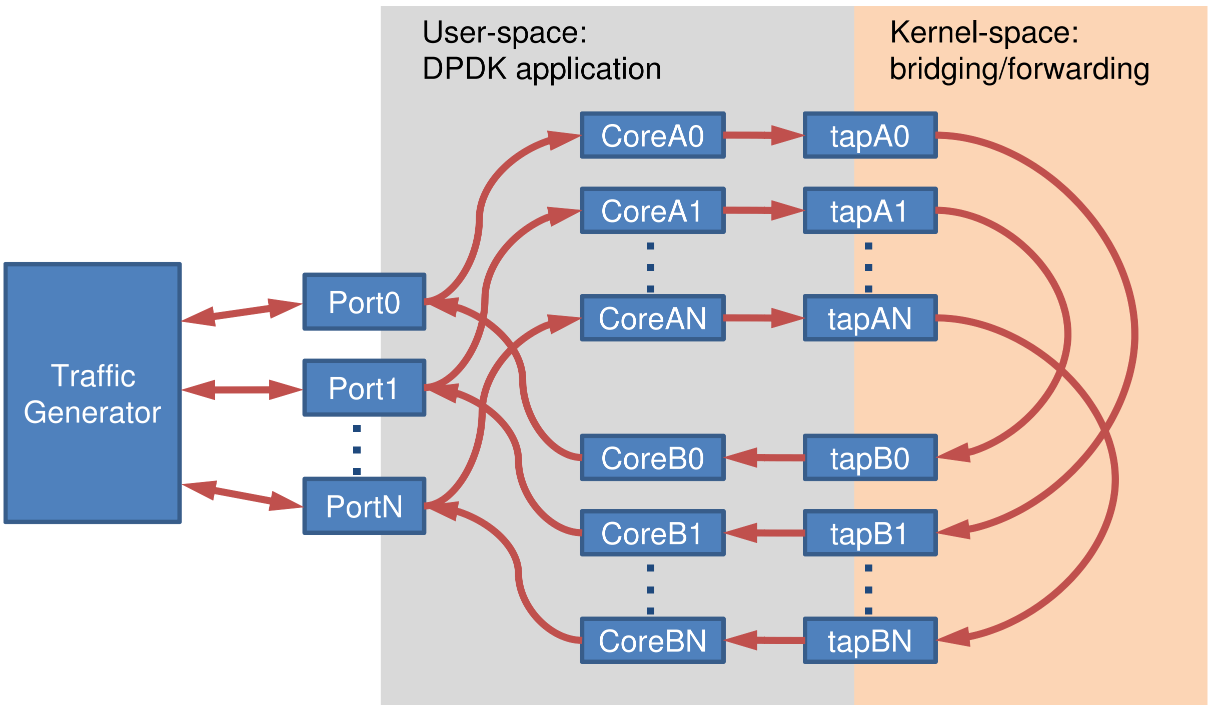


Fig. 4.1: Packet Flow

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

4.2 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-native-linuxapp-gcc
   ```

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

1. Build the application:

   ```
   make
   ```

4.3 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 *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
```

4.3.1 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.

4.4 Explanation

The following sections provide some explanation of the code.

4.4.1 Initialization

Setup of the mbuf pool, driver and queues is similar to the setup done in the L2 Forwarding sample application (see Chapter 9 "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, IFNAMSIZ, name);

    ret = ioctl(fd, TUNSETIFF, (void *) &ifr);

    if (ret < 0) {
        close(fd);
        return ret;

    }

    if (name)
        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 & (1ULL << 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 & (1ULL << 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++;
     }
}
```

4.4.2 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”). 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.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 section that follows.

4.4.3 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
```

CHAPTER

FIVE

HELLO WORLD SAMPLE APPLICATION

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

5.1 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-native-linuxapp-gcc
   ```

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

3. Build the application:

   ```
   make
   ```

5.2 Running the Application

To run the example in a linuxapp environment:

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

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

5.3 Explanation

The following sections provide some explanation of code.

5.3.1 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.

5.3.2 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 *DPDK API Reference* for detailed information on the rte_eal_mp_remote_launch() function.

CHAPTER

SIX

BASIC FORWARDING SAMPLE APPLICATION

The Basic Forwarding sample application is a simple *skeleton* example of a forwarding application.

It is intended as a demonstration of the basic components of a DPDK forwarding application. For more detailed implementations see the L2 and L3 forwarding sample applications.

6.1 Compiling the Application

To compile the application export the path to the DPDK source tree and go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk

cd ${RTE_SDK}/examples/skeleton
```

Set the target, for example:

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

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

Build the application as follows:

```
make
```

6.2 Running the Application

To run the example in a `linuxapp` environment:

```
./build/basicfwd -c 2 -n 4
```

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

6.3 Explanation

The following sections provide an explanation of the main components of the code.

All DPDK library functions used in the sample code are prefixed with `rte_` and are explained in detail in the *DPDK API Documentation*.

6.3.1 The Main Function

The `main()` function performs the initialization and calls the execution threads for each lcore.

The first task is to initialize the Environment Abstraction Layer (EAL). The `argc` and `argv` arguments are provided to the `rte_eal_init()` function. The value returned is the number of parsed arguments:

```
int ret = rte_eal_init(argc, argv);
if (ret < 0)
    rte_exit(EXIT_FAILURE, "Error with EAL initialization\n");
```

The `main()` also allocates a mempool to hold the mbufs (Message Buffers) used by the application:

```
mbuf_pool = rte_mempool_create("MBUF_POOL",
                               NUM_MBUFS * nb_ports,
                               MBUF_SIZE,
                               MBUF_CACHE_SIZE,
                               sizeof(struct rte_pktmbuf_pool_private),
                               rte_pktmbuf_pool_init, NULL,
                               rte_pktmbuf_init,      NULL,
                               rte_socket_id(),
                               0);
```

Mbufs are the packet buffer structure used by DPDK. They are explained in detail in the "Mbuf Library" section of the *DPDK Programmer's Guide*.

The `main()` function also initializes all the ports using the user defined `port_init()` function which is explained in the next section:

```
for (portid = 0; portid < nb_ports; portid++) {
    if (port_init(portid, mbuf_pool) != 0) {
        rte_exit(EXIT_FAILURE,
                 "Cannot init port %" PRIu8 "\n", portid);
    }
}
```

Once the initialization is complete, the application is ready to launch a function on an lcore. In this example `lcore_main()` is called on a single lcore.

```
lcore_main();
```

The `lcore_main()` function is explained below.

6.3.2 The Port Initialization Function

The main functional part of the port initialization used in the Basic Forwarding application is shown below:

```
static inline int
port_init(uint8_t port, struct rte_mempool *mbuf_pool)
{
    struct rte_eth_conf port_conf = port_conf_default;
    const uint16_t rx_rings = 1, tx_rings = 1;
    struct ether_addr addr;
    int retval;
    uint16_t q;

    if (port >= rte_eth_dev_count())
        return -1;
    /* Configure the Ethernet device. */
    retval = rte_eth_dev_configure(port, rx_rings, tx_rings, &port_conf);
    if (retval != 0)
        return retval;

    /* Allocate and set up 1 RX queue per Ethernet port. */
    for (q = 0; q < rx_rings; q++) {
        retval = rte_eth_rx_queue_setup(port, q, RX_RING_SIZE,
                rte_eth_dev_socket_id(port), NULL, mbuf_pool);
        if (retval < 0)
            return retval;
    }

    /* Allocate and set up 1 TX queue per Ethernet port. */
    for (q = 0; q < tx_rings; q++) {
        retval = rte_eth_tx_queue_setup(port, q, TX_RING_SIZE,
                rte_eth_dev_socket_id(port), NULL);
        if (retval < 0)
            return retval;
    }

    /* Start the Ethernet port. */
    retval = rte_eth_dev_start(port);
    if (retval < 0)
        return retval;

    /* Enable RX in promiscuous mode for the Ethernet device. */
    rte_eth_promiscuous_enable(port);

    return 0;
}
```

The Ethernet ports are configured with default settings using the `rte_eth_dev_configure()` function and the `port_conf_default` struct:

```
static const struct rte_eth_conf port_conf_default = {
    .rxmode = { .max_rx_pkt_len = ETHER_MAX_LEN }
};
```

For this example the ports are set up with 1 RX and 1 TX queue using the `rte_eth_rx_queue_setup()` and `rte_eth_tx_queue_setup()` functions.

The Ethernet port is then started:

```
retval  = rte_eth_dev_start(port);
```

Finally the RX port is set in promiscuous mode:

```
rte_eth_promiscuous_enable(port);
```

6.3.3 The Lcores Main

As we saw above the `main()` function calls an application function on the available lcores. For the Basic Forwarding application the lcore function looks like the following:

```
static __attribute__((noreturn)) void
lcore_main(void)
{
    const uint8_t nb_ports = rte_eth_dev_count();
    uint8_t port;

    /*
     * Check that the port is on the same NUMA node as the polling thread
```

```
         * for best performance.
         */
        for (port = 0; port < nb_ports; port++)
            if (rte_eth_dev_socket_id(port) > 0 &&
                    rte_eth_dev_socket_id(port) !=
                            (int)rte_socket_id())
                printf("WARNING, port %u is on remote NUMA node to "
                        "polling thread.\n\tPerformance will "
                        "not be optimal.\n", port);

        printf("\nCore %u forwarding packets. [Ctrl+C to quit]\n",
                rte_lcore_id());

        /* Run until the application is quit or killed. */
        for (;;) {
            /*
             * Receive packets on a port and forward them on the paired
             * port. The mapping is 0 -> 1, 1 -> 0, 2 -> 3, 3 -> 2, etc.
             */
            for (port = 0; port < nb_ports; port++) {

                /* Get burst of RX packets, from first port of pair. */
                struct rte_mbuf *bufs[BURST_SIZE];
                const uint16_t nb_rx = rte_eth_rx_burst(port, 0,
                        bufs, BURST_SIZE);

                if (unlikely(nb_rx == 0))
                    continue;

                /* Send burst of TX packets, to second port of pair. */
                const uint16_t nb_tx = rte_eth_tx_burst(port ^ 1, 0,
                        bufs, nb_rx);

                /* Free any unsent packets. */
                if (unlikely(nb_tx < nb_rx)) {
                    uint16_t buf;
                    for (buf = nb_tx; buf < nb_rx; buf++)
                        rte_pktmbuf_free(bufs[buf]);
                }
            }
        }
    }
```

The main work of the application is done within the loop:

```
    for (;;) {
        for (port = 0; port < nb_ports; port++) {

            /* Get burst of RX packets, from first port of pair. */
            struct rte_mbuf *bufs[BURST_SIZE];
            const uint16_t nb_rx = rte_eth_rx_burst(port, 0,
                    bufs, BURST_SIZE);

            if (unlikely(nb_rx == 0))
                continue;

            /* Send burst of TX packets, to second port of pair. */
            const uint16_t nb_tx = rte_eth_tx_burst(port ^ 1, 0,
                    bufs, nb_rx);

            /* Free any unsent packets. */
            if (unlikely(nb_tx < nb_rx)) {
                uint16_t buf;
                for (buf = nb_tx; buf < nb_rx; buf++)
                rte_pktmbuf_free(bufs[buf]);
            }
        }
    }
```

Packets are received in bursts on the RX ports and transmitted in bursts on the TX ports. The ports are grouped in pairs with a simple mapping scheme using the an XOR on the port number:

```
0 -> 1
1 -> 0

2 -> 3
3 -> 2

etc.
```

The `rte_eth_tx_burst()` function frees the memory buffers of packets that are transmitted. If packets fail to transmit, `(nb_tx < nb_rx)`, then they must be freed explicitly using `rte_pktmbuf_free()`.

The forwarding loop can be interrupted and the application closed using `Ctrl-C`.

CHAPTER

SEVEN

RX/TX CALLBACKS SAMPLE APPLICATION

The RX/TX Callbacks sample application is a packet forwarding application that demonstrates the use of user defined callbacks on received and transmitted packets. The application performs a simple latency check, using callbacks, to determine the time packets spend within the application.

In the sample application a user defined callback is applied to all received packets to add a timestamp. A separate callback is applied to all packets prior to transmission to calculate the elapsed time, in CPU cycles.

7.1 Compiling the Application

To compile the application export the path to the DPDK source tree and go to the example directory:

```
export RTE_SDK=/path/to/rte_sdk

cd ${RTE_SDK}/examples/rxtx_callbacks
```

Set the target, for example:

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

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

The callbacks feature requires that the `CONFIG_RTE_ETHDEV_RXTX_CALLBACKS` setting is on in the `config/common_` config file that applies to the target. This is generally on by default:

```
CONFIG_RTE_ETHDEV_RXTX_CALLBACKS=y
```

Build the application as follows:

```
make
```

7.2 Running the Application

To run the example in a `linuxapp` environment:

```
./build/rxtx_callbacks -c 2 -n 4
```

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

7.3 Explanation

The rxtx_callbacks application is mainly a simple forwarding application based on the Basic Forwarding Sample Application. See that section of the documentation for more details of the forwarding part of the application.

The sections below explain the additional RX/TX callback code.

7.3.1 The Main Function

The main() function performs the application initialization and calls the execution threads for each lcore. This function is effectively identical to the main() function explained in Basic Forwarding Sample Application.

The lcore_main() function is also identical.

The main difference is in the user defined port_init() function where the callbacks are added. This is explained in the next section:

7.3.2 The Port Initialization Function

The main functional part of the port initialization is shown below with comments:

```
static inline int
port_init(uint8_t port, struct rte_mempool *mbuf_pool)
{
    struct rte_eth_conf port_conf = port_conf_default;
    const uint16_t rx_rings = 1, tx_rings = 1;
    struct ether_addr addr;
    int retval;
    uint16_t q;

    if (port >= rte_eth_dev_count())
        return -1;

    /* Configure the Ethernet device. */
    retval = rte_eth_dev_configure(port, rx_rings, tx_rings, &port_conf);
    if (retval != 0)
        return retval;

    /* Allocate and set up 1 RX queue per Ethernet port. */
    for (q = 0; q < rx_rings; q++) {
        retval = rte_eth_rx_queue_setup(port, q, RX_RING_SIZE,
                rte_eth_dev_socket_id(port), NULL, mbuf_pool);
        if (retval < 0)
            return retval;
    }

    /* Allocate and set up 1 TX queue per Ethernet port. */
    for (q = 0; q < tx_rings; q++) {
        retval = rte_eth_tx_queue_setup(port, q, TX_RING_SIZE,
                rte_eth_dev_socket_id(port), NULL);
        if (retval < 0)
            return retval;
    }

    /* Start the Ethernet port. */
    retval = rte_eth_dev_start(port);
```

```
        if (retval < 0)
            return retval;

        /* Enable RX in promiscuous mode for the Ethernet device. */
        rte_eth_promiscuous_enable(port);


        /* Add the callbacks for RX and TX.*/
        rte_eth_add_rx_callback(port, 0, add_timestamps, NULL);
        rte_eth_add_tx_callback(port, 0, calc_latency, NULL);

        return 0;
    }
```

The RX and TX callbacks are added to the ports/queues as function pointers:

```
rte_eth_add_rx_callback(port, 0, add_timestamps, NULL);
rte_eth_add_tx_callback(port, 0, calc_latency,   NULL);
```

More than one callback can be added and additional information can be passed to callback function pointers as a `void*`. In the examples above `NULL` is used.

The `add_timestamps()` and `calc_latency()` functions are explained below.

7.3.3 The add_timestamps() Callback

The `add_timestamps()` callback is added to the RX port and is applied to all packets received:

```
static uint16_t
add_timestamps(uint8_t port __rte_unused, uint16_t qidx __rte_unused,
        struct rte_mbuf **pkts, uint16_t nb_pkts, void *_ __rte_unused)
{
    unsigned i;
    uint64_t now = rte_rdtsc();

    for (i = 0; i < nb_pkts; i++)
        pkts[i]->udata64 = now;

    return nb_pkts;
}
```

The DPDK function `rte_rdtsc()` is used to add a cycle count timestamp to each packet (see the *cycles* section of the *DPDK API Documentation* for details).

7.3.4 The calc_latency() Callback

The `calc_latency()` callback is added to the TX port and is applied to all packets prior to transmission:

```
static uint16_t
calc_latency(uint8_t port __rte_unused, uint16_t qidx __rte_unused,
        struct rte_mbuf **pkts, uint16_t nb_pkts, void *_ __rte_unused)
{
    uint64_t cycles = 0;
    uint64_t now = rte_rdtsc();
    unsigned i;

    for (i = 0; i < nb_pkts; i++)
        cycles += now - pkts[i]->udata64;
    latency_numbers.total_cycles += cycles;
    latency_numbers.total_pkts   += nb_pkts;

    if (latency_numbers.total_pkts > (100 * 1000 * 1000ULL)) {
        printf("Latency = %"PRIu64" cycles\n",
                latency_numbers.total_cycles / latency_numbers.total_pkts);

        latency_numbers.total_cycles = latency_numbers.total_pkts = 0;
    }

    return nb_pkts;
}
```

The `calc_latency()` function accumulates the total number of packets and the total number of cycles used. Once more than 100 million packets have been transmitted the average cycle count per packet is printed out and the counters are reset.

CHAPTER

EIGHT

IP FRAGMENTATION SAMPLE APPLICATION

The IPv4 Fragmentation application is a simple example of packet processing using the Data Plane Development Kit (DPDK). The application does L3 forwarding with IPv4 and IPv6 packet fragmentation.

8.1 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 “L2 Forwarding Simple Application (in Real and Virtualized Environments)” for more information). This guide highlights the differences between the two applications.

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

- The first difference is that the IP Fragmentation 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 IP header.
- The third difference is that the application differentiates between IP and non-IP traffic by means of offload flags.

The Longest Prefix Match (LPM for IPv4, LPM6 for IPv6) table is used to store/lookup an outgoing port number, associated with that IP address. Any unmatched packets are forwarded to the originating port.

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

8.2 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/ip_fragmentation
   ```

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

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

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

1. Build the application:

   ```
   make
   ```

8.3 Running the Application

The LPM object is created and loaded with the pre-configured entries read from global l3fwd_ipv4_route_array and l3fwd_ipv6_route_array tables. 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/ip_fragmentation [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/ip_fragmentation -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 3IP_FRAG: Socket 0: adding route 100.10.0.0/16 (port 0)
IP_FRAG: Socket 0: adding route 100.20.0.0/16 (port 1)
...
IP_FRAG: Socket 0: adding route 0101:0101:0101:0101:0101:0101:0101:0101/48 (port 0)
IP_FRAG: Socket 0: adding route 0201:0101:0101:0101:0101:0101:0101:0101/48 (port 1)
...
IP_FRAG: entering main loop on lcore 4
IP_FRAG: -- lcoreid=4 portid=2
IP_FRAG: entering main loop on lcore 2
IP_FRAG: -- 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/ip_fragmentation -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_ipv4_route_array and/or l3fwd_ipv6_route_array table.

The default l3fwd_ipv4_route_array table is:

```
struct l3fwd_ipv4_route l3fwd_ipv4_route_array[] = {
    {IPv4(100, 10, 0, 0), 16, 0},
```

```
        {IPv4(100, 20, 0, 0), 16, 1},
        {IPv4(100, 30, 0, 0), 16, 2},
        {IPv4(100, 40, 0, 0), 16, 3},
        {IPv4(100, 50, 0, 0), 16, 4},
        {IPv4(100, 60, 0, 0), 16, 5},
        {IPv4(100, 70, 0, 0), 16, 6},
        {IPv4(100, 80, 0, 0), 16, 7},
    };
```

The default l3fwd_ipv6_route_array table is:

```
    struct l3fwd_ipv6_route l3fwd_ipv6_route_array[] = {
        {{1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 0},
        {{2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 1},
        {{3, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 2},
        {{4, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 3},
        {{5, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 4},
        {{6, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 5},
        {{7, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 6},
        {{8, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 7},
    };
```

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 #0 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. IP Fragmentation sample application provides basic NUMA support in that all the memory structures are allocated on all sockets that have active lcores on them.

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

CHAPTER

NINE

IPV4 MULTICAST SAMPLE APPLICATION

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

9.1 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 “L2 Forwarding Sample Application (in Real and Virtualized Environments)” for details 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.

9.2 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-native-linuxapp-gcc
   ```

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

1. 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.

9.3 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 *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. 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 “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.

9.4.1 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 r
                                 rte_pktmbuf_pool_init, NULL, rte_pktmbuf_init, NULL, rte_socke

header_pool = rte_mempool_create("header_pool", NB_HDR_MBUF, HDR_MBUF_SIZE, 32, 0, NULL, NULL,
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.

9.4.2 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
                    return -1;
        }
    }
    return 0;
}
```

9.4.3 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 OR-ed 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 lc
{
    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);
}
```

9.4.4 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);
}
```

CHAPTER

TEN

IP REASSEMBLY SAMPLE APPLICATION

The L3 Forwarding application is a simple example of packet processing using the DPDK. The application performs L3 forwarding with reassembly for fragmented IPv4 and IPv6 packets.

10.1 Overview

The application demonstrates the use of the DPDK libraries to implement packet forwarding with reassembly for IPv4 and IPv6 fragmented packets. The initialization and run- time paths are very similar to those of the L2 forwarding application (see Chapter 9 "L2 Forwarding Sample Application" for more information). The main difference from the L2 Forwarding sample application is that it reassembles fragmented IPv4 and IPv6 packets before forwarding. The maximum allowed size of reassembled packet is 9.5 KB.

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

- The first difference is that the forwarding decision is taken based on information read from the input packet's IP header.
- The second difference is that the application differentiates between IP and non-IP traffic by means of offload flags.

10.2 The Longest Prefix Match (LPM for IPv4, LPM6 for IPv6) table is used to store/lookup an outgoing port number, associated with that IPv4 address. Any unmatched packets are forwarded to the originating port.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
   ```

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

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

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

1. Build the application:

   ```
   make
   ```

10.3 Running the Application

The application has a number of command line options:

```
./build/ip_reassembly [EAL options] -- -p PORTMASK [-q NQ] [--maxflows=FLOWS>] [--flowttl=TTL[(
```

where:

- -p PORTMASK: Hexadecimal bitmask of ports to configure
- -q NQ: Number of RX queues per lcore
- –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.

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

```
./build/ip_reassembly -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 3IP_FRAG: Socket 0: adding route 100.10.0.0/16 (port 0)
IP_RSMBL: Socket 0: adding route 100.20.0.0/16 (port 1)
...

IP_RSMBL: Socket 0: adding route 0101:0101:0101:0101:0101:0101:0101:0101/48 (port 0)
IP_RSMBL: Socket 0: adding route 0201:0101:0101:0101:0101:0101:0101:0101/48 (port 1)
...

IP_RSMBL: entering main loop on lcore 4
IP_RSMBL: -- lcoreid=4 portid=2
IP_RSMBL: entering main loop on lcore 2
IP_RSMBL: -- 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/ip_reassembly -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_ipv4_route_array and/or l3fwd_ipv6_route_array table.

Please note that in order to test this application, the traffic generator should be generating valid fragmented IP packets. For IPv6, the only supported case is when no other extension headers other than fragment extension header are present in the packet.

The default l3fwd_ipv4_route_array table is:

```
struct l3fwd_ipv4_route l3fwd_ipv4_route_array[] = {
    {IPv4(100, 10, 0, 0), 16, 0},
    {IPv4(100, 20, 0, 0), 16, 1},
    {IPv4(100, 30, 0, 0), 16, 2},
    {IPv4(100, 40, 0, 0), 16, 3},
    {IPv4(100, 50, 0, 0), 16, 4},
    {IPv4(100, 60, 0, 0), 16, 5},
    {IPv4(100, 70, 0, 0), 16, 6},
    {IPv4(100, 80, 0, 0), 16, 7},
};
```

The default l3fwd_ipv6_route_array table is:

```
struct l3fwd_ipv6_route l3fwd_ipv6_route_array[] = {
    {{1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 0},
    {{2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 1},
    {{3, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 2},
    {{4, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 3},
    {{5, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 4},
    {{6, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 5},
    {{7, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 6},
    {{8, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}, 48, 7},
};
```

For example, for the fragmented input IPv4 packet with destination address: 100.10.1.1, a reassembled IPv4 packet be sent out from port #0 to the destination address 100.10.1.1 once all the fragments are collected.

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 "L2 Forwarding Sample Application" for more information). The following sections describe aspects that are specific to the IP reassemble sample application.

10.4.1 IPv4 Fragment Table Initialization

This application uses the rte_ip_frag library. Please refer to Programmer's Guide for more detailed explanation of how to use this library. Fragment table maintains information about already received fragments of the packet. Each IP packet is uniquely identified by triple <Source IP address>, <Destination IP address>, <ID>. To avoid lock contention, each RX queue has its 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 RTE_LIBRTE_IP_FRAG_MAX_FRAGS fragments.

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

if ((qconf->frag_tbl[queue] = rte_ip_frag_tbl_create(max_flow_num, IPV4_FRAG_TBL_BUCKET_ENTRIES
{
    RTE_LOG(ERR, IP_RSMBL, "ip_frag_tbl_create(%u) on " "lcore: %u for queue: %u failed\n",  ma
    return -1;
}
```

10.4.2 Mempools Initialization

The reassembly application demands a lot of mbuf's to be allocated. At any given time up to (2 * max_flow_num * RTE_LIBRTE_IP_FRAG_MAX_FRAGS * <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 its own mempool.

```
nb_mbuf = RTE_MAX(max_flow_num, 2UL * MAX_PKT_BURST) * RTE_LIBRTE_IP_FRAG_MAX_FRAGS;
nb_mbuf *= (port_conf.rxmode.max_rx_pkt_len + BUF_SIZE - 1) / BUF_SIZE;
nb_mbuf *= 2; /* ipv4 and ipv6 */
nb_mbuf += RTE_TEST_RX_DESC_DEFAULT + RTE_TEST_TX_DESC_DEFAULT;
nb_mbuf = RTE_MAX(nb_mbuf, (uint32_t)NB_MBUF);

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

if ((rxq->pool = rte_mempool_create(buf, nb_mbuf, MBUF_SIZE, 0, sizeof(struct rte_pktmbuf_pool_
    rte_pktmbuf_init, NULL, socket, MEMPOOL_F_SP_PUT | MEMPOOL_F_SC_GET)) == NULL) {

        RTE_LOG(ERR, IP_RSMBL, "mempool_create(%s) failed", buf);
        return -1;
}
```

10.4.3 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 or IPv6 fragment, then it calls rte_ipv4_reassemble_packet() for IPv4 packets, or rte_ipv6_reassemble_packet() for IPv6 packets. These functions either return a pointer to valid mbuf that contains reassembled packet, or NULL (if the packet can't be reassembled for some reason). Then l3fwd_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 rte_ipv4_reassemble_packet() or rte_ipv6_reassemble_packet() are responsible for:

1. Searching the Fragment Table for entry with packet's <IP Source Address, IP 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 a reassembly function encounters an error (can't insert new entry into the Fragment table, or invalid/timed-out fragment), then it will free all associated with the packet fragments, mark the table entry as invalid and return NULL to the caller.

10.4.4 Debug logging and Statistics Collection

The RTE_LIBRTE_IP_FRAG_TBL_STAT controls statistics collection for the IP Fragment Table. This macro is disabled 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.

CHAPTER

ELEVEN

KERNEL NIC INTERFACE SAMPLE APPLICATION

The Kernel NIC Interface (KNI) is a DPDK control plane solution that allows userspace applications to exchange packets with the kernel networking stack. To accomplish this, 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 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 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 DPDK's FIFO queue to receive/transmit packets from/to the DPDK userspace application. The FIFO queues contain pointers to data packets in the DPDK. This:

- Provides a faster mechanism to interface with the kernel net stack and eliminates system calls
- Facilitates the 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 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 DPDK ports. The application allows the use of standard Linux tools (ethtool, ifconfig, tcpdump) with the DPDK ports and also the exchange of packets between the DPDK application and the Linux* kernel.

11.1 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.

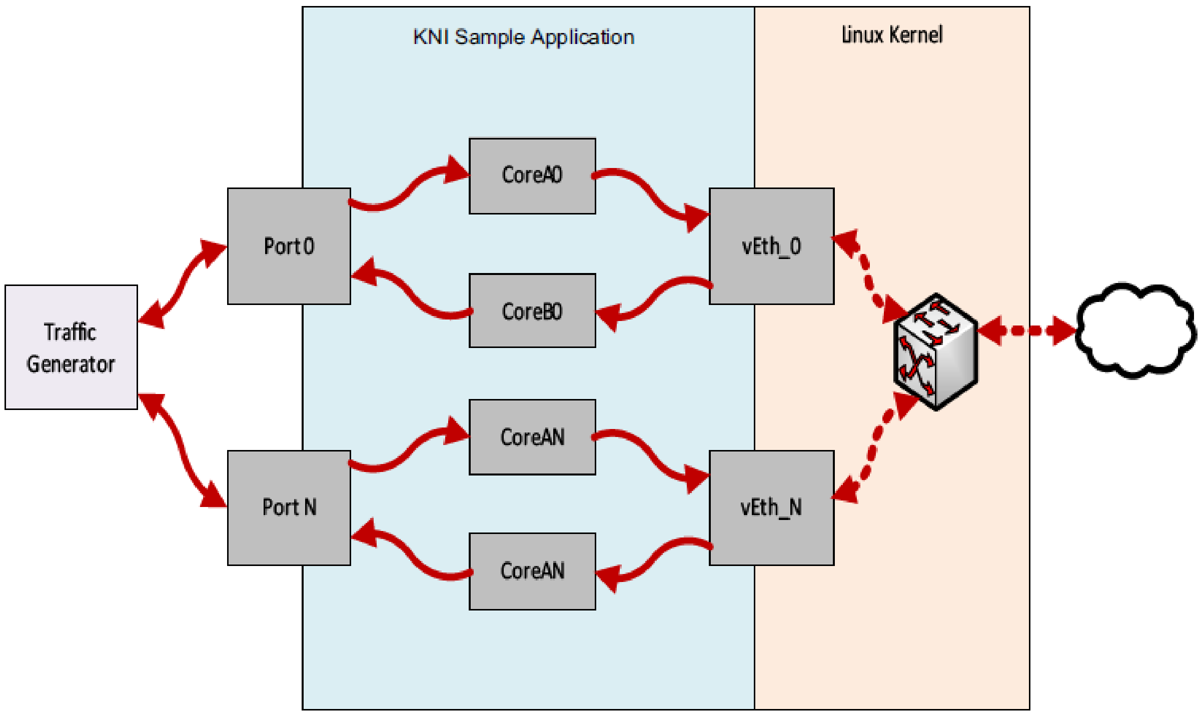


Fig. 11.1: Kernel NIC Application Packet Flow

11.2 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-native-linuxapp-gcc
```

3. Build the application:

```
make
```

11.3 Loading the Kernel Module

Loading the KNI kernel module without any parameter is the typical way a 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 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 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.

11.4 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,...])[,por
```

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 *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)"
```

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

11.6 Explanation

The following sections provide some explanation of code.

11.6.1 Initialization

Setup of mbuf pool, driver and queues is similar to the setup done in the L2 Forwarding sample application (see Chapter 9 “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 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) {
                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
                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_inf

                    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;
        }

        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"
        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[
            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]->l
            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;

}
```

11.6.2 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”). 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 Packet’s”).

```
/**
 *   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;
            }
        }
}
```

11.6.3 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;
}
```

CHAPTER

TWELVE

KEEP ALIVE SAMPLE APPLICATION

The Keep Alive application is a simple example of a heartbeat/watchdog for packet processing cores. It demonstrates how to detect 'failed' DPDK cores and notify a fault management entity of this failure. Its purpose is to ensure the failure of the core does not result in a fault that is not detectable by a management entity.

12.1 Overview

The application demonstrates how to protect against 'silent outages' on packet processing cores. A Keep Alive Monitor Agent Core (master) monitors the state of packet processing cores (worker cores) by dispatching pings at a regular time interval (default is 5ms) and monitoring the state of the cores. Cores states are: Alive, MIA, Dead or Buried. MIA indicates a missed ping, and Dead indicates two missed pings within the specified time interval. When a core is Dead, a callback function is invoked to restart the packet processing core; A real life application might use this callback function to notify a higher level fault management entity of the core failure in order to take the appropriate corrective action.

Note: Only the worker cores are monitored. A local (on the host) mechanism or agent to supervise the Keep Alive Monitor Agent Core DPDK core is required to detect its failure.

Note: This application is based on the L2 forwarding application. As such, the initialization and run-time paths are very similar to those of the L2 forwarding application.

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/keep_alive
   ```

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

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

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

3. Build the application:

   ```
   make
   ```

12.3 Running the Application

The application has a number of command line options:

```
./build/l2fwd-keepalive [EAL options] \
        -- -p PORTMASK [-q NQ] [-K PERIOD] [-T PERIOD]
```

where,

- `p PORTMASK`: A hexadecimal bitmask of the ports to configure
- `q NQ`: A number of queues (=ports) per lcore (default is 1)
- `K PERIOD`: Heartbeat check period in ms(5ms default; 86400 max)
- `T PERIOD`: statistics will be refreshed each PERIOD seconds (0 to disable, 10 default, 86400 maximum).

To run the application in linuxapp environment with 4 lcores, 16 ports 8 RX queues per lcore and a ping interval of 10ms, issue the command:

```
./build/l2fwd-keepalive -c f -n 4 -- -q 8 -p ffff -K 10
```

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

12.4 Explanation

The following sections provide some explanation of the The Keep-Alive/'Liveliness' conceptual scheme. 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 "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for more information).

The Keep-Alive/'Liveliness' conceptual scheme:

- A Keep- Alive Agent Runs every N Milliseconds.
- DPDK Cores respond to the keep-alive agent.
- If keep-alive agent detects time-outs, it notifies the fault management entity through a callback function.

The following sections provide some explanation of the code aspects that are specific to the Keep Alive sample application.

The heartbeat functionality is initialized with a struct rte_heartbeat and the callback function to invoke in the case of a timeout.

```
rte_global_keepalive_info = rte_keepalive_create(&dead_core, NULL);
if (rte_global_hbeat_info == NULL)
    rte_exit(EXIT_FAILURE, "keepalive_create() failed");
```

The function that issues the pings hbeat_dispatch_pings() is configured to run every check_period milliseconds.

```
if (rte_timer_reset(&hb_timer,
        (check_period * rte_get_timer_hz()) / 1000,
        PERIODICAL,
        rte_lcore_id(),
        &hbeat_dispatch_pings, rte_global_keepalive_info
        ) != 0 )
    rte_exit(EXIT_FAILURE, "Keepalive setup failure.\n");
```

The rest of the initialization and run-time path follows the same paths as the the L2 forwarding application. The only addition to the main processing loop is the mark alive functionality and the example random failures.

```
rte_keepalive_mark_alive(&rte_global_hbeat_info);
cur_tsc = rte_rdtsc();

/* Die randomly within 7 secs for demo purposes.. */
if (cur_tsc - tsc_initial > tsc_lifetime)
break;
```

The rte_keepalive_mark_alive function simply sets the core state to alive.

```
static inline void
rte_keepalive_mark_alive(struct rte_heartbeat *keepcfg)
{
    keepcfg->state_flags[rte_lcore_id()] = 1;
}
```

CHAPTER

THIRTEEN

L2 FORWARDING SAMPLE APPLICATION (IN REAL AND VIRTUALIZED ENVIRONMENTS) WITH CORE LOAD STATISTICS.

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

Note: This application is a variation of L2 Forwarding sample application. It demonstrate possible scheme of job stats library usage therefore some parts of this document is identical with original L2 forwarding application.

13.1 Overview

The L2 Forwarding sample application, which can operate in real and virtualized environments, performs L2 forwarding for each packet that is received. 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 Fig. 13.1.

The application can also be used in a virtualized environment as shown in Fig. 13.2.

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

13.1.1 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
```

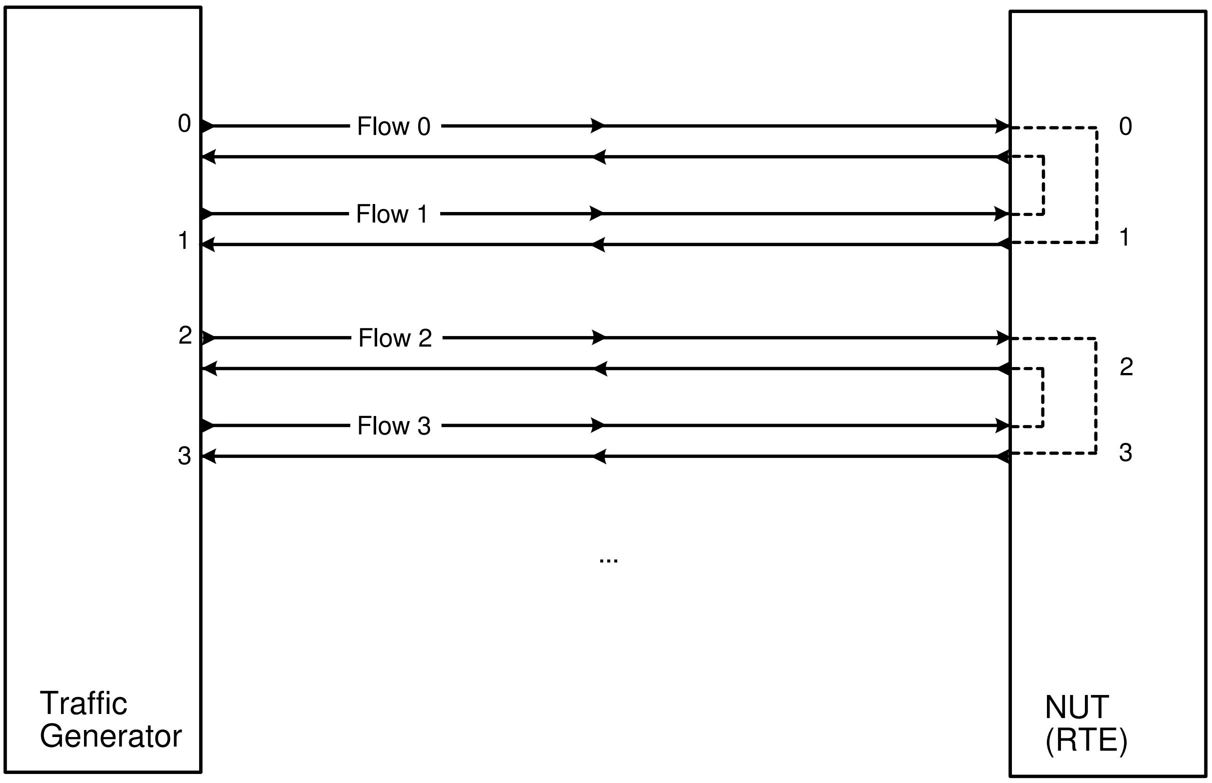


Fig. 13.1: Performance Benchmark Setup (Basic Environment)

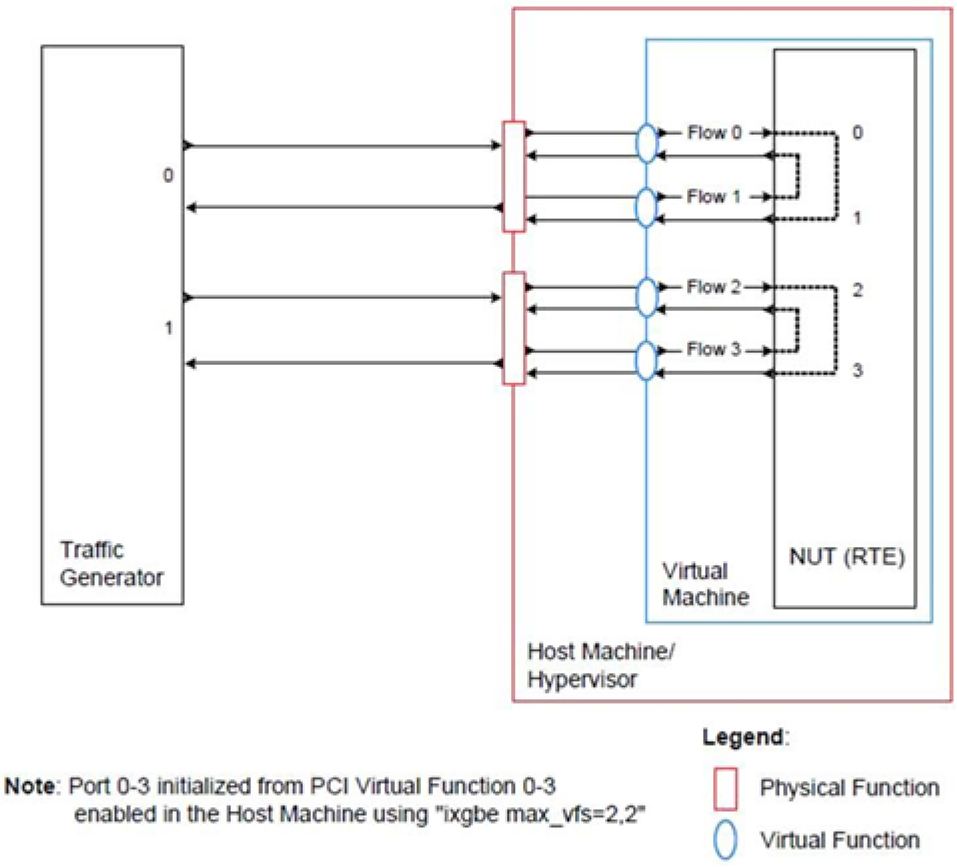


Fig. 13.2: Performance Benchmark Setup (Virtualized Environment)

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.

13.2 Compiling the Application

1. Go to the example directory:

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

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

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

   See the DPDK Getting Started Guide for possible RTE_TARGET values.

3. Build the application:

   ```
   make
   ```

13.3 Running the Application

The application requires a number of command line options:

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

where,

- p PORTMASK: A hexadecimal bitmask of the ports to configure
- q NQ: A number of queues (=ports) per lcore (default is 1)
- l: Use locale thousands separator when formatting big numbers.

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

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

Refer to the *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 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");
```

13.4.2 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,
                rte_socket_id(), 0);

if (l2fwd_pktmbuf_pool == NULL)
    rte_exit(EXIT_FAILURE, "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 pkt mbufs is NB_MBUF, with a size of MBUF_SIZE each. A per-lcore cache of 32 mbufs is kept. The memory is allocated in rte_socket_id() 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.

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 *DPDK Programmer's Guide* and the *DPDK API Reference*.

```
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);
}
```

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
    },
};
```

13.4.4 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(portid, 0, nb_rxd,
            rte_eth_dev_socket_id(portid),
            NULL,
            l2fwd_pktmbuf_pool);

if (ret < 0)
    rte_exit(EXIT_FAILURE, "rte_eth_rx_queue_setup:err=%d, port=%u\n",
            ret, (unsigned) 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];
    truct mbuf_table tx_mbufs[RTE_MAX_ETHPORTS];

    struct rte_timer rx_timers[MAX_RX_QUEUE_PER_LCORE];
    struct rte_jobstats port_fwd_jobs[MAX_RX_QUEUE_PER_LCORE];

    struct rte_timer flush_timer;
    struct rte_jobstats flush_job;
    struct rte_jobstats idle_job;
    struct rte_jobstats_context jobs_context;

    rte_atomic16_t stats_read_pending;
    rte_spinlock_t lock;
} __rte_cache_aligned;
```

Values of struct lcore_queue_conf:

- 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” later in this chapter).
- rx_timers and flush_timer are used to ensure forced TX on low packet rate.
- flush_job, idle_job and jobs_context are librte_jobstats objects used for managing l2fwd jobs.
- stats_read_pending and lock are used during job stats read phase.

13.4.5 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(portid, 0, nb_txd,
        rte_eth_dev_socket_id(portid),
        NULL);
if (ret < 0)
    rte_exit(EXIT_FAILURE, "rte_eth_tx_queue_setup:err=%d, port=%u\n",
            ret, (unsigned) portid);
```

13.4.6 Jobs statistics initialization

There are several statistics objects available:

- Flush job statistics

```
rte_jobstats_init(&qconf->flush_job, "flush", drain_tsc, drain_tsc,
        drain_tsc, 0);

rte_timer_init(&qconf->flush_timer);
ret = rte_timer_reset(&qconf->flush_timer, drain_tsc, PERIODICAL,
            lcore_id, &l2fwd_flush_job, NULL);

if (ret < 0) {
    rte_exit(1, "Failed to reset flush job timer for lcore %u: %s",
                lcore_id, rte_strerror(-ret));
}
```

- Statistics per RX port

```
rte_jobstats_init(job, name, 0, drain_tsc, 0, MAX_PKT_BURST);
rte_jobstats_set_update_period_function(job, l2fwd_job_update_cb);

rte_timer_init(&qconf->rx_timers[i]);
ret = rte_timer_reset(&qconf->rx_timers[i], 0, PERIODICAL, lcore_id,
        l2fwd_fwd_job, (void *)(uintptr_t)i);

if (ret < 0) {
    rte_exit(1, "Failed to reset lcore %u port %u job timer: %s",
                lcore_id, qconf->rx_port_list[i], rte_strerror(-ret));
}
```

Following parameters are passed to rte_jobstats_init():

- 0 as minimal poll period
- drain_tsc as maximum poll period
- MAX_PKT_BURST as desired target value (RX burst size)

13.4.7 Main loop

The forwarding path is reworked comparing to original L2 Forwarding application. In the l2fwd_main_loop() function three loops are placed.

```
for (;;) {
    rte_spinlock_lock(&qconf->lock);

    do {
        rte_jobstats_context_start(&qconf->jobs_context);
```

```
            /* Do the Idle job:
             * - Read stats_read_pending flag
             * - check if some real job need to be executed
             */
            rte_jobstats_start(&qconf->jobs_context, &qconf->idle_job);

            do {
                uint8_t i;
                uint64_t now = rte_get_timer_cycles();

                need_manage = qconf->flush_timer.expire < now;
                /* Check if we was esked to give a stats. */
                stats_read_pending =
                        rte_atomic16_read(&qconf->stats_read_pending);
                need_manage |= stats_read_pending;

                for (i = 0; i < qconf->n_rx_port && !need_manage; i++)
                    need_manage = qconf->rx_timers[i].expire < now;

            } while (!need_manage);
            rte_jobstats_finish(&qconf->idle_job, qconf->idle_job.target);

            rte_timer_manage();
            rte_jobstats_context_finish(&qconf->jobs_context);
        } while (likely(stats_read_pending == 0));

        rte_spinlock_unlock(&qconf->lock);
        rte_pause();
    }
```

First infinite for loop is to minimize impact of stats reading. Lock is only locked/unlocked when asked.

Second inner while loop do the whole jobs management. When any job is ready, the use rte_timer_manage() is used to call the job handler. In this place functions l2fwd_fwd_job() and l2fwd_flush_job() are called when needed. Then rte_jobstats_context_finish() is called to mark loop end - no other jobs are ready to execute. By this time stats are ready to be read and if stats_read_pending is set, loop breaks allowing stats to be read.

Third do-while loop is the idle job (idle stats counter). Its only purpose is monitoring if any job is ready or stats job read is pending for this lcore. Statistics from this part of code is considered as the headroom available for additional processing.

13.4.8 Receive, Process and Transmit Packets

The main task of l2fwd_fwd_job() function is to read ingress packets from the RX queue of particular port and forward it. This is done using the following code:

```
total_nb_rx = rte_eth_rx_burst((uint8_t) portid, 0, pkts_burst,
        MAX_PKT_BURST);

for (j = 0; j < total_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. 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.

The rte_eth_rx_burst() function writes the mbuf pointers in a local table and returns the number of available mbufs in the table.

After first read second try is issued.

```
if (total_nb_rx == MAX_PKT_BURST) {
    const uint16_t nb_rx = rte_eth_rx_burst((uint8_t) portid, 0, pkts_burst,
            MAX_PKT_BURST);

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

This second read is important to give job stats library a feedback how many packets was processed.

```
/* Adjust period time in which we are running here. */
if (rte_jobstats_finish(job, total_nb_rx) != 0) {
    rte_timer_reset(&qconf->rx_timers[port_idx], job->period, PERIODICAL,
            lcore_id, l2fwd_fwd_job, arg);
}
```

To maximize performance exactly MAX_PKT_BURST is expected (the target value) to be read for each l2fwd_fwd_job() call. If total_nb_rx is smaller than target value job->period will be increased. If it is greater the period will be decreased.

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, the flush job exists. The l2fwd_flush_job() is called periodically to for each lcore draining TX queue of each port. This technique introduces some latency when there are not many packets to send, however it improves performance:

```
static void
l2fwd_flush_job(__rte_unused struct rte_timer *timer, __rte_unused void *arg)
{
    uint64_t now;
    unsigned lcore_id;
    struct lcore_queue_conf *qconf;
    struct mbuf_table *m_table;
    uint8_t portid;

    lcore_id = rte_lcore_id();
    qconf = &lcore_queue_conf[lcore_id];

    rte_jobstats_start(&qconf->jobs_context, &qconf->flush_job);

    now = rte_get_timer_cycles();
    lcore_id = rte_lcore_id();
    qconf = &lcore_queue_conf[lcore_id];
    for (portid = 0; portid < RTE_MAX_ETHPORTS; portid++) {
        m_table = &qconf->tx_mbufs[portid];
        if (m_table->len == 0 || m_table->next_flush_time <= now)
            continue;
        l2fwd_send_burst(qconf, portid);
    }


    /* Pass target to indicate that this job is happy of time interval
     * in which it was called. */
    rte_jobstats_finish(&qconf->flush_job, qconf->flush_job.target);
}
```

CHAPTER

FOURTEEN

L2 FORWARDING SAMPLE APPLICATION (IN REAL AND VIRTUALIZED ENVIRONMENTS)

The L2 Forwarding sample application is a simple example of packet processing using the Data Plane Development Kit (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 DPDK versions these sample applications have been merged.

14.1 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 Fig. 14.1.

The application can also be used in a virtualized environment as shown in Fig. 14.2.

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

14.1.1 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
```

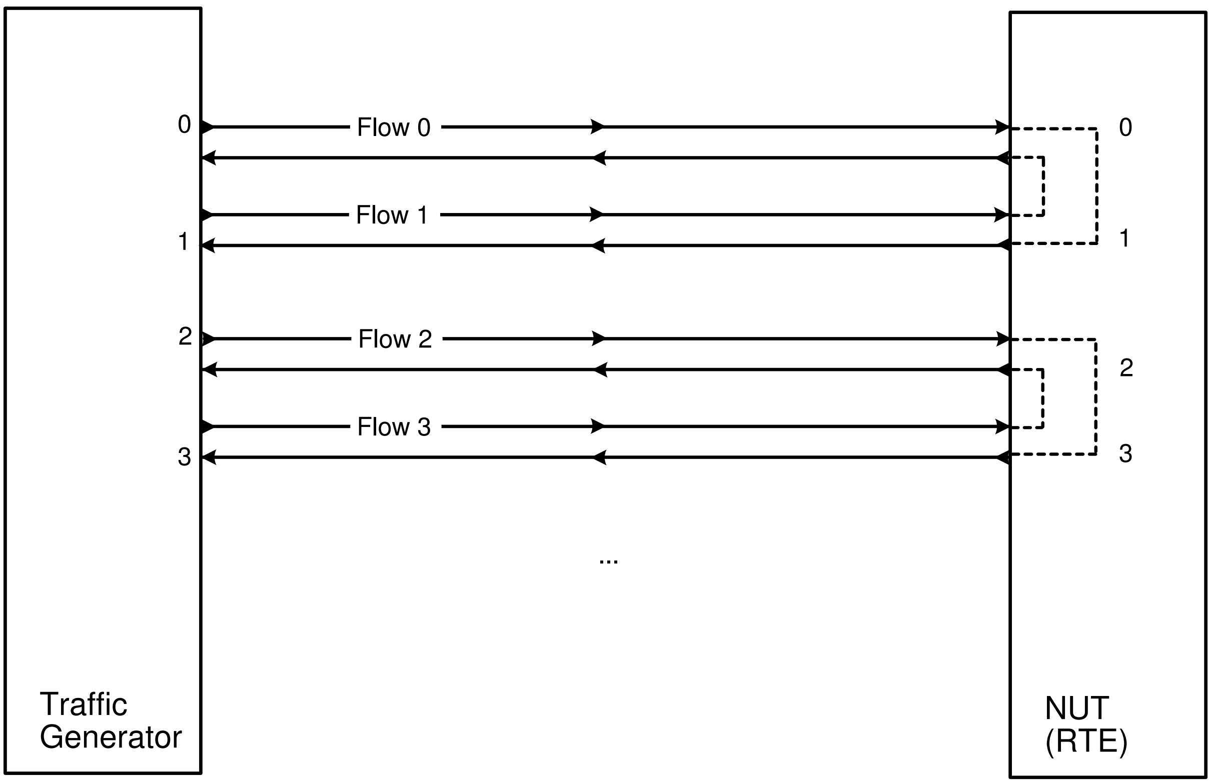


Fig. 14.1: Performance Benchmark Setup (Basic Environment)

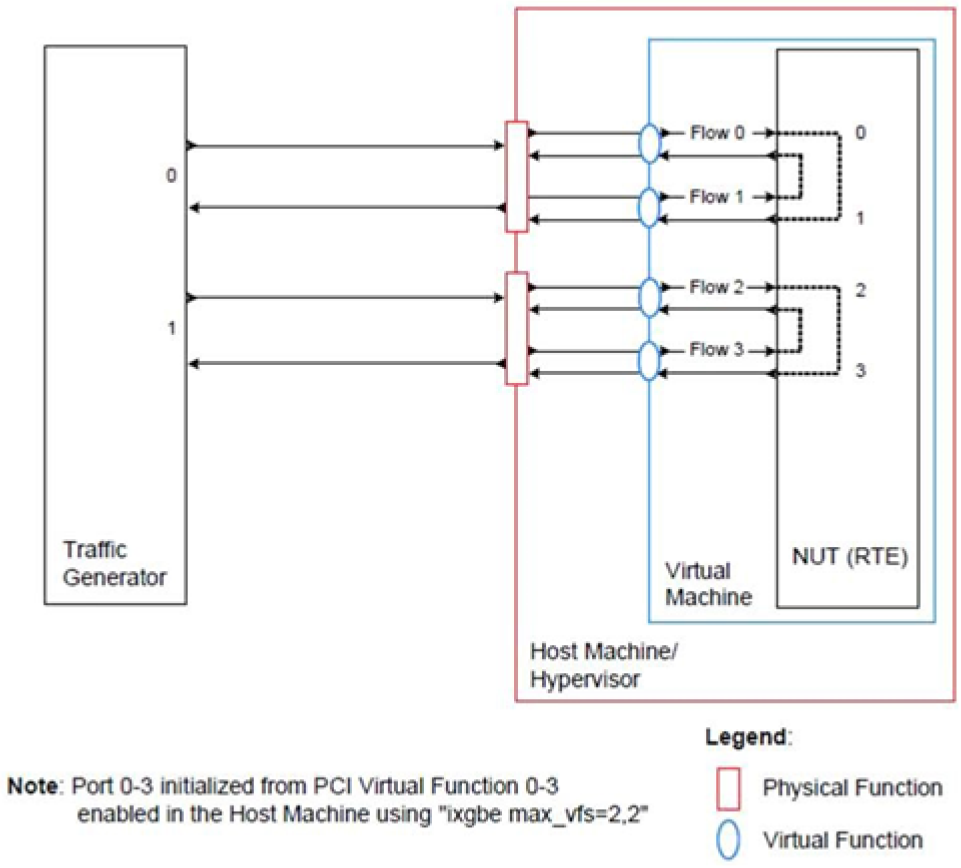


Fig. 14.2: Performance Benchmark Setup (Virtualized Environment)

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.

14.2 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-native-linuxapp-gcc
   ```

   See the DPDK Getting Started Guide for possible RTE_TARGET values.

3. Build the application:

   ```
   make
   ```

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

14.4 Explanation

The following sections provide some explanation of the code.

14.4.1 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");
```

14.4.2 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_
    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 pkt mbufs 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.

14.4.3 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 *DPDK Programmer's Guide* - Rel 1.4 EAR and the *DPDK API Reference*.

```
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
    },
};
```

14.4.4 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” 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,
    },
};
```

14.4.5 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_co
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 */
};
```

14.4.6 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) po

        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;
}
```

CHAPTER

FIFTEEN

L3 FORWARDING SAMPLE APPLICATION

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

15.1 Overview

The application demonstrates the use of the hash and LPM libraries in the DPDK to implement packet forwarding. The initialization and run-time paths are very similar to those of the L2 forwarding application (see Chapter 9 “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.

15.2 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-native-linuxapp-gcc
   ```

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

3. Build the application:

   ```
   make
   ```

15.3 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: optional, 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: optional, enables jumbo frames
- –max-pkt-len: optional, maximum packet length in decimal (64-9600)
- –no-numa: optional, disables numa awareness
- –hash-entry-num: optional, specifies the hash entry number in hexadecimal to be setup
- –ipv6: optional, set it if running ipv6 packets

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

15.4 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 “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.

15.4.1 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_ent
            } else {
                /* populate the ipv6 hash */
                populate_ipv6_many_flow_into_table( ipv6_l3fwd_lookup_struct[socketid], hash_er
            }
        } 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
```

15.4.2 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 */

    snprintf(s, sizeof(s), "IPV4_L3FWD_LPM_%d", socketid);

    ipv4_l3fwd_lookup_struct[socketid] = rte_lpm_create(s, socketid, IPV4_L3FWD_LPM_MAX_RULES,

    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++) {
        /* skip unused ports */

        if ((1 << ipv4_l3fwd_route_array[i].if_out & enabled_port_mask) == 0)
            continue;

        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_o

        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
    }
}
#endif
```

15.4.3 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
    data[1] = _mm_loadu_si128(( m128i*)(rte_pktmbuf_mtod(m[1], unsigned char *) + sizeof(struct
    data[2] = _mm_loadu_si128(( m128i*)(rte_pktmbuf_mtod(m[2], unsigned char *) + sizeof(struct
    data[3] = _mm_loadu_si128(( m128i*)(rte_pktmbuf_mtod(m[3], unsigned char *) + sizeof(struct

    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.

15.4.4 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
{
    uint8_t next_hop;

    return (uint8_t) ((rte_lpm_lookup(ipv4_l3fwd_lookup_struct, rte_be_to_cpu_32(ipv4_hdr->dst_
}
```

CHAPTER

SIXTEEN

L3 FORWARDING WITH POWER MANAGEMENT SAMPLE APPLICATION

16.1 Introduction

The L3 Forwarding with Power Management application is an example of power-aware packet processing using the 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.

16.2 Overview

The application demonstrates the use of the Power libraries in the 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 “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 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 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 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 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.

16.3 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-power
   ```

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

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

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

3. Build the application:

   ```
   make
   ```

16.4 Running 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,
```

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: optional, enables jumbo frames
- –max-pkt-len: optional, maximum packet length in decimal (64-9600)
- –no-numa: optional, disables numa awareness

See Chapter 10 "L3 Forwarding Sample Application" for details. The L3fwd-power example reuses the L3fwd command line options.

16.5 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.

16.5.1 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,

            // ...
        }

        // ...
    }
```

16.5.2 Monitoring Loads of Rx Queues

In general, the polling nature of the 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_
        x_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_qu
                    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 ruining thread to suspend */
                    usleep(lcore_idle_hint);

               stats[lcore_id].sleep_time += lcore_idle_hint;
            }
        }
    }
```

16.5.3 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.

16.5.4 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.

CHAPTER

SEVENTEEN

L3 FORWARDING WITH ACCESS CONTROL SAMPLE APPLICATION

The L3 Forwarding with Access Control application is a simple example of packet processing using the DPDK. The application performs a security check on received packets. Packets that are in the Access Control List (ACL), which is loaded during initialization, are dropped. Others are forwarded to the correct port.

17.1 Overview

The application demonstrates the use of the ACL library in the DPDK to implement access control and packet L3 forwarding. The application loads two types of rules at initialization:

- Route information rules, which are used for L3 forwarding
- Access Control List (ACL) rules that blacklist (or block) packets with a specific characteristic

When packets are received from a port, the application extracts the necessary information from the TCP/IP header of the received packet and performs a lookup in the rule database to figure out whether the packets should be dropped (in the ACL range) or forwarded to desired ports. The initialization and run-time paths are similar to those of the L3 forwarding application (see Chapter 10, "L3 Forwarding Sample Application" for more information). However, there are significant differences in the two applications. For example, the original L3 forwarding application uses either LPM or an exact match algorithm to perform forwarding port lookup, while this application uses the ACL library to perform both ACL and route entry lookup. The following sections provide more detail.

Classification for both IPv4 and IPv6 packets is supported in this application. The application also assumes that all the packets it processes are TCP/UDP packets and always extracts source/destination port information from the packets.

17.1.1 Tuple Packet Syntax

The application implements packet classification for the IPv4/IPv6 5-tuple syntax specifically. The 5-tuple syntax consist of a source IP address, a destination IP address, a source port, a destination port and a protocol identifier. The fields in the 5-tuple syntax have the following formats:

- **Source IP address and destination IP address** : Each is either a 32-bit field (for IPv4), or a set of 4 32-bit fields (for IPv6) represented by a value and a mask length. For example, an IPv4 range of 192.168.1.0 to 192.168.1.255 could be represented by a value = [192, 168, 1, 0] and a mask length = 24.

- **Source port and destination port** : Each is a 16-bit field, represented by a lower start and a higher end. For example, a range of ports 0 to 8192 could be represented by lower = 0 and higher = 8192.
- **Protocol identifier** : An 8-bit field, represented by a value and a mask, that covers a range of values. To verify that a value is in the range, use the following expression: "(VAL & mask) == value"

The trick in how to represent a range with a mask and value is as follows. A range can be enumerated in binary numbers with some bits that are never changed and some bits that are dynamically changed. Set those bits that dynamically changed in mask and value with 0. Set those bits that never changed in the mask with 1, in value with number expected. For example, a range of 6 to 7 is enumerated as 0b110 and 0b111. Bit 1-7 are bits never changed and bit 0 is the bit dynamically changed. Therefore, set bit 0 in mask and value with 0, set bits 1-7 in mask with 1, and bits 1-7 in value with number 0b11. So, mask is 0xfe, value is 0x6.

Note: The library assumes that each field in the rule is in LSB or Little Endian order when creating the database. It internally converts them to MSB or Big Endian order. When performing a lookup, the library assumes the input is in MSB or Big Endian order.

17.1.2 Access Rule Syntax

In this sample application, each rule is a combination of the following:

- 5-tuple field: This field has a format described in Section.
- priority field: A weight to measure the priority of the rules. The rule with the higher priority will ALWAYS be returned if the specific input has multiple matches in the rule database. Rules with lower priority will NEVER be returned in any cases.
- userdata field: A user-defined field that could be any value. It can be the forwarding port number if the rule is a route table entry or it can be a pointer to a mapping address if the rule is used for address mapping in the NAT application. The key point is that it is a useful reserved field for user convenience.

17.1.3 ACL and Route Rules

The application needs to acquire ACL and route rules before it runs. Route rules are mandatory, while ACL rules are optional. To simplify the complexity of the priority field for each rule, all ACL and route entries are assumed to be in the same file. To read data from the specified file successfully, the application assumes the following:

- Each rule occupies a single line.
- Only the following four rule line types are valid in this application:
- ACL rule line, which starts with a leading character '@'
- Route rule line, which starts with a leading character 'R'
- Comment line, which starts with a leading character '#'

- Empty line, which consists of a space, form-feed (‘f’), newline (‘n’), carriage return (‘r’), horizontal tab (‘t’), or vertical tab (‘v’).

Other lines types are considered invalid.

- Rules are organized in descending order of priority, which means rules at the head of the file always have a higher priority than those further down in the file.
- A typical IPv4 ACL rule line should have a format as shown below:

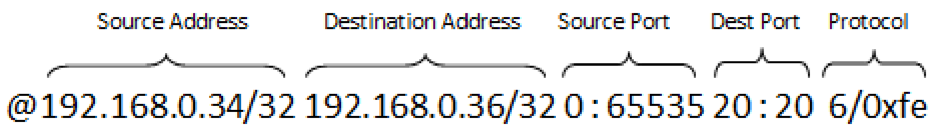


Fig. 17.1: A typical IPv4 ACL rule

IPv4 addresses are specified in CIDR format as specified in RFC 4632. They consist of the dot notation for the address and a prefix length separated by ‘/’. For example, 192.168.0.34/32, where the address is 192.168.0.34 and the prefix length is 32.

Ports are specified as a range of 16-bit numbers in the format MIN:MAX, where MIN and MAX are the inclusive minimum and maximum values of the range. The range 0:65535 represents all possible ports in a range. When MIN and MAX are the same value, a single port is represented, for example, 20:20.

The protocol identifier is an 8-bit value and a mask separated by ‘/’. For example: 6/0xfe matches protocol values 6 and 7.

- Route rules start with a leading character ‘R’ and have the same format as ACL rules except an extra field at the tail that indicates the forwarding port number.

17.1.4 Rules File Example

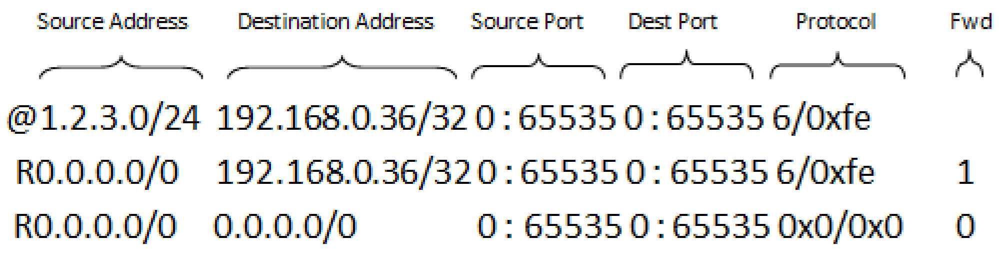

Source Address
Destination Address
Source Port
Dest Port
Protocol
Fwd
@1.2.3.0/24 192.168.0.36/32 0 : 65535 0 : 65535 6/0xfe
R0.0.0.0/0 192.168.0.36/32 0 : 65535 0 : 65535 6/0xfe 1
R0.0.0.0/0 0.0.0.0/0 0 : 65535 0 : 65535 0x0/0x0 0

Fig. 17.2: Rules example

Each rule is explained as follows:

- Rule 1 (the first line) tells the application to drop those packets with source IP address = [1.2.3.*], destination IP address = [192.168.0.36], protocol = [6]/[7]
- Rule 2 (the second line) is similar to Rule 1, except the source IP address is ignored. It tells the application to forward packets with destination IP address = [192.168.0.36], protocol = [6]/[7], destined to port 1.
- Rule 3 (the third line) tells the application to forward all packets to port 0. This is something like a default route entry.

As described earlier, the application assume rules are listed in descending order of priority, therefore Rule 1 has the highest priority, then Rule 2, and finally, Rule 3 has the lowest priority.

Consider the arrival of the following three packets:

- Packet 1 has source IP address = [1.2.3.4], destination IP address = [192.168.0.36], and protocol = [6]
- Packet 2 has source IP address = [1.2.4.4], destination IP address = [192.168.0.36], and protocol = [6]
- Packet 3 has source IP address = [1.2.3.4], destination IP address = [192.168.0.36], and protocol = [8]

Observe that:

- Packet 1 matches all of the rules
- Packet 2 matches Rule 2 and Rule 3
- Packet 3 only matches Rule 3

For priority reasons, Packet 1 matches Rule 1 and is dropped. Packet 2 matches Rule 2 and is forwarded to port 1. Packet 3 matches Rule 3 and is forwarded to port 0.

For more details on the rule file format, please refer to rule_ipv4.db and rule_ipv6.db files (inside <RTE_SDK>/examples/l3fwd-acl/).

17.1.5 Application Phases

Once the application starts, it transitions through three phases:

- **Initialization Phase** - Perform the following tasks:
- Parse command parameters. Check the validity of rule file(s) name(s), number of logical cores, receive and transmit queues. Bind ports, queues and logical cores. Check ACL search options, and so on.
- Call Environmental Abstraction Layer (EAL) and Poll Mode Driver (PMD) functions to initialize the environment and detect possible NICs. The EAL creates several threads and sets affinity to a specific hardware thread CPU based on the configuration specified by the command line arguments.
- Read the rule files and format the rules into the representation that the ACL library can recognize. Call the ACL library function to add the rules into the database and compile them as a trie of pattern sets. Note that application maintains a separate AC contexts for IPv4 and IPv6 rules.
- **Runtime Phase** - Process the incoming packets from a port. Packets are processed in three steps:
  - Retrieval: Gets a packet from the receive queue. Each logical core may process several queues for different ports. This depends on the configuration specified by command line arguments.
  - Lookup: Checks that the packet type is supported (IPv4/IPv6) and performs a 5-tuple lookup over corresponding AC context. If an ACL rule is matched, the packets will be dropped and return back to step 1. If a route rule is matched, it indicates the

packet is not in the ACL list and should be forwarded. If there is no matches for the packet, then the packet is dropped.

– Forwarding: Forwards the packet to the corresponding port.

- **Final Phase** - Perform the following tasks:

  Calls the EAL, PMD driver and ACL library to free resource, then quits.

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/l3fwd-acl
   ```

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

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

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

3. Build the application:

   ```
   make
   ```

17.3 Running the Application

The application has a number of command line options:

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

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
- –rule_ipv4 FILENAME: Specifies the IPv4 ACL and route rules file
- –rule_ipv6 FILENAME: Specifies the IPv6 ACL and route rules file
- –scalar: Use a scalar function to perform rule lookup
- –enable-jumbo: optional, enables jumbo frames
- –max-pkt-len: optional, maximum packet length in decimal (64-9600)
- –no-numa: optional, disables numa awareness

As an 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 user wants to use memory from both NUMA nodes, the platform has only two ports and the user wants to use two cores from each processor socket to do the packet processing.

To enable L3 forwarding between two ports, using two cores from each processor, while also taking advantage of local memory access by optimizing around NUMA, the user 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-acl -c f -n 4 -- -p 0x3 --config="(0,0,0),(0,1,2),(1,0,1),(1,1,3)" --rule_ipv4=".
```

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.

- The –rule_ipv4 option specifies the reading of IPv4 rules sets from the ./ rule_ipv4.db file.
- The –rule_ipv6 option specifies the reading of IPv6 rules sets from the ./ rule_ipv6.db file.
- The –scalar option specifies the performing of rule lookup with a scalar function.

17.4 Explanation

The following sections provide some explanation of the sample application code. The aspects of port, device and CPU configuration are similar to those of the L3 forwarding application (see Chapter 10, “L3 Forwarding Sample Application” for more information). The following sections describe aspects that are specific to L3 forwarding with access control.

17.4.1 Parse Rules from File

As described earlier, both ACL and route rules are assumed to be saved in the same file. The application parses the rules from the file and adds them to the database by calling the ACL library function. It ignores empty and comment lines, and parses and validates the rules it reads. If errors are detected, the application exits with messages to identify the errors encountered.

The application needs to consider the userdata and priority fields. The ACL rules save the index to the specific rules in the userdata field, while route rules save the forwarding port number. In order to differentiate the two types of rules, ACL rules add a signature in the userdata field. As for the priority field, the application assumes rules are organized in descending order of priority. Therefore, the code only decreases the priority number with each rule it parses.

17.4.2 Setting Up the ACL Context

For each supported AC rule format (IPv4 5-tuple, IPv6 6-tuple) application creates a separate context handler from the ACL library for each CPU socket on the board and adds parsed rules into that context.

Note, that for each supported rule type, application needs to calculate the expected offset of the fields from the start of the packet. That's why only packets with fixed IPv4/ IPv6 header are supported. That allows to perform ACL classify straight over incoming packet buffer - no extra protocol field retrieval need to be performed.

Subsequently, the application checks whether NUMA is enabled. If it is, the application records the socket IDs of the CPU cores involved in the task.

Finally, the application creates contexts handler from the ACL library, adds rules parsed from the file into the database and build an ACL trie. It is important to note that the application creates an independent copy of each database for each socket CPU involved in the task to reduce the time for remote memory access.

CHAPTER

EIGHTEEN

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 DPDK. The application performs L3 forwarding that takes advantage of Single Root I/O Virtualization (SR-IOV) features in a virtualized environment.

18.1 Overview

The application demonstrates the use of the hash and LPM libraries in the DPDK to implement packet forwarding. The initialization and run-time paths are very similar to those of the L3 forwarding application (see Chapter 10 “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” for virtualized test case setup.

18.2 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-native-linuxapp-gcc
   ```

   See the *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.

18.3 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
- –no-numa: optional, disables numa awareness

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	1	1	Map queue 0 from port 1 to lcore 1

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

18.4 Explanation

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

CHAPTER

NINETEEN

LINK STATUS INTERRUPT SAMPLE APPLICATION

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

19.1 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.

19.2 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-native-linuxapp-gcc
   ```

   See the *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.

19.3 Running the Application

The application requires a number of command line options:

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

where,

- -p PORTMASK: A hexadecimal bitmask of the ports to configure
- -q NQ: A number of queues (=ports) per lcore (default is 1)
- -T PERIOD: statistics will be refreshed each PERIOD seconds (0 to disable, 10 default)

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

19.4 Explanation

The following sections provide some explanation of the code.

19.4.1 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” for more information.

19.4.2 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” for more information.

19.4.3 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 *DPDK Programmer’s Guide and the DPDK API Reference*.

```
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_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.

19.4.4 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 ever

    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, NULI
```

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.

19.4.5 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” 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,
    },
};
```

19.4.6 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 */
};
```

19.4.7 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 ofte

        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;
    }
```

CHAPTER

TWENTY

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.

20.1 Overview

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

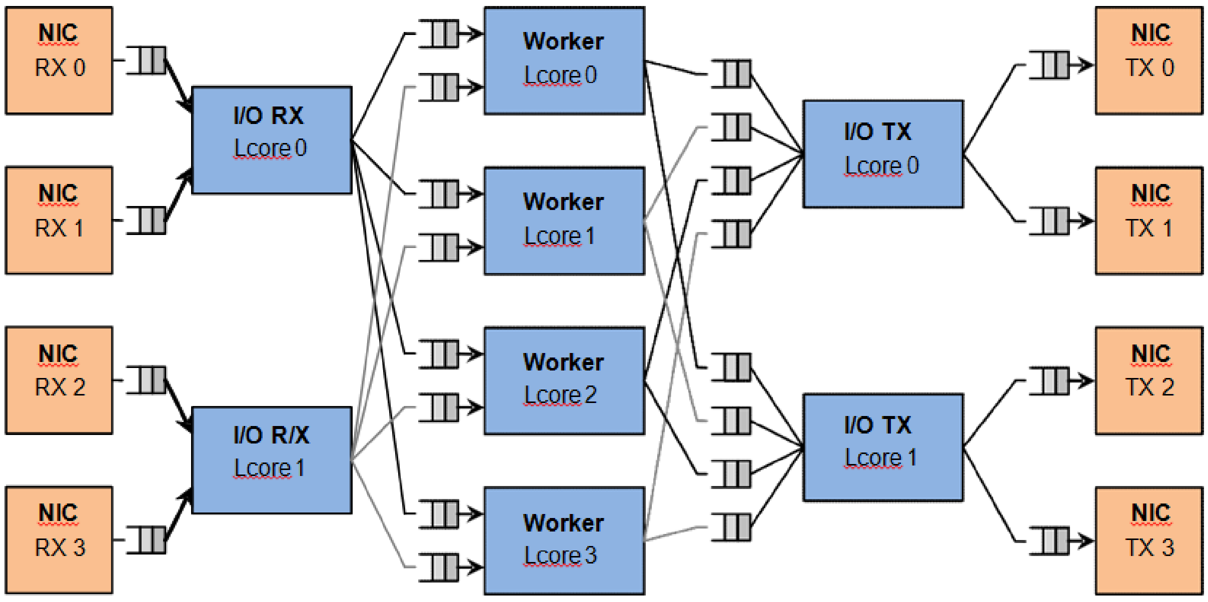


Fig. 20.1: Load Balancer Application Architecture

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.

20.1.1 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).

20.1.2 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.

20.1.3 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.

20.2 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 DPDK installation folder>
   export RTE_TARGET=x86_64-native-linuxapp-gcc
   ```

2. Build the application executable file:

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

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

20.3 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 DPDK Test Report. For more details on how to set up and run the sample applications provided with DPDK package, please refer to the *DPDK Getting Started Guide*.

20.4 Explanation

20.4.1 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 "
```

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

20.4.2 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 fulfill 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.

CHAPTER

TWENTYONE

MULTI-PROCESS SAMPLE APPLICATION

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

21.1 Example Applications

21.1.1 Building the Sample Applications

The multi-process example applications are built in the same way as other sample applications, and as documented in the *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-native-linuxapp-gcc
   ```

   See the *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.

21.1.2 Basic Multi-process Example

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

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 DPDK process run, the proc-type flag can be omitted or set to auto, since all 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_secon
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.

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_
} 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.

21.1.3 Symmetric Multi-process Example

The second example of 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.

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.

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.

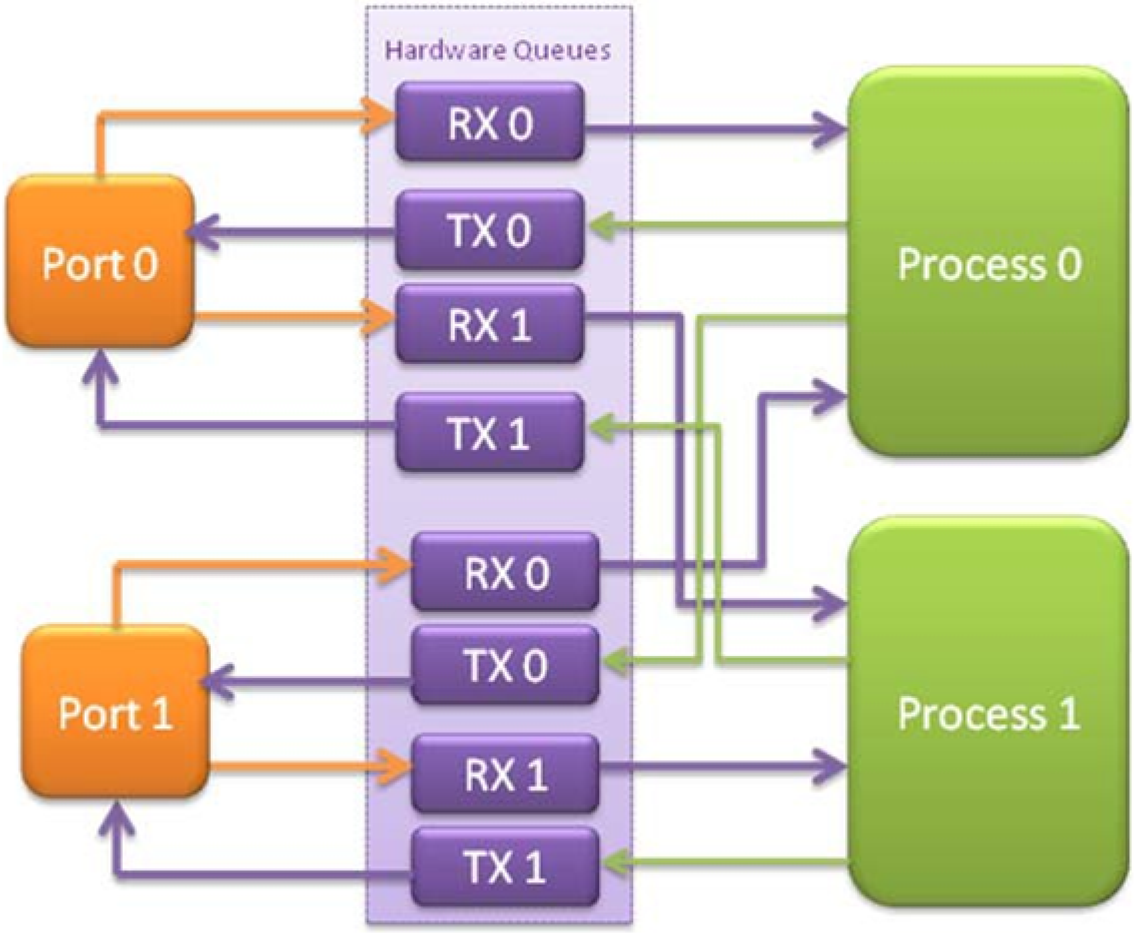


Fig. 21.1: Example Data Flow in a Symmetric Multi-process Application

- –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.)

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(), 1 G 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 initializing 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_creat
```

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.

21.1.4 Client-Server Multi-process Example

The third example multi-process application included with the 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.

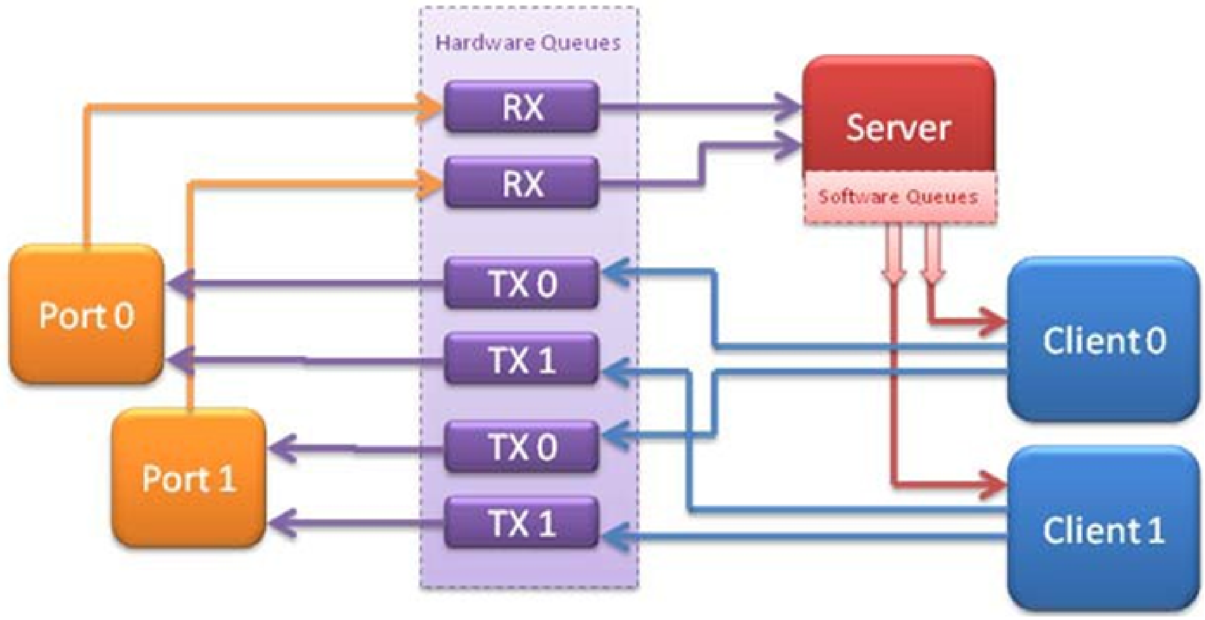


Fig. 21.2: Example Data Flow in a Client-Server Symmetric Multi-process Application

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.

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.

21.1.5 Master-slave Multi-process Example

The fourth example of 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, "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 describes this in more detail.

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.

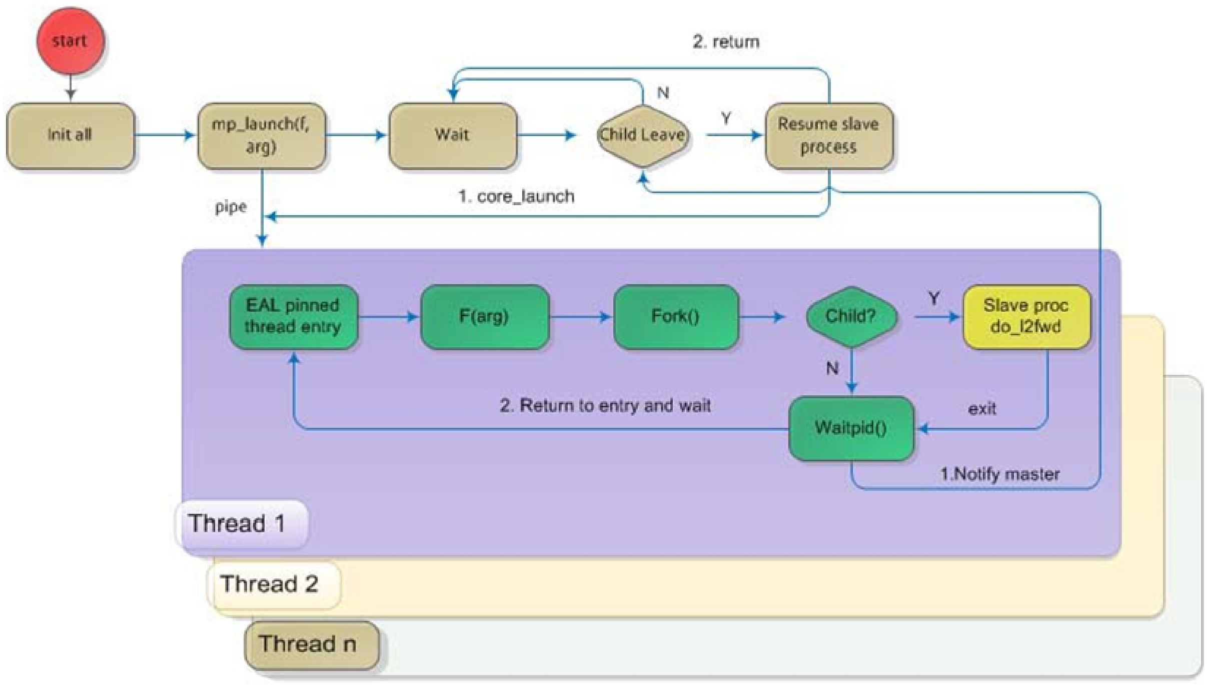


Fig. 21.3: Master-slave Process Workflow

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 mem zone.

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 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".
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.

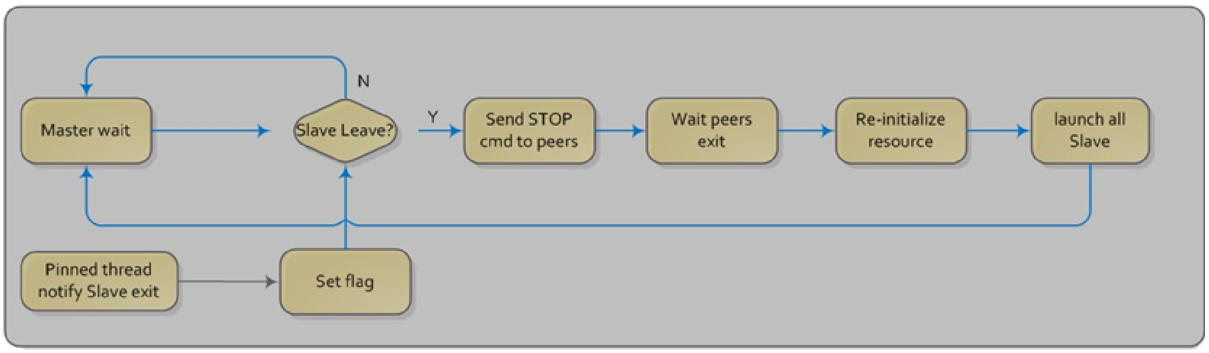


Fig. 21.4: Slave Process Recovery Process Flow

Floating Process Support

When the DPDK application runs, there is always a -c option passed in to indicate the cores that are enabled. Then, the 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 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 DPDK mempool library provides a local cache mechanism (refer to *DPDK Programmer's Guide* , 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 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.

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.

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 accidentally.

```
static int
l2fwd_malloc_shared_struct(void)
{
    port_statistics = rte_zmalloc("port_stat", sizeof(struct l2fwd_port_statistics) * RTE_MAX_F

    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;
}
```

CHAPTER

TWENTYTWO

QOS METERING SAMPLE APPLICATION

The QoS meter sample application is an example that demonstrates the use of 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.

22.1 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.

22.2 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-native-linuxapp-gcc
```

3. Build the application:

   ```
   make
   ```

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

22.4 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 (for example, 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 22.1: 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

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.

CHAPTER

TWENTYTHREE

QOS SCHEDULER SAMPLE APPLICATION

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

23.1 Overview

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

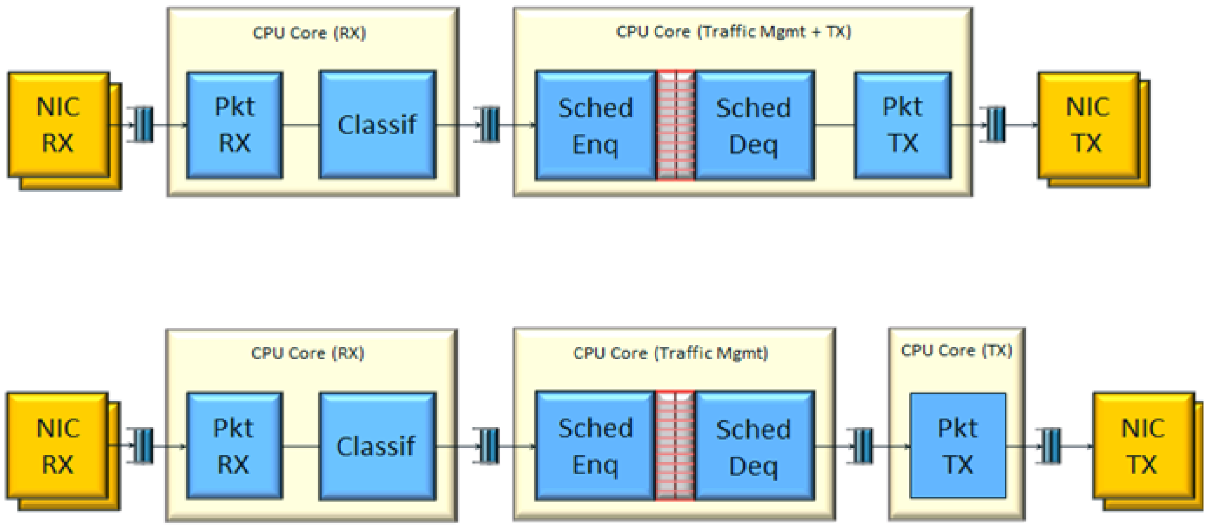


Fig. 23.1: QoS Scheduler Application Architecture

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.

23.2 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-native-linuxapp-gcc
   ```

3. Build the application:

   ```
   make
   ```

Note: 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.

23.3 Running the Application

Note: In order to run the application, a total of at least 4 G 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 *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
```

23.3.1 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.

23.3.2 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.

23.4 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 23.1: 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	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 *DPDK Programmer’s Guide* for more information about these parameters.

CHAPTER

TWENTYFOUR

INTEL® QUICKASSIST TECHNOLOGY SAMPLE APPLICATION

This sample application demonstrates the use of the cryptographic operations provided by the Intel® QuickAssist Technology from within the DPDK environment. Therefore, building and running this application requires having both the 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 either of:

- Intel® Communications Chipset 8900 to 8920 Series Software for Linux* package
- Intel® Communications Chipset 8925 to 8955 Series Software for Linux* package

24.1 Overview

An overview of the application is provided in Fig. 24.1. 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.

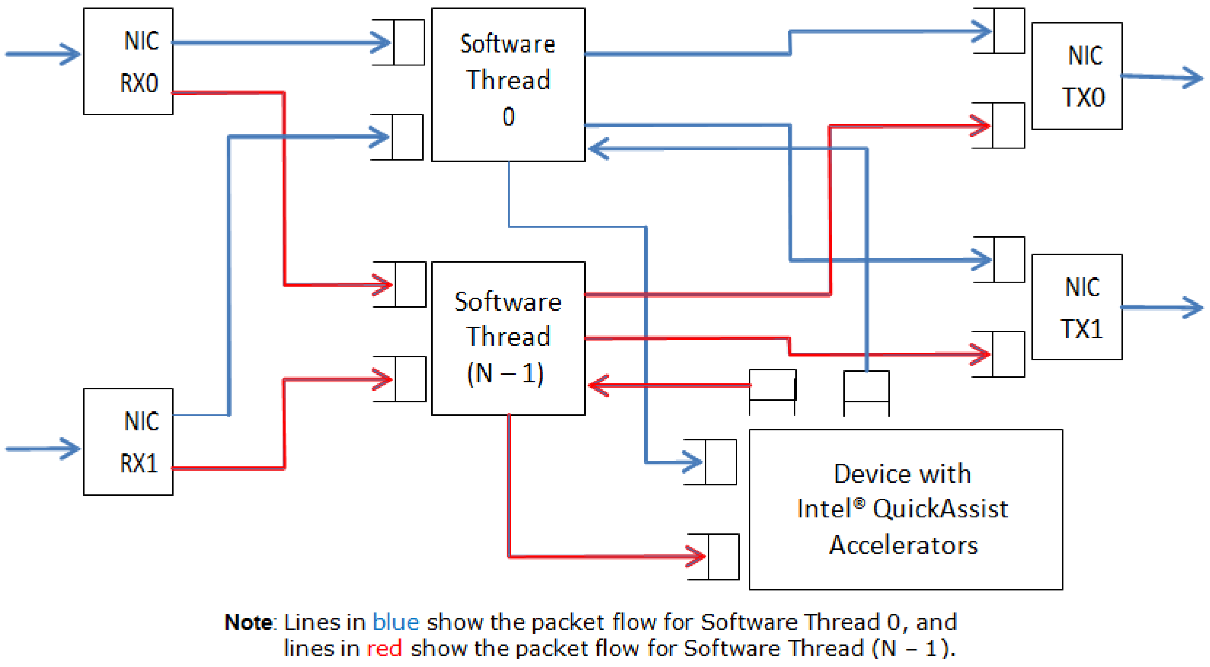

NIC RX0
Software Thread 0
NIC TX0
Software Thread (N – 1)
NIC TX1
NIC RX1
Device with Intel® QuickAssist Accelerators
Note: Lines in blue show the packet flow for Software Thread 0, and lines in red show the packet flow for Software Thread (N – 1).

Fig. 24.1: Intel® QuickAssist Technology Application Block Diagram

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.

24.1.1 Setup

Building and running this application requires having both the 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 DPDK and Intel® QuickAssist Technology applications, please refer to the following documents:

- *DPDK Getting Started Guide*
- Intel® Communications Chipset 8900 to 8920 Series Software for Linux* Getting Started Guide (440005)

- Intel® Communications Chipset 8925 to 8955 Series Software for Linux* Getting Started Guide (523128)

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.

24.2 Building the Application

Steps to build the application:

1. Set up the following environment variables:

   ```
   export RTE_SDK=<Absolute path to the 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-native-linuxapp-gcc
   ```

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

3. Build the application:

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

24.3 Running the Application

24.3.1 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 following sets of configuration files are included in the DPDK package:

- 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
- Coleto Creek: located in the coleto folder
  - dh895xcc_qa_dev0.conf

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 following documents for information on the Intel® QuickAssist Technology configuration files:

- Intel® Communications Chipset 8900 to 8920 Series Software Programmer's Guide

- Intel® Communications Chipset 8925 to 8955 Series Software Programmer's Guide
- Intel® Communications Chipset 8900 to 8920 Series Software for Linux* Getting Started Guide.
- Intel® Communications Chipset 8925 to 8955 Series Software for Linux* Getting Started Guide.

24.3.2 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 Chapter 10 , "L3 Forwarding Sample Application" 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 *DPDK Test Report* 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.

CHAPTER

TWENTYFIVE

QUOTA AND WATERMARK SAMPLE APPLICATION

The Quota and Watermark sample application is a simple example of packet processing using Data Plane Development Kit (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

25.1 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 Fig. 25.1.

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.

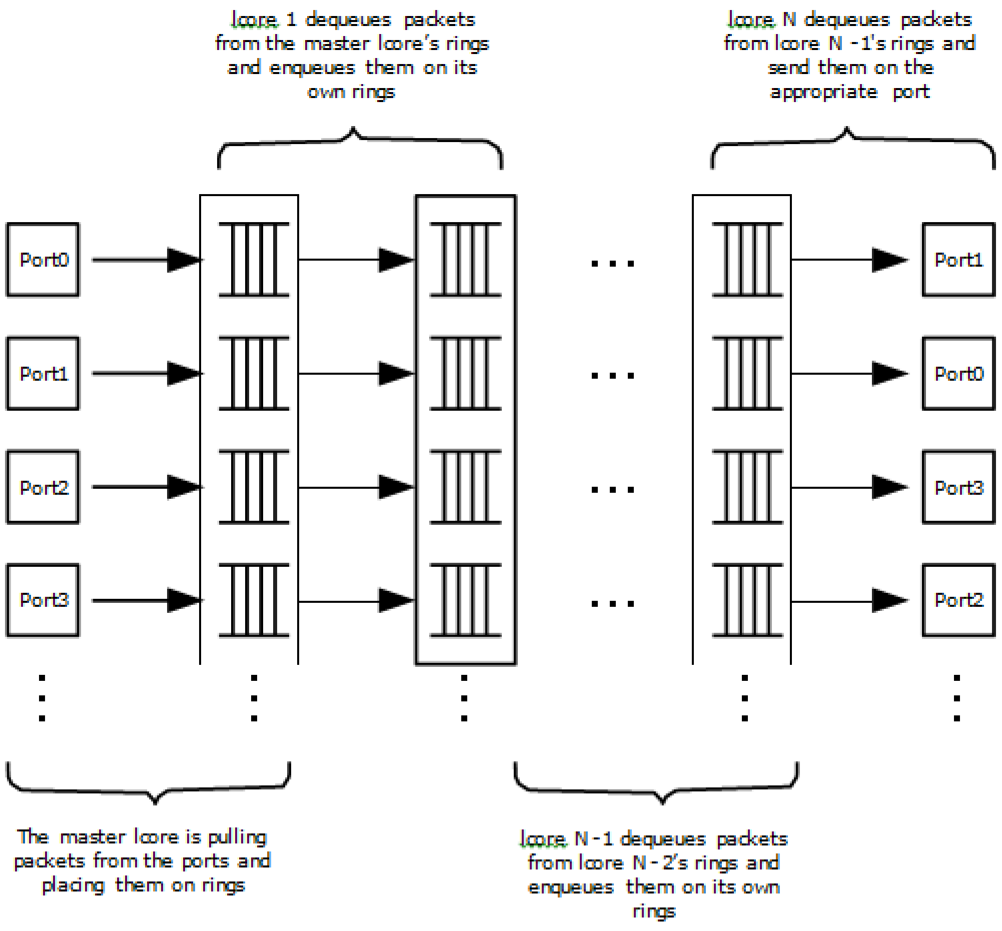

lcore 1 dequeues packets from the master lcore's rings and enqueues them on its own rings
lcore N dequeues packets from lcore N -1's rings and send them on the appropriate port
Port0
Port1
Port2
Port3
Port1
Port0
Port3
Port2
The master lcore is pulling packets from the ports and placing them on rings
lcore N - 1 dequeues packets from lcore N - 2's rings and enqueues them on its own rings

Fig. 25.1: Pipeline Overview

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 Fig. 25.2.

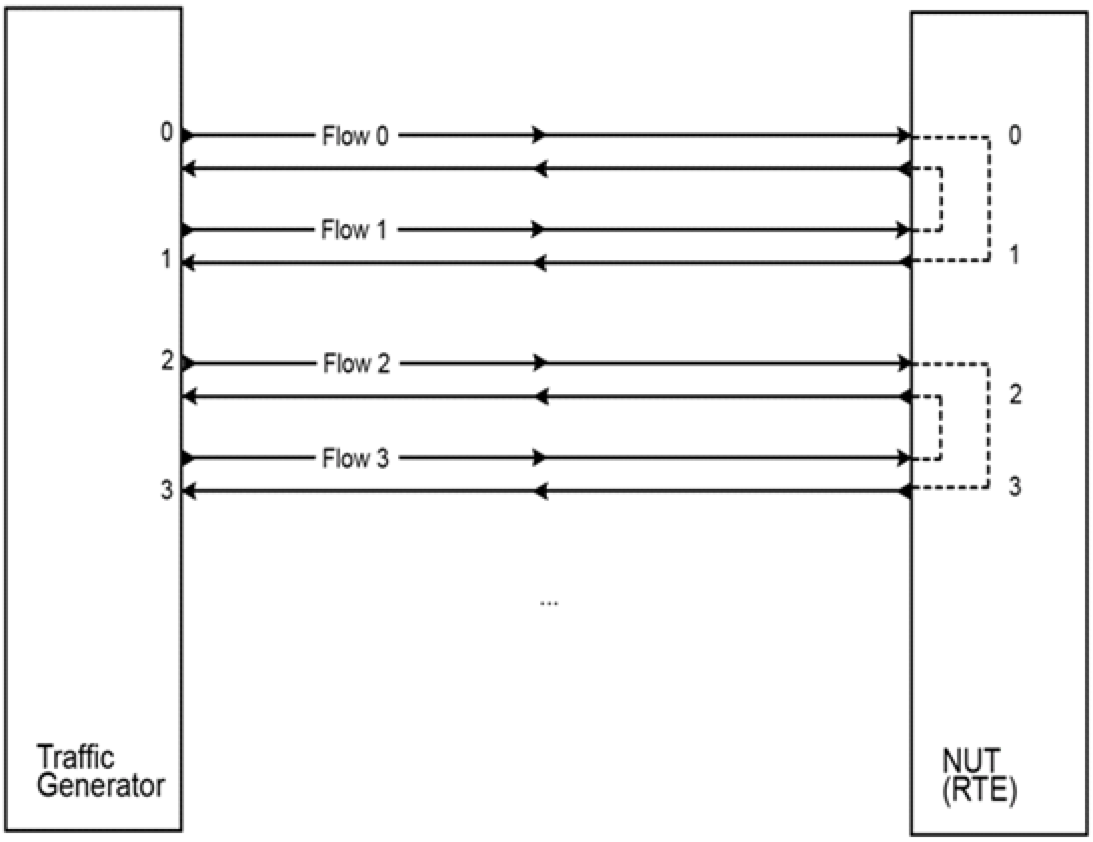


Fig. 25.2: Ring-based Processing Pipeline Performance Setup

25.2 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-native-linuxapp-gcc
```

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

3. Build the application:

```
make
```

25.3 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.

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

25.3.2 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 *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
```

25.4 Code Overview

The following sections provide a quick guide to the application's source code.

25.4.1 Core Application - qw

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;

    /* 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 *DPDK Getting Started Guide* and the *DPDK API Reference*.

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

     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.

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.

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_pkt
    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 pkt mbufs 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.

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 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.

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 Fig. 25.3.

```
/* 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);
```

Receive, Process and Transmit Packets

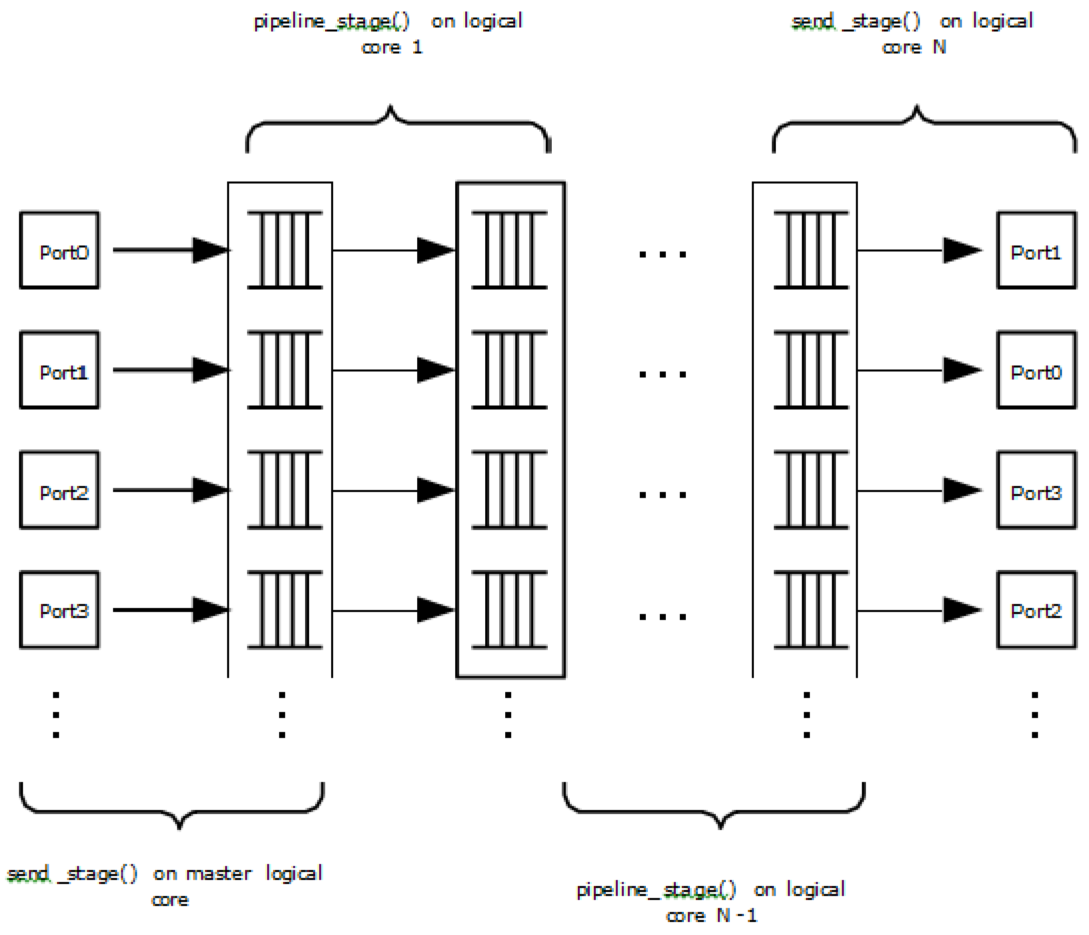

pipeline_stage() on logical core 1
send_stage() on logical core N
Port0
Port1
Port2
Port3
Port1
Port0
Port3
Port2
send_stage() on master logical core
pipeline_stage() on logical core N -1

Fig. 25.3: 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.

25.4.2 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.

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.

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);
}
```

CHAPTER

TWENTYSIX

TIMER SAMPLE APPLICATION

The Timer sample application is a simple application that demonstrates the use of a timer in a DPDK application. This application prints some messages from different lcores regularly, demonstrating the use of timers.

26.1 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-native-linuxapp-gcc
   ```

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

3. Build the application:

   ```
   make
   ```

26.2 Running the Application

To run the example in linuxapp environment:

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

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

26.3 Explanation

The following sections provide some explanation of the code.

26.3.1 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.

26.3.2 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 2

    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);
}
```

CHAPTER

TWENTYSEVEN

PACKET ORDERING APPLICATION

The Packet Ordering sample app simply shows the impact of reordering a stream. It's meant to stress the library with different configurations for performance.

27.1 Overview

The application uses at least three CPU cores:

- RX core (maser core) receives traffic from the NIC ports and feeds Worker cores with traffic through SW queues.
- Worker core (slave core) basically do some light work on the packet. Currently it modifies the output port of the packet for configurations with more than one port enabled.
- TX Core (slave core) receives traffic from Worker cores through software queues, inserts out-of-order packets into reorder buffer, extracts ordered packets from the reorder buffer and sends them to the NIC ports for transmission.

27.2 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-native-linuxapp-gcc
   ```

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

3. Build the application:

   ```
   make
   ```

27.3 Running the Application

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

27.3.1 Application Command Line

The application execution command line is:

```
./test-pipeline [EAL options] -- -p PORTMASK [--disable-reorder]
```

The -c EAL CPU_COREMASK option has to contain at least 3 CPU cores. The first CPU core in the core mask is the master core and would be assigned to RX core, the last to TX core and the rest to Worker cores.

The PORTMASK parameter must contain either 1 or even enabled port numbers. When setting more than 1 port, traffic would be forwarded in pairs. For example, if we enable 4 ports, traffic from port 0 to 1 and from 1 to 0, then the other pair from 2 to 3 and from 3 to 2, having [0,1] and [2,3] pairs.

The disable-reorder long option does, as its name implies, disable the reordering of traffic, which should help evaluate reordering performance impact.

CHAPTER

TWENTYEIGHT

VMDQ AND DCB FORWARDING SAMPLE APPLICATION

The VMDQ and DCB Forwarding sample application is a simple example of packet processing using the 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.

28.1 Overview

This sample application can be used as a starting point for developing a new application that is based on the 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 a 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 Fig. 28.1. 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.

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:

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 , “L2 Forwarding Sample Application (in Real and Virtualized Environments)”) as it performs unidirectional L2 forwarding of packets from one port to

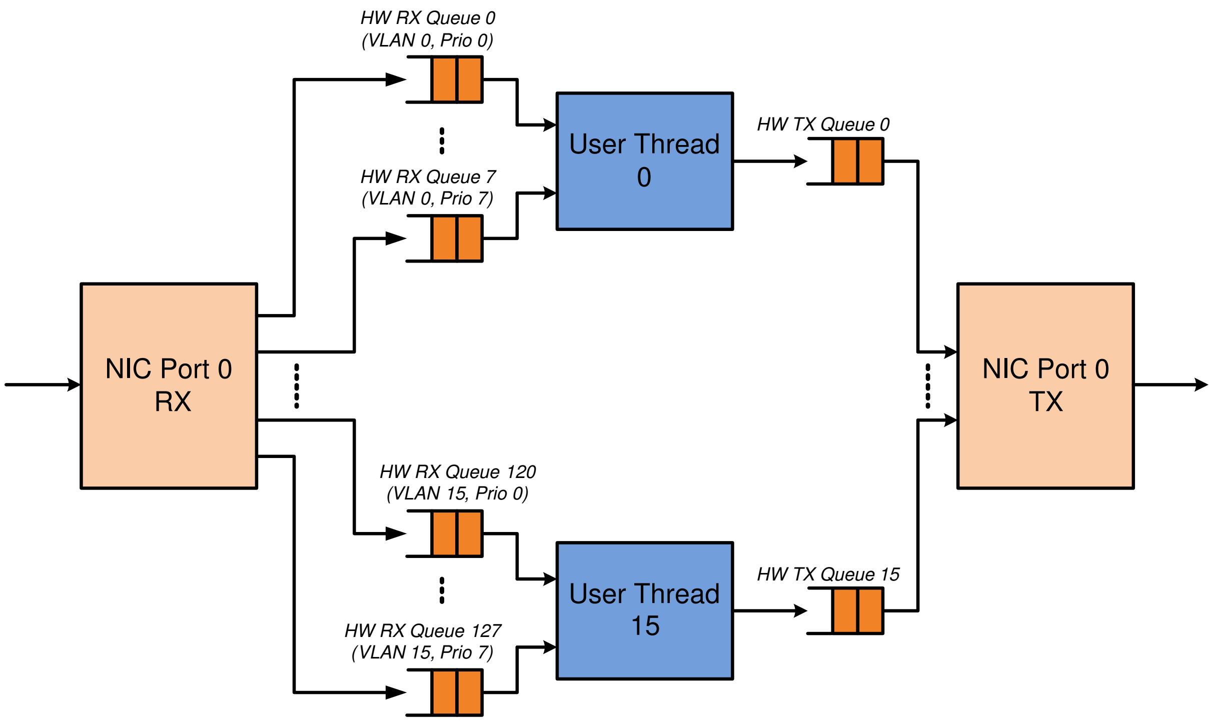


Fig. 28.1: Packet Flow Through the VMDQ and DCB Sample Application

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).

28.2 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-native-linuxapp-gcc
   ```

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

3. Build the application:

   ```
   make
   ```

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

28.4 Explanation

The following sections provide some explanation of the code.

28.4.1 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, “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 programmatically */

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

    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, "L2 Forwarding Sample Application (in Real and Virtualized Environments)" for more information.

28.4.2 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.

CHAPTER

TWENTYNINE

VHOST SAMPLE APPLICATION

The vhost sample application demonstrates integration of the Data Plane Development Kit (DPDK) with the Linux* KVM hypervisor by implementing the vhost-net offload API. The sample application performs simple packet switching between virtual machines based on Media Access Control (MAC) address or Virtual Local Area Network (VLAN) tag. The splitting of Ethernet traffic from an external switch is performed in hardware by the Virtual Machine Device Queues (VMDQ) and Data Center Bridging (DCB) features of the Intel® 82599 10 Gigabit Ethernet Controller.

29.1 Background

Virtio networking (virtio-net) was developed as the Linux* KVM para-virtualized method for communicating network packets between host and guest. It was found that virtio-net performance was poor due to context switching and packet copying between host, guest, and QEMU. The following figure shows the system architecture for a virtio-based networking (virtio-net).

The Linux* Kernel vhost-net module was developed as an offload mechanism for virtio-net. The vhost-net module enables KVM (QEMU) to offload the servicing of virtio-net devices to the vhost-net kernel module, reducing the context switching and packet copies in the virtual dataplane.

This is achieved by QEMU sharing the following information with the vhost-net module through the vhost-net API:

- The layout of the guest memory space, to enable the vhost-net module to translate addresses.
- The locations of virtual queues in QEMU virtual address space, to enable the vhost module to read/write directly to and from the virtqueues.
- An event file descriptor (eventfd) configured in KVM to send interrupts to the virtio- net device driver in the guest. This enables the vhost-net module to notify (call) the guest.
- An eventfd configured in KVM to be triggered on writes to the virtio-net device's Peripheral Component Interconnect (PCI) config space. This enables the vhost-net module to receive notifications (kicks) from the guest.

The following figure shows the system architecture for virtio-net networking with vhost-net offload.

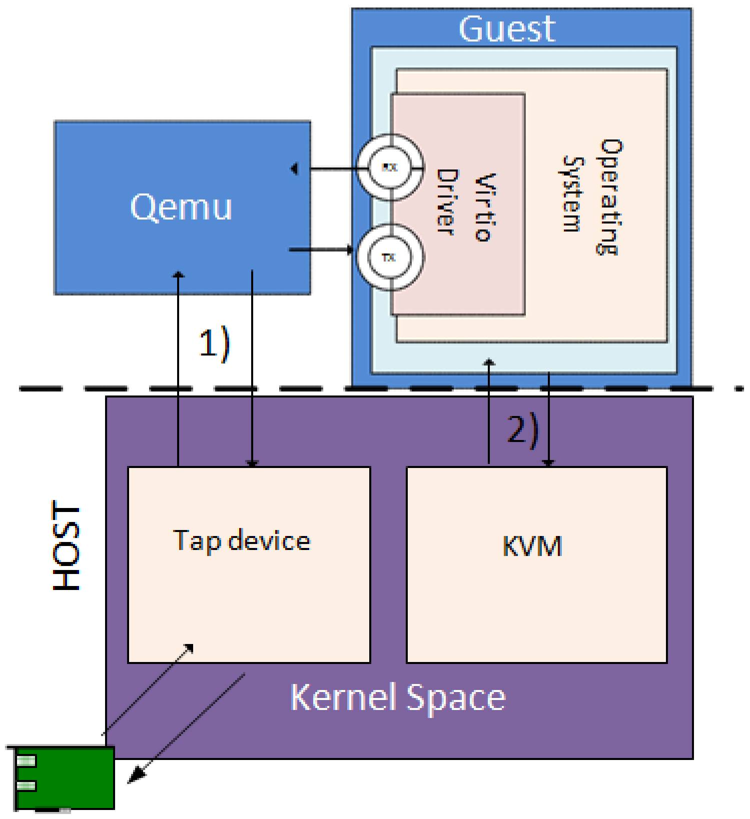


Fig. 29.1: System Architecture for Virtio-based Networking (virtio-net).

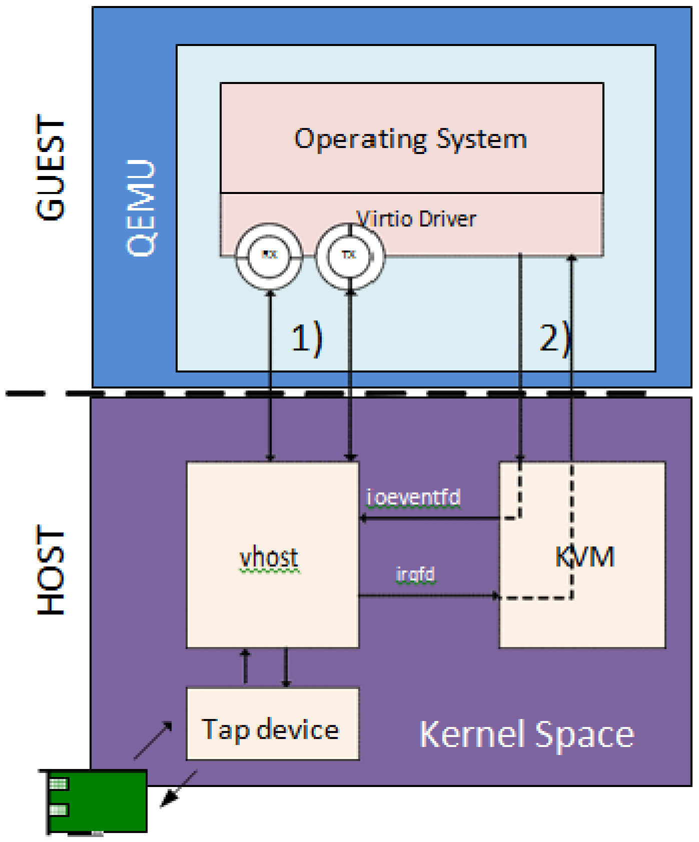


Fig. 29.2: Virtio with Linux

29.2 Sample Code Overview

The DPDK vhost-net sample code demonstrates KVM (QEMU) offloading the servicing of a Virtual Machine's (VM's) virtio-net devices to a DPDK-based application in place of the kernel's vhost-net module.

The DPDK vhost-net sample code is based on vhost library. Vhost library is developed for user space Ethernet switch to easily integrate with vhost functionality.

The vhost library implements the following features:

- Management of virtio-net device creation/destruction events.
- Mapping of the VM's physical memory into the DPDK vhost-net's address space.
- Triggering/receiving notifications to/from VMs via eventfds.
- A virtio-net back-end implementation providing a subset of virtio-net features.

There are two vhost implementations in vhost library, vhost cuse and vhost user. In vhost cuse, a character device driver is implemented to receive and process vhost requests through ioctl messages. In vhost user, a socket server is created to received vhost requests through socket messages. Most of the messages share the same handler routine.

Note: Any vhost cuse specific requirement in the following sections will be emphasized.

Two implementations are turned on and off statically through configure file. Only one implementation could be turned on. They don't co-exist in current implementation.

The vhost sample code application is a simple packet switching application with the following feature:

- Packet switching between virtio-net devices and the network interface card, including using VMDQs to reduce the switching that needs to be performed in software.

The following figure shows the architecture of the Vhost sample application based on vhost-cuse.

The following figure shows the flow of packets through the vhost-net sample application.

29.3 Supported Distributions

The example in this section have been validated with the following distributions:

- Fedora* 18
- Fedora* 19
- Fedora* 20

29.4 Prerequisites

This section lists prerequisite packages that must be installed.

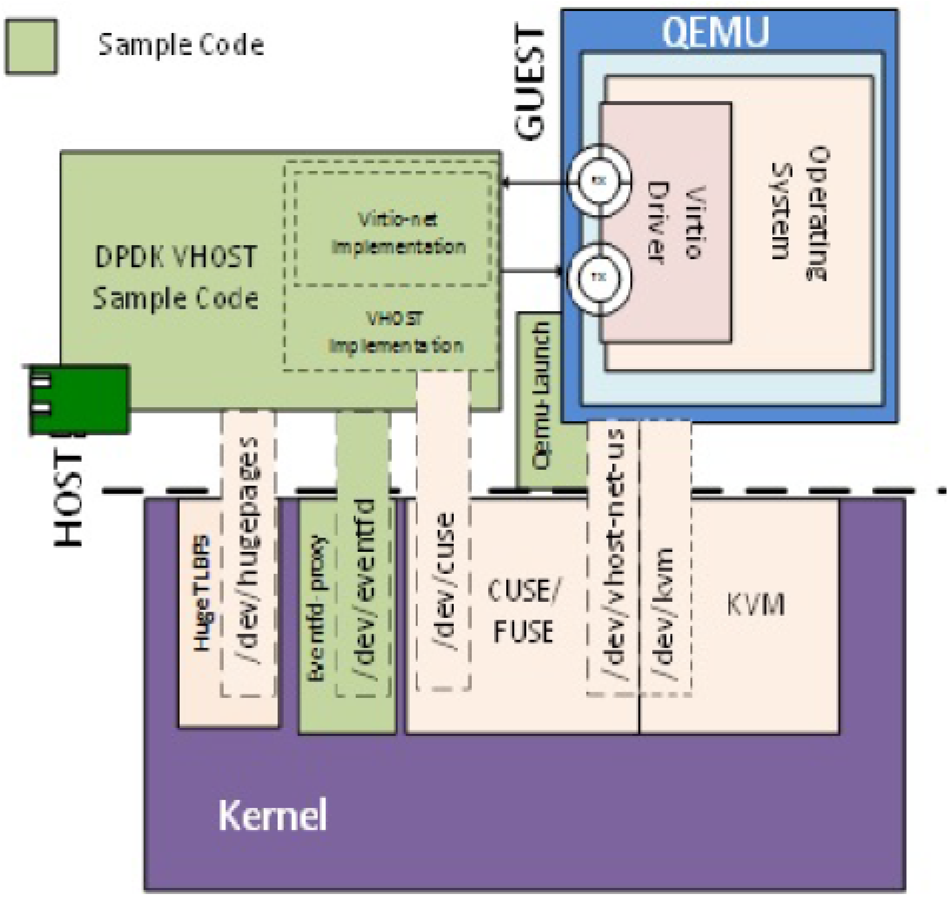


Fig. 29.3: Vhost-net Architectural Overview

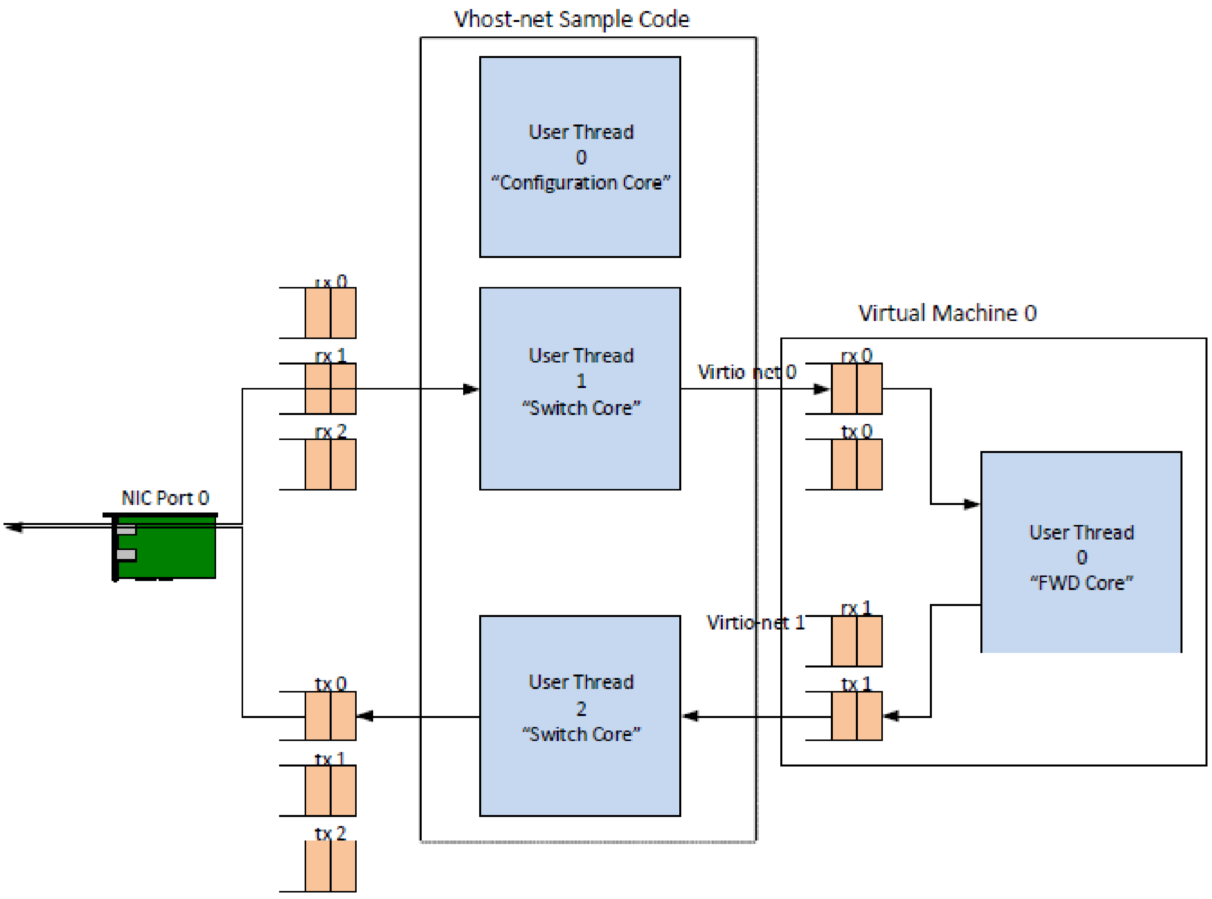


Fig. 29.4: Packet Flow Through the vhost-net Sample Application

29.4.1 Installing Packages on the Host(vhost cuse required)

The vhost cuse code uses the following packages; fuse, fuse-devel, and kernel-modules-extra. The vhost user code don't rely on those modules as eventfds are already installed into vhost process through Unix domain socket.

1. Install Fuse Development Libraries and headers:

   ```
   yum -y install fuse fuse-devel
   ```

2. Install the Cuse Kernel Module:

   ```
   yum -y install kernel-modules-extra
   ```

29.4.2 QEMU simulator

For vhost user, qemu 2.2 is required.

29.4.3 Setting up the Execution Environment

The vhost sample code requires that QEMU allocates a VM's memory on the hugetlbfs file system. As the vhost sample code requires hugepages, the best practice is to partition the system into separate hugepage mount points for the VMs and the vhost sample code.

Note: This is best-practice only and is not mandatory. For systems that only support 2 MB page sizes, both QEMU and vhost sample code can use the same hugetlbfs mount point without issue.

QEMU

VMs with gigabytes of memory can benefit from having QEMU allocate their memory from 1 GB huge pages. 1 GB huge pages must be allocated at boot time by passing kernel parameters through the grub boot loader.

1. Calculate the maximum memory usage of all VMs to be run on the system. Then, round this value up to the nearest Gigabyte the execution environment will require.

2. Edit the /etc/default/grub file, and add the following to the GRUB_CMDLINE_LINUX entry:

   ```
   GRUB_CMDLINE_LINUX="... hugepagesz=1G hugepages=<Number of hugepages required> default_hug
   ```

3. Update the grub boot loader:

   ```
   grub2-mkconfig -o /boot/grub2/grub.cfg
   ```

4. Reboot the system.

5. The hugetlbfs mount point (/dev/hugepages) should now default to allocating gigabyte pages.

Note: Making the above modification will change the system default hugepage size to 1 GB for all applications.

Vhost Sample Code

In this section, we create a second hugetlbs mount point to allocate hugepages for the DPDK vhost sample code.

1. Allocate sufficient 2 MB pages for the DPDK vhost sample code:

   ```
   echo 256 > /sys/kernel/mm/hugepages/hugepages-2048kB/nr_hugepages
   ```

2. Mount hugetlbs at a separate mount point for 2 MB pages:

   ```
   mount -t hugetlbfs nodev /mnt/huge -o pagesize=2M
   ```

The above steps can be automated by doing the following:

1. Edit /etc/fstab to add an entry to automatically mount the second hugetlbfs mount point:

   ```
   hugetlbfs <tab> /mnt/huge <tab> hugetlbfs defaults,pagesize=1G 0 0
   ```

2. Edit the /etc/default/grub file, and add the following to the GRUB_CMDLINE_LINUX entry:

   ```
   GRUB_CMDLINE_LINUX="... hugepagesz=2M hugepages=256 ... default_hugepagesz=1G"
   ```

3. Update the grub bootloader:

   ```
   grub2-mkconfig -o /boot/grub2/grub.cfg
   ```

4. Reboot the system.

Note: Ensure that the default hugepage size after this setup is 1 GB.

29.4.4 Setting up the Guest Execution Environment

It is recommended for testing purposes that the DPDK testpmd sample application is used in the guest to forward packets, the reasons for this are discussed in Section 22.7, “Running the Virtual Machine (QEMU)”.

The testpmd application forwards packets between pairs of Ethernet devices, it requires an even number of Ethernet devices (virtio or otherwise) to execute. It is therefore recommended to create multiples of two virtio-net devices for each Virtual Machine either through libvirt or at the command line as follows.

Note: Observe that in the example, “-device” and “-netdev” are repeated for two virtio-net devices.

For vhost cuse:

```
qemu-system-x86_64 ... \
-netdev tap,id=hostnet1,vhost=on,vhostfd=<open fd> \
-device virtio-net-pci, netdev=hostnet1,id=net1 \
-netdev tap,id=hostnet2,vhost=on,vhostfd=<open fd> \
-device virtio-net-pci, netdev=hostnet2,id=net1
```

For vhost user:

```
qemu-system-x86_64 ... \
-chardev socket,id=char1,path=<sock_path> \
-netdev type=vhost-user,id=hostnet1,chardev=char1 \
-device virtio-net-pci,netdev=hostnet1,id=net1 \
-chardev socket,id=char2,path=<sock_path> \
-netdev type=vhost-user,id=hostnet2,chardev=char2 \
-device virtio-net-pci,netdev=hostnet2,id=net2
```

sock_path is the path for the socket file created by vhost.

29.5 Compiling the Sample Code

1. Compile vhost lib:

   To enable vhost, turn on vhost library in the configure file config/common_linuxapp.

   ```
   CONFIG_RTE_LIBRTE_VHOST=n
   ```

   vhost user is turned on by default in the configure file config/common_linuxapp. To enable vhost cuse, disable vhost user.

   ```
      CONFIG_RTE_LIBRTE_VHOST_USER=y

   After vhost is enabled and the implementation is selected, build the vhost library.
   ```

2. Go to the examples directory:

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

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

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

   See the DPDK Getting Started Guide for possible RTE_TARGET values.

4. Build the application:

   ```
   cd ${RTE_SDK}
   make config ${RTE_TARGET}
   make install ${RTE_TARGET}
   cd ${RTE_SDK}/examples/vhost
   make
   ```

5. Go to the eventfd_link directory(vhost cuse required):

   ```
   cd ${RTE_SDK}/lib/librte_vhost/eventfd_link
   ```

6. Build the eventfd_link kernel module(vhost cuse required):

   ```
   make
   ```

29.6 Running the Sample Code

1. Install the cuse kernel module(vhost cuse required):

   ```
   modprobe cuse
   ```

2. Go to the eventfd_link directory(vhost cuse required):

   ```
   export RTE_SDK=/path/to/rte_sdk
   cd ${RTE_SDK}/lib/librte_vhost/eventfd_link
   ```

3. Install the eventfd_link module(vhost cuse required):

   ```
   insmod ./eventfd_link.ko
   ```

4. Go to the examples directory:

   ```
   export RTE_SDK=/path/to/rte_sdk
   cd ${RTE_SDK}/examples/vhost/build/app
   ```

5. Run the vhost-switch sample code:

   vhost cuse:

   ```
   ./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
    -- -p 0x1 --dev-basename usvhost
   ```

   vhost user: a socket file named usvhost will be created under current directory. Use its path as the socket path in guest's qemu commandline.

   ```
   ./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
    -- -p 0x1 --dev-basename usvhost
   ```

Note: Please note the huge-dir parameter instructs the DPDK to allocate its memory from the 2 MB page hugetlbfs.

Note: The number used with the –socket-mem parameter may need to be more than 1024. The number required depends on the number of mbufs allocated by vhost-switch.

29.6.1 Parameters

Basename. vhost cuse uses a Linux* character device to communicate with QEMU. The basename is used to generate the character devices name.

/dev/<basename>

For compatibility with the QEMU wrapper script, a base name of "usvhost" should be used:

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- -p 0x1 --dev-basename usvhost
```

vm2vm. The vm2vm parameter disable/set mode of packet switching between guests in the host. Value of "0" means disabling vm2vm implies that on virtual machine packet transmission will always go to the Ethernet port; Value of "1" means software mode packet forwarding between guests, it needs packets copy in vHOST, so valid only in one-copy implementation, and invalid for zero copy implementation; value of "2" means hardware mode packet forwarding between guests, it allows packets go to the Ethernet port, hardware L2 switch will determine which guest the packet should forward to or need send to external, which bases on the packet destination MAC address and VLAN tag.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --vm2vm [0,1,2]
```

Mergeable Buffers. The mergeable buffers parameter controls how virtio-net descriptors are used for virtio-net headers. In a disabled state, one virtio-net header is used per packet buffer; in an enabled state one virtio-net header is used for multiple packets. The default value is 0 or disabled since recent kernels virtio-net drivers show performance degradation with this feature is enabled.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --mergeable [0,1]
```

Stats. The stats parameter controls the printing of virtio-net device statistics. The parameter specifies an interval second to print statistics, with an interval of 0 seconds disabling statistics.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
-- --stats [0,n]
```

RX Retry. The rx-retry option enables/disables enqueue retries when the guests RX queue is full. This feature resolves a packet loss that is observed at high data-rates, by allowing it to delay and retry in the receive path. This option is enabled by default.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --rx-retry [0,1]
```

RX Retry Number. The rx-retry-num option specifies the number of retries on an RX burst, it takes effect only when rx retry is enabled. The default value is 4.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --rx-retry 1 --rx-retry-num 5
```

RX Retry Delay Time. The rx-retry-delay option specifies the timeout (in micro seconds) between retries on an RX burst, it takes effect only when rx retry is enabled. The default value is 15.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --rx-retry 1 --rx-retry-delay 20
```

Zero copy. The zero copy option enables/disables the zero copy mode for RX/TX packet, in the zero copy mode the packet buffer address from guest translate into host physical address and then set directly as DMA address. If the zero copy mode is disabled, then one copy mode is utilized in the sample. This option is disabled by default.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --zero-copy [0,1]
```

RX descriptor number. The RX descriptor number option specify the Ethernet RX descriptor number, Linux legacy virtio-net has different behavior in how to use the vring descriptor from DPDK based virtio-net PMD, the former likely allocate half for virtio header, another half for frame buffer, while the latter allocate all for frame buffer, this lead to different number for available frame buffer in vring, and then lead to different Ethernet RX descriptor number could be used in zero copy mode. So it is valid only in zero copy mode is enabled. The value is 32 by default.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --zero-copy 1 --rx-desc-num [0, n]
```

TX descriptor number. The TX descriptor number option specify the Ethernet TX descriptor number, it is valid only in zero copy mode is enabled. The value is 64 by default.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --zero-copy 1 --tx-desc-num [0, n]
```

VLAN strip. The VLAN strip option enable/disable the VLAN strip on host, if disabled, the guest will receive the packets with VLAN tag. It is enabled by default.

```
./vhost-switch -c f -n 4 --socket-mem 1024 --huge-dir /mnt/huge \
 -- --vlan-strip [0, 1]
```

29.7 Running the Virtual Machine (QEMU)

QEMU must be executed with specific parameters to:

- Ensure the guest is configured to use virtio-net network adapters.

  ```
  qemu-system-x86_64 ... -device virtio-net-pci,netdev=hostnet1, \
  id=net1 ...
  ```

- Ensure the guest's virtio-net network adapter is configured with offloads disabled.

```
qemu-system-x86_64 ... -device virtio-net-pci,netdev=hostnet1, \
id=net1, csum=off,gso=off,guest_tso4=off,guest_tso6=off,guest_ecn=off
```

- Redirect QEMU to communicate with the DPDK vhost-net sample code in place of the vhost-net kernel module(vhost cuse).

  ```
  qemu-system-x86_64 ... -netdev tap,id=hostnet1,vhost=on, \
  vhostfd=<open fd> ...
  ```

- Enable the vhost-net sample code to map the VM's memory into its own process address space.

  ```
  qemu-system-x86_64 ... -mem-prealloc -mem-path /dev/hugepages ...
  ```

Note: The QEMU wrapper (qemu-wrap.py) is a Python script designed to automate the QEMU configuration described above. It also facilitates integration with libvirt, although the script may also be used standalone without libvirt.

29.7.1 Redirecting QEMU to vhost-net Sample Code(vhost cuse)

To redirect QEMU to the vhost-net sample code implementation of the vhost-net API, an open file descriptor must be passed to QEMU running as a child process.

```
#!/usr/bin/python
fd = os.open("/dev/usvhost-1", os.O_RDWR)
subprocess.call
("qemu-system-x86_64 ... -netdev tap,id=vhostnet0,vhost=on,vhostfd="
  + fd +"...", shell=True)
```

Note: This process is automated in the QEMU wrapper script discussed in Section 24.7.3.

29.7.2 Mapping the Virtual Machine's Memory

For the DPDK vhost-net sample code to be run correctly, QEMU must allocate the VM's memory on hugetlbfs. This is done by specifying mem-prealloc and mem-path when executing QEMU. The vhost-net sample code accesses the virtio-net device's virtual rings and packet buffers by finding and mapping the VM's physical memory on hugetlbfs. In this case, the path passed to the guest should be that of the 1 GB page hugetlbfs:

```
qemu-system-x86_64 ... -mem-prealloc -mem-path /dev/hugepages ...
```

Note: This process is automated in the QEMU wrapper script discussed in Section 24.7.3. The following two sections only applies to vhost cuse. For vhost-user, please make corresponding changes to qemu-wrapper script and guest XML file.

29.7.3 QEMU Wrapper Script

The QEMU wrapper script automatically detects and calls QEMU with the necessary parameters required to integrate with the vhost sample code. It performs the following actions:

- Automatically detects the location of the hugetlbfs and inserts this into the command line parameters.

- Automatically open file descriptors for each virtio-net device and inserts this into the command line parameters.
- Disables offloads on each virtio-net device.
- Calls Qemu passing both the command line parameters passed to the script itself and those it has auto-detected.

The QEMU wrapper script will automatically configure calls to QEMU:

```
qemu-wrap.py -machine pc-i440fx-1.4,accel=kvm,usb=off \
-cpu SandyBridge -smp 4,sockets=4,cores=1,threads=1 \
-netdev tap,id=hostnet1,vhost=on \
-device virtio-net-pci,netdev=hostnet1,id=net1 \
-hda <disk img> -m 4096
```

which will become the following call to QEMU:

```
qemu-system-x86_64 -machine pc-i440fx-1.4,accel=kvm,usb=off \
-cpu SandyBridge -smp 4,sockets=4,cores=1,threads=1 \
-netdev tap,id=hostnet1,vhost=on,vhostfd=<open fd> \
-device virtio-net-pci,netdev=hostnet1,id=net1, \
csum=off,gso=off,guest_tso4=off,guest_tso6=off,guest_ecn=off \
-hda <disk img> -m 4096 -mem-path /dev/hugepages -mem-prealloc
```

29.7.4 Libvirt Integration

The QEMU wrapper script (qemu-wrap.py) “wraps” libvirt calls to QEMU, such that QEMU is called with the correct parameters described above. To call the QEMU wrapper automatically from libvirt, the following configuration changes must be made:

- Place the QEMU wrapper script in libvirt’s binary search PATH ($PATH). A good location is in the directory that contains the QEMU binary.
- Ensure that the script has the same owner/group and file permissions as the QEMU binary.
- Update the VM xml file using virsh edit <vm name>:
  - Set the VM to use the launch script
  - Set the emulator path contained in the #<emulator><emulator/> tags For example, replace <emulator>/usr/bin/qemu-kvm<emulator/> with <emulator>/usr/bin/qemu-wrap.py<emulator/>
  - Set the VM’s virtio-net device’s to use vhost-net offload:

    ```
    <interface type="network">
    <model type="virtio"/>
    <driver name="vhost"/>
    <interface/>
    ```

  - Enable libvirt to access the DPDK Vhost sample code’s character device file by adding it to controllers cgroup for libvirtd using the following steps:

    ```
    cgroup_controllers = [ ... "devices", ... ] clear_emulator_capabilities = 0
    user = "root" group = "root"
    cgroup_device_acl = [
        "/dev/null", "/dev/full", "/dev/zero",
        "/dev/random", "/dev/urandom",
        "/dev/ptmx", "/dev/kvm", "/dev/kqemu",
        "/dev/rtc", "/dev/hpet", "/dev/net/tun",
    ```

```
            "/dev/<devbase-name>-<index>",
        ]
```

- Disable SELinux or set to permissive mode.
- Mount cgroup device controller:

  ```
  mkdir /dev/cgroup
  mount -t cgroup none /dev/cgroup -o devices
  ```

- Restart the libvirtd system process

  For example, on Fedora* "systemctl restart libvirtd.service"

- Edit the configuration parameters section of the script:
  - Configure the "emul_path" variable to point to the QEMU emulator.

    ```
    emul_path = "/usr/local/bin/qemu-system-x86_64"
    ```

  - Configure the "us_vhost_path" variable to point to the DPDK vhost-net sample code's character devices name. DPDK vhost-net sample code's character device will be in the format "/dev/<basename>".

    ```
    us_vhost_path = "/dev/usvhost"
    ```

29.7.5 Common Issues

- QEMU failing to allocate memory on hugetlbfs, with an error like the following:

  ```
  file_ram_alloc: can't mmap RAM pages: Cannot allocate memory
  ```

  When running QEMU the above error indicates that it has failed to allocate memory for the Virtual Machine on the hugetlbfs. This is typically due to insufficient hugepages being free to support the allocation request. The number of free hugepages can be checked as follows:

  ```
  cat /sys/kernel/mm/hugepages/hugepages-<pagesize>/nr_hugepages
  ```

  The command above indicates how many hugepages are free to support QEMU's allocation request.

- User space VHOST when the guest has 2MB sized huge pages:

  The guest may have 2MB or 1GB sized huge pages. The user space VHOST should work properly in both cases.

- User space VHOST will not work with QEMU without the `-mem-prealloc` option:

  The current implementation works properly only when the guest memory is pre-allocated, so it is required to use a QEMU version (e.g. 1.6) which supports `-mem-prealloc`. The `-mem-prealloc` option must be specified explicitly in the QEMU command line.

- User space VHOST will not work with a QEMU version without shared memory mapping:

  As shared memory mapping is mandatory for user space VHOST to work properly with the guest, user space VHOST needs access to the shared memory from the guest to receive and transmit packets. It is important to make sure the QEMU version supports shared memory mapping.

- In an Ubuntu environment, QEMU fails to start a new guest normally with user space VHOST due to not being able to allocate huge pages for the new guest:

The solution for this issue is to add `-boot c` into the QEMU command line to make sure the huge pages are allocated properly and then the guest should start normally.

Use `cat /proc/meminfo` to check if there is any changes in the value of `HugePages_Total` and `HugePages_Free` after the guest startup.

- Log message: `eventfd_link: module verification failed: signature and/or required key missing - tainting kernel`:

  This log message may be ignored. The message occurs due to the kernel module `eventfd_link`, which is not a standard Linux module but which is necessary for the user space VHOST current implementation (CUSE-based) to communicate with the guest.

29.8 Running DPDK in the Virtual Machine

For the DPDK vhost-net sample code to switch packets into the VM, the sample code must first learn the MAC address of the VM's virtio-net device. The sample code detects the address from packets being transmitted from the VM, similar to a learning switch.

This behavior requires no special action or configuration with the Linux* virtio-net driver in the VM as the Linux* Kernel will automatically transmit packets during device initialization. However, DPDK-based applications must be modified to automatically transmit packets during initialization to facilitate the DPDK vhost- net sample code's MAC learning.

The DPDK testpmd application can be configured to automatically transmit packets during initialization and to act as an L2 forwarding switch.

29.8.1 Testpmd MAC Forwarding

At high packet rates, a minor packet loss may be observed. To resolve this issue, a "wait and retry" mode is implemented in the testpmd and vhost sample code. In the "wait and retry" mode if the virtqueue is found to be full, then testpmd waits for a period of time before retrying to enqueue packets.

The "wait and retry" algorithm is implemented in DPDK testpmd as a forwarding method call "mac_retry". The following sequence diagram describes the algorithm in detail.

29.8.2 Running Testpmd

The testpmd application is automatically built when DPDK is installed. Run the testpmd application as follows:

```
cd ${RTE_SDK}/x86_64-native-linuxapp-gcc/app
./testpmd -c 0x3 -n 4 --socket-mem 512 \
-- --burst=64 --i --disable-hw-vlan-filter
```

The destination MAC address for packets transmitted on each port can be set at the command line:

```
./testpmd -c 0x3 -n 4 --socket-mem 512 \
-- --burst=64 --i --disable-hw-vlan-filter \
--eth-peer=0,aa:bb:cc:dd:ee:ff --eth-peer=1,ff:ee:dd:cc:bb:aa
```

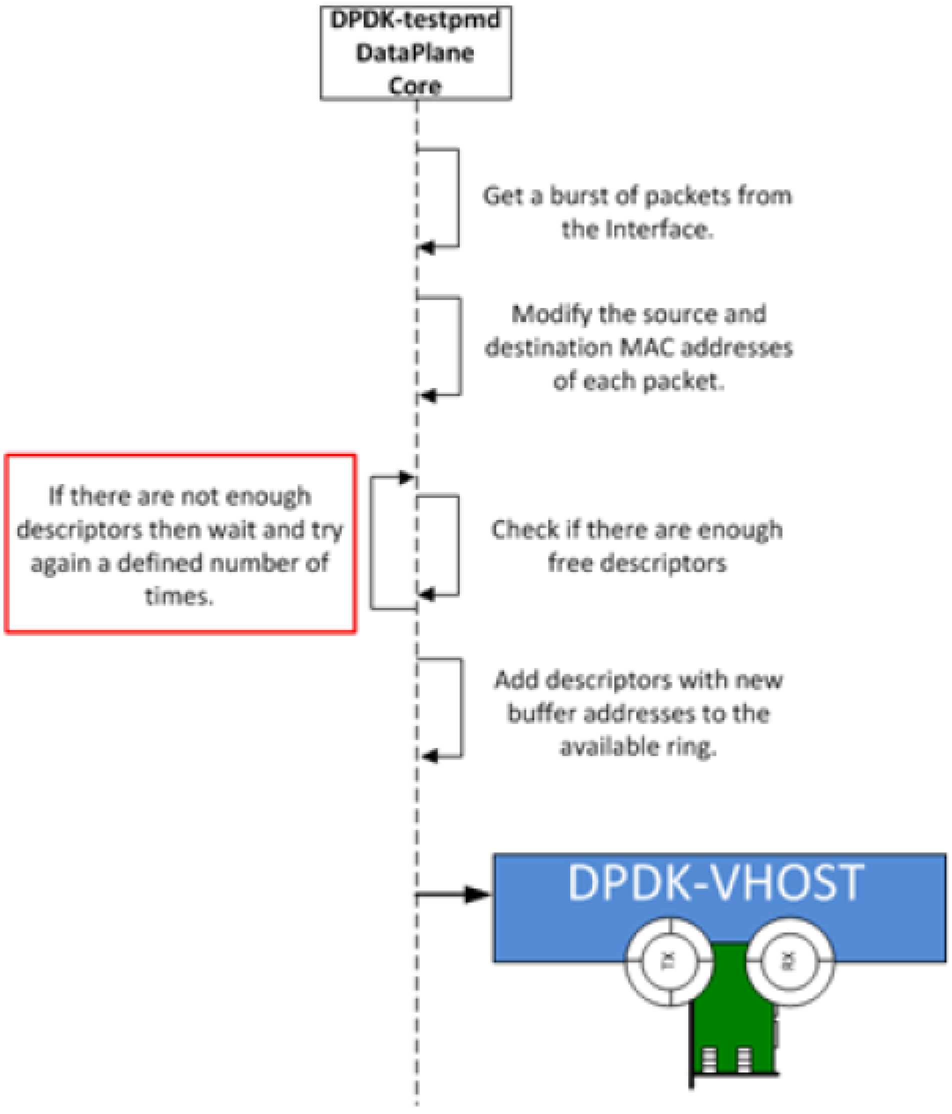

DPDK-testpmd DataPlane Core
Get a burst of packets from the Interface.
Modify the source and destination MAC addresses of each packet.
If there are not enough descriptors then wait and try again a defined number of times.
Check if there are enough free descriptors
Add descriptors with new buffer addresses to the available ring.
DPDK-VHOST
TX
RX

Fig. 29.5: Packet Flow on TX in DPDK-testpmd

- Packets received on port 1 will be forwarded on port 0 to MAC address

  aa:bb:cc:dd:ee:ff
- Packets received on port 0 will be forwarded on port 1 to MAC address

  ff:ee:dd:cc:bb:aa

The testpmd application can then be configured to act as an L2 forwarding application:

```
testpmd> set fwd mac_retry
```

The testpmd can then be configured to start processing packets, transmitting packets first so the DPDK vhost sample code on the host can learn the MAC address:

```
testpmd> start tx_first
```

Note: Please note "set fwd mac_retry" is used in place of "set fwd mac_fwd" to ensure the retry feature is activated.

29.9 Passing Traffic to the Virtual Machine Device

For a virtio-net device to receive traffic, the traffic's Layer 2 header must include both the virtio-net device's MAC address and VLAN tag. The DPDK sample code behaves in a similar manner to a learning switch in that it learns the MAC address of the virtio-net devices from the first transmitted packet. On learning the MAC address, the DPDK vhost sample code prints a message with the MAC address and VLAN tag virtio-net device. For example:

```
DATA: (0) MAC_ADDRESS cc:bb:bb:bb:bb:bb and VLAN_TAG 1000 registered
```

The above message indicates that device 0 has been registered with MAC address cc:bb:bb:bb:bb:bb and VLAN tag 1000. Any packets received on the NIC with these values is placed on the devices receive queue. When a virtio-net device transmits packets, the VLAN tag is added to the packet by the DPDK vhost sample code.

CHAPTER

THIRTY

NETMAP COMPATIBILITY SAMPLE APPLICATION

30.1 Introduction

The Netmap compatibility library provides a minimal set of APIs to give programs written against the Netmap APIs the ability to be run, with minimal changes to their source code, using the DPDK to perform the actual packet I/O.

Since Netmap applications use regular system calls, like `open()`, `ioctl()` and `mmap()` to communicate with the Netmap kernel module performing the packet I/O, the `compat_netmap` library provides a set of similar APIs to use in place of those system calls, effectively turning a Netmap application into a DPDK application.

The provided library is currently minimal and doesn't support all the features that Netmap supports, but is enough to run simple applications, such as the bridge example detailed below.

Knowledge of Netmap is required to understand the rest of this section. Please refer to the Netmap distribution for details about Netmap.

30.2 Available APIs

The library provides the following drop-in replacements for system calls usually used in Netmap applications:

- `rte_netmap_close()`
- `rte_netmap_ioctl()`
- `rte_netmap_open()`
- `rte_netmap_mmap()`
- `rte_netmap_poll()`

They use the same signature as their libc counterparts, and can be used as drop-in replacements in most cases.

30.3 Caveats

Given the difference between the way Netmap and the DPDK approach packet I/O, there are caveats and limitations to be aware of when trying to use the `compat_netmap` library, the most important of these are listed below. These may change as the library is updated:

- Any system call that can potentially affect file descriptors cannot be used with a descriptor returned by the `rte_netmap_open()` function.

Note that:

- The `rte_netmap_mmap()` function merely returns the address of a DPDK memzone. The address, length, flags, offset, and other arguments are ignored.
- The `rte_netmap_poll()` function only supports infinite (negative) or zero time outs. It effectively turns calls to the `poll()` system call made in a Netmap application into polling of the DPDK ports, changing the semantics of the usual POSIX defined poll.
- Not all of Netmap's features are supported: host rings, slot flags and so on are not supported or are simply not relevant in the DPDK model.
- The Netmap manual page states that "*a device obtained through /dev/netmap also supports the ioctl supported by network devices*". This is not the case with this compatibility layer.
- The Netmap kernel module exposes a sysfs interface to change some internal parameters, such as the size of the shared memory region. This interface is not available when using this compatibility layer.

30.4 Porting Netmap Applications

Porting Netmap applications typically involves two major steps:

- Changing the system calls to use their `compat_netmap` library counterparts.
- Adding further DPDK initialization code.

Since the `compat_netmap` functions have the same signature as the usual libc calls, the change is trivial in most cases.

The usual DPDK initialization code involving `rte_eal_init()` and `rte_eal_pci_probe()` has to be added to the Netmap application in the same way it is used in all other DPDK sample applications. Please refer to the *DPDK Programmer's Guide* and example source code for details about initialization.

In addition of the regular DPDK initialization code, the ported application needs to call initialization functions for the `compat_netmap` library, namely `rte_netmap_init()` and `rte_netmap_init_port()`.

These two initialization functions take `compat_netmap` specific data structures as parameters: `struct rte_netmap_conf` and `struct rte_netmap_port_conf`. The structures' fields are Netmap related and are self-explanatory for developers familiar with Netmap. They are defined in `$RTE_SDK/examples/netmap_compat/lib/compat_netmap.h`.

The bridge application is an example largely based on the bridge example shipped with the Netmap distribution. It shows how a minimal Netmap application with minimal and straightforward source code changes can be run on top of the DPDK. Please refer to `$RTE_SDK/examples/netmap_compat/bridge/bridge.c` for an example of a ported application.

30.5 Compiling the “bridge” Sample Application

1. Go to the example directory:

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

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

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

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

3. Build the application:

   ```
   make
   ```

30.6 Running the “bridge” Sample Application

The application requires a single command line option:

```
./build/bridge [EAL options] -- -i INTERFACE_A [-i INTERFACE_B]
```

where,

- `-i INTERFACE`: Interface (DPDK port number) to use.

  If a single `-i` parameter is given, the interface will send back all the traffic it receives. If two `-i` parameters are given, the two interfaces form a bridge, where traffic received on one interface is replicated and sent to the other interface.

For example, to run the application in a linuxapp environment using port 0 and 2:

```
./build/bridge [EAL options] -- -i 0 -i 2
```

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

Note that unlike a traditional bridge or the `l2fwd` sample application, no MAC address changes are done on the frames. Do not forget to take this into account when configuring a traffic generators and testing this sample application.

CHAPTER

THIRTYONE

INTERNET PROTOCOL (IP) PIPELINE APPLICATION

31.1 Application overview

The *Internet Protocol (IP) Pipeline* application is intended to be a vehicle for rapid development of packet processing applications running on multi-core CPUs.

The application provides a library of reusable functional blocks called pipelines. These pipelines can be seen as prefabricated blocks that can be instantiated and inter-connected through packet queues to create complete applications (super-pipelines).

Pipelines are created and inter-connected through the application configuration file. By using different configuration files, different applications are effectively created, therefore this application can be seen as an application generator. The configuration of each pipeline can be updated at run-time through the application Command Line Interface (CLI).

Main application components are:

A Library of reusable pipelines

- Each pipeline represents a functional block, e.g. flow classification, firewall, routing, master, etc.
- Each pipeline type can be instantiated several times in the same application, which each instance configured separately and mapped to a single CPU core. Each CPU core can run one or several pipeline instances, which can be of same or different type.
- Pipeline instances are inter-connected through packet queues (for packet processing) and message queues (for run-time configuration).
- Pipelines are implemented using DPDK Packet Framework.
- More pipeline types can always be built and added to the existing pipeline types.

The Configuration file

- The configuration file defines the application structure. By using different configuration files, different applications are created.
- All the application resources are created and configured through the application configuration file: pipeline instances, buffer pools, links (i.e. network interfaces), hardware device RX/TX queues, software queues, traffic manager devices, EAL startup arguments, etc.
- The configuration file syntax is “define by reference”, meaning that resources are defined as they are referenced. First time a resource name is detected, it is registered with default parameters. Optionally, the resource parameters can be further refined through a configuration file section dedicated to that resource.

- Command Line Interface (CLI)

Global CLI commands: link configuration, etc.

- Common pipeline CLI commands: ping (keep-alive), statistics, etc.
- Pipeline type specific CLI commands: used to configure instances of specific pipeline type. These commands are registered with the application when the pipeline type is registered. For example, the commands for routing pipeline instances include: route add, route delete, route list, etc.
- CLI commands can be grouped into scripts that can be invoked at initialization and at runtime.

31.2 Design goals

31.2.1 Rapid development

This application enables rapid development through quick connectivity of standard components called pipelines. These components are built using DPDK Packet Framework and encapsulate packet processing features at different levels: ports, tables, actions, pipelines and complete applications.

Pipeline instances are instantiated, configured and inter-connected through low complexity configuration files loaded during application initialization. Each pipeline instance is mapped to a single CPU core, with each CPU core able to run one or multiple pipeline instances of same or different types. By loading a different configuration file, a different application is effectively started.

31.2.2 Flexibility

Each packet processing application is typically represented as a chain of functional stages which is often called the functional pipeline of the application. These stages are mapped to CPU cores to create chains of CPU cores (pipeline model), clusters of CPU cores (run-to-completion model) or chains of clusters of CPU cores (hybrid model).

This application allows all the above programming models. By applying changes to the configuration file, the application provides the flexibility to reshuffle its building blocks in different ways until the configuration providing the best performance is identified.

Move pipelines around

The mapping of pipeline instances to CPU cores can be reshuffled through the configuration file. One or several pipeline instances can be mapped to the same CPU core.

Move tables around

There is some degree of flexibility for moving tables from one pipeline instance to another. Based on the configuration arguments passed to each pipeline instance in the configuration file, specific tables can be enabled or disabled. This way, a specific table can be “moved” from

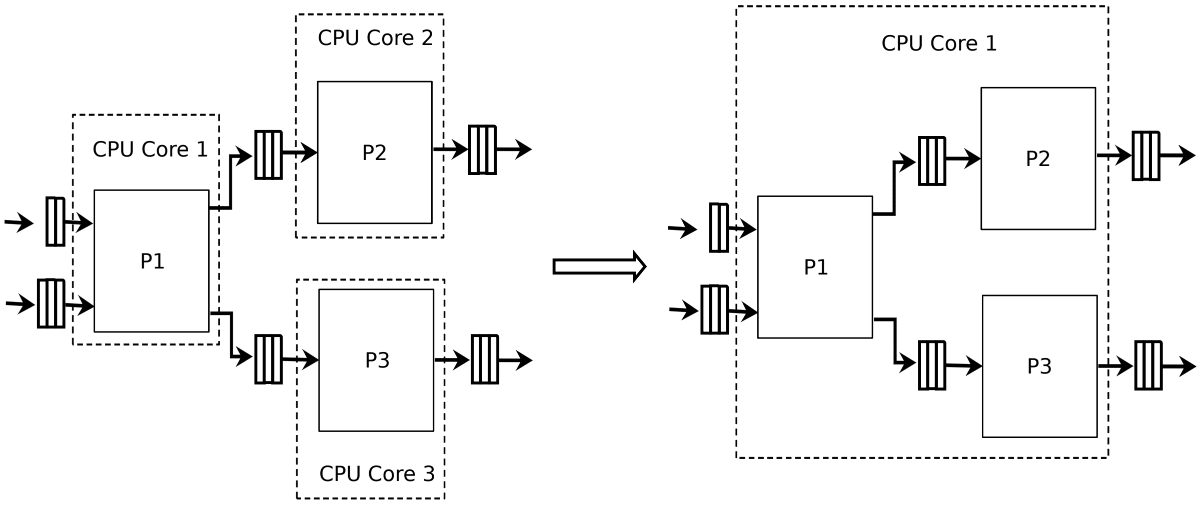


Fig. 31.1: Example of moving pipeline instances across different CPU cores

pipeline instance A to pipeline instance B by simply disabling its associated functionality for pipeline instance A while enabling it for pipeline instance B.

Due to requirement to have simple syntax for the configuration file, moving tables across different pipeline instances is not as flexible as the mapping of pipeline instances to CPU cores, or mapping actions to pipeline tables. Complete flexibility in moving tables from one pipeline to another could be achieved through a complex pipeline description language that would detail the structural elements of the pipeline (ports, tables and actions) and their connectivity, resulting in complex syntax for the configuration file, which is not acceptable. Good configuration file readability through simple syntax is preferred.

Example: the IP routing pipeline can run the routing function only (with ARP function run by a different pipeline instance), or it can run both the routing and ARP functions as part of the same pipeline instance.

Move actions around

When it makes sense, packet processing actions can be moved from one pipeline instance to another. Based on the configuration arguments passed to each pipeline instance in the configuration file, specific actions can be enabled or disabled. This way, a specific action can be "moved" from pipeline instance A to pipeline instance B by simply disabling its associated functionality for pipeline instance A while enabling it for pipeline instance B.

Example: The flow actions of accounting, traffic metering, application identification, NAT, etc can be run as part of the flow classification pipeline instance or split across several flow actions pipeline instances, depending on the number of flow instances and their compute requirements.

31.2.3 Performance

Performance of the application is the highest priority requirement. Flexibility is not provided at the expense of performance.

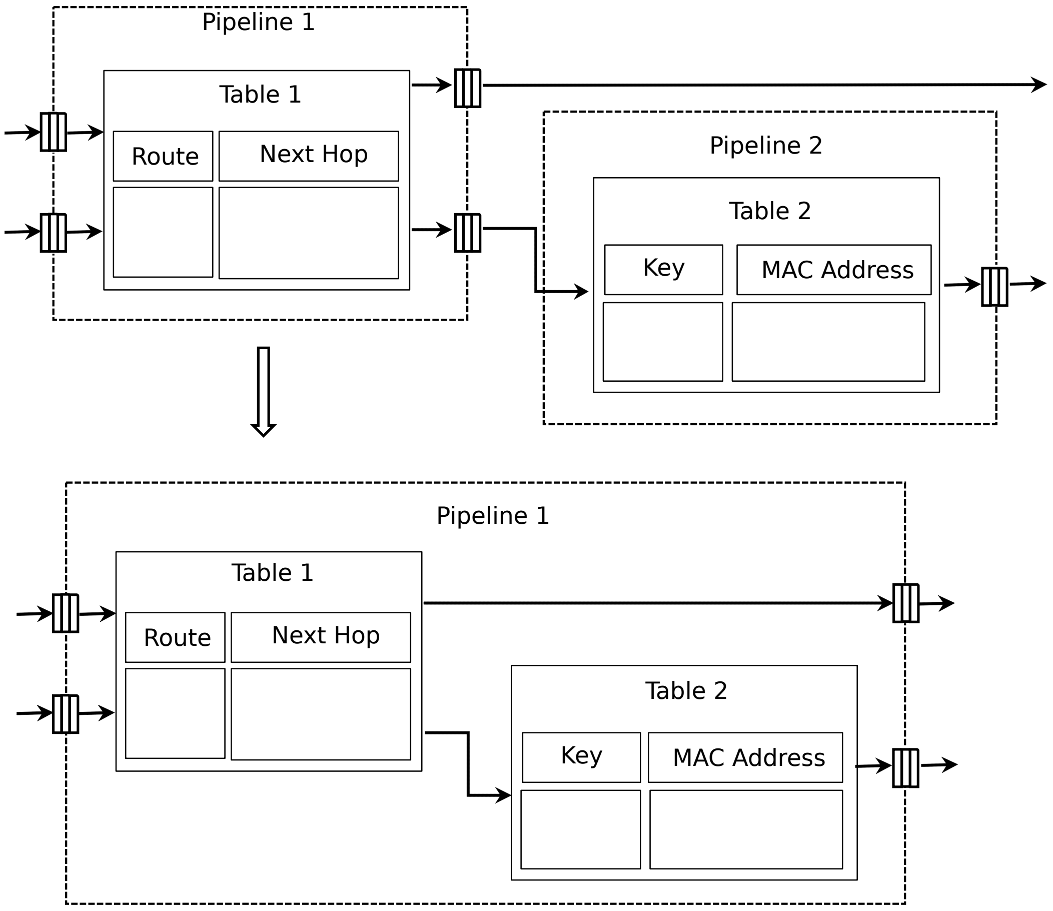


Fig. 31.2: Example of moving tables across different pipeline instances

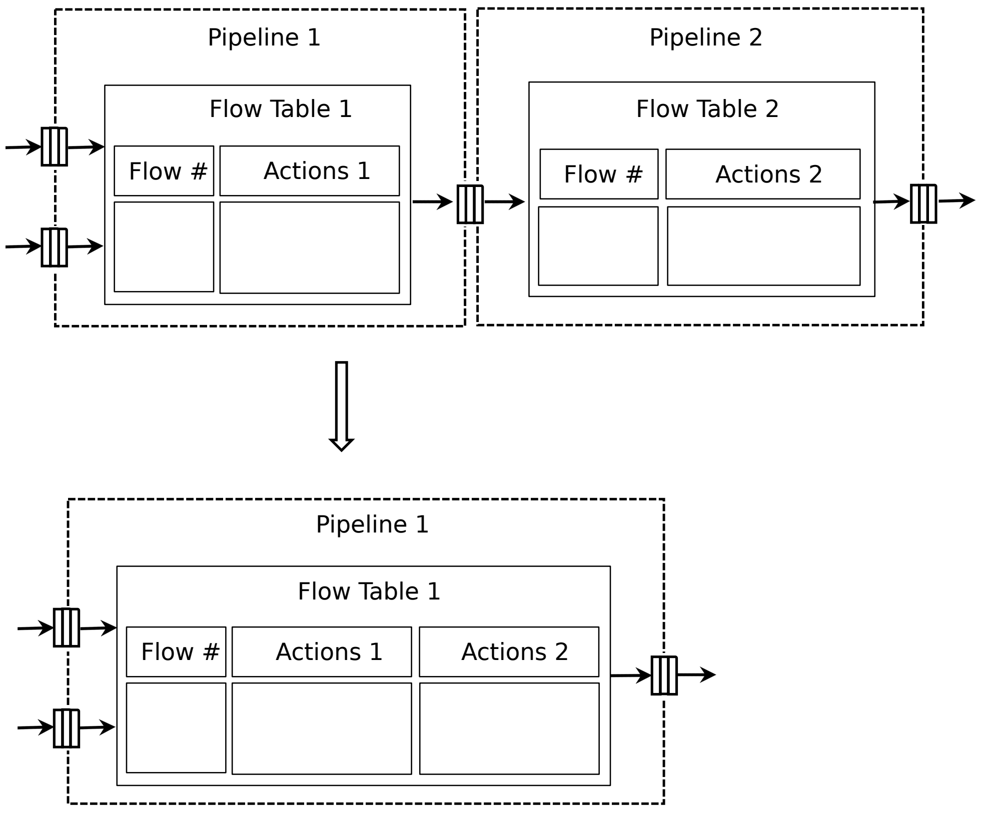


Fig. 31.3: Example of moving actions across different tables and pipeline instances

The purpose of flexibility is to provide an incremental development methodology that allows monitoring the performance evolution:

- Apply incremental changes in the configuration (e.g. mapping on pipeline instances to CPU cores) in order to identify the configuration providing the best performance for a given application;
- Add more processing incrementally (e.g. by enabling more actions for specific pipeline instances) until the application is feature complete while checking the performance impact at each step.

31.2.4 Debug capabilities

The application provides a significant set of debug capabilities:

- Command Line Interface (CLI) support for statistics polling: pipeline instance ping (keep-alive checks), pipeline instance statistics per input port/output port/table, link statistics, etc;
- Logging: Turn on/off application log messages based on priority level;

31.3 Running the application

The application startup command line is:

```
ip_pipeline [-f CONFIG_FILE] [-s SCRIPT_FILE] -p PORT_MASK [-l LOG_LEVEL]
```

The application startup arguments are:

`-f CONFIG_FILE`

- Optional: Yes
- Default: `./config/ip_pipeline.cfg`
- Argument: Path to the configuration file to be loaded by the application. Please refer to the *Configuration file syntax* for details on how to write the configuration file.

`-s SCRIPT_FILE`

- Optional: Yes
- Default: Not present
- Argument: Path to the CLI script file to be run by the master pipeline at application startup. No CLI script file will be run at startup of this argument is not present.

`-p PORT_MASK`

- Optional: No
- Default: N/A
- Argument: Hexadecimal mask of NIC port IDs to be used by the application. First port enabled in this mask will be referenced as LINK0 as part of the application configuration file, next port as LINK1, etc.

`-l LOG_LEVEL`

- Optional: Yes
- Default: 1 (High priority)
- Argument: Log level to determine which application messages are to be printed to standard output. Available log levels are: 0 (None), 1 (High priority), 2 (Low priority). Only application messages whose priority is higher than or equal to the application log level will be printed.

31.4 Application stages

31.4.1 Configuration

During this stage, the application configuration file is parsed and its content is loaded into the application data structures. In case of any configuration file parse error, an error message is displayed and the application is terminated. Please refer to the *Configuration file syntax* for a description of the application configuration file format.

31.4.2 Configuration checking

In the absence of any parse errors, the loaded content of application data structures is checked for overall consistency. In case of any configuration check error, an error message is displayed and the application is terminated.

31.4.3 Initialization

During this stage, the application resources are initialized and the handles to access them are saved into the application data structures. In case of any initialization error, an error message is displayed and the application is terminated.

The typical resources to be initialized are: pipeline instances, buffer pools, links (i.e. network interfaces), hardware device RX/TX queues, software queues, traffic management devices, etc.

31.4.4 Run-time

Each CPU core runs the pipeline instances assigned to it in time sharing mode and in round robin order:

1. *Packet processing task*: The pipeline run-time code is typically a packet *processing* task built on top of DPDK Packet Framework rte_pipeline library, which reads bursts of packets from the pipeline input ports, performs table lookups and executes the identified actions for all tables in the pipeline, with packet eventually written to pipeline output ports or dropped.
2. *Message handling task*: Each CPU core will also periodically execute the *message handling* code of each of the pipelines mapped to it. The pipeline message handling code is processing the messages that are pending in the pipeline input message queues, which are typically sent by the master CPU core for the on-the-fly pipeline configuration: check that pipeline is still alive (ping), add/delete entries in the pipeline tables, get statistics, etc. The frequency of executing the message handling code is usually much smaller than the frequency of executing the packet processing work.

Please refer to the *PIPELINE section* for more details about the application pipeline module encapsulation.

31.5 Configuration file syntax

31.5.1 Syntax overview

The syntax of the configuration file is designed to be simple, which favors readability. The configuration file is parsed using the DPDK library librte_cfgfile, which supports simple INI file format for configuration files.

As result, the configuration file is split into several sections, with each section containing one or more entries. The scope of each entry is its section, and each entry specifies a variable that is assigned a specific value. Any text after the `;` character is considered a comment and is therefore ignored.

The following are application specific: number of sections, name of each section, number of entries of each section, name of the variables used for each section entry, the value format (e.g. signed/unsigned integer, string, etc) and range of each section entry variable.

Generic example of configuration file section:

```
[<section_name>]

<variable_name_1> = <value_1>
```

```
...

<variable_name_N> = <value_N>
```

31.5.2 Application resources present in the configuration file

Table 31.1: Application resource names in the configuration file

Resource type	Format	Examples
Pipeline	`PIPELINE<ID>`	`PIPELINE0`, `PIPELINE1`
Mempool	`MEMPOOL<ID>`	`MEMPOOL0`, `MEMPOOL1`
Link (network interface)	`LINK<ID>`	`LINK0`, `LINK1`
Link RX queue	`RXQ<LINK_ID>.<QUEUE_ID>`	`RXQ0.0`, `RXQ1.5`
Link TX queue	`TXQ<LINK_ID>.<QUEUE_ID>`	`TXQ0.0`, `TXQ1.5`
Software queue	`SWQ<ID>`	`SWQ0`, `SWQ1`
Traffic Manager	`TM<LINK_ID>`	`TM0`, `TM1`
Source	`SOURCE<ID>`	`SOURCE0`, `SOURCE1`
Sink	`SINK<ID>`	`SINK0`, `SINK1`
Message queue	`MSGQ<ID>` `MSGQ-REQ-PIPELINE<ID>` `MSGQ-RSP-PIPELINE<ID>` `MSGQ-REQ-CORE-<CORE_ID>` `MSGQ-RSP-CORE-<CORE_ID>`	`MSGQ0`, `MSGQ1`, `MSGQ-REQ-PIPELINE2`, `MSGQ-RSP-PIPELINE2`, `MSGQ-REQ-CORE-s0c1`, `MSGQ-RSP-CORE-s0c1`

`LINK` instances are created implicitly based on the `PORT_MASK` application startup argument. `LINK0` is the first port enabled in the `PORT_MASK`, port 1 is the next one, etc. The LINK ID is different than the DPDK PMD-level NIC port ID, which is the actual position in the bitmask mentioned above. For example, if bit 5 is the first bit set in the bitmask, then `LINK0` is having the PMD ID of 5. This mechanism creates a contiguous LINK ID space and isolates the configuration file against changes in the board PCIe slots where NICs are plugged in.

`RXQ`, `TXQ` and `TM` instances have the LINK ID as part of their name. For example, `RXQ2.1`, `TXQ2.1` and `TM2` are all associated with `LINK2`.

31.5.3 Rules to parse the configuration file

The main rules used to parse the configuration file are:

1. Application resource name determines the type of resource based on the name prefix.

   Example: all software queues need to start with `SWQ` prefix, so `SWQ0` and `SWQ5` are valid software queue names.

2. An application resource is defined by creating a configuration file section with its name. The configuration file section allows fine tuning on any of the resource parameters. Some resource parameters are mandatory, in which case it is required to have them specified as part of the section, while some others are optional, in which case they get assigned their default value when not present.

   Example: section `SWQ0` defines a software queue named SWQ0, whose parameters are detailed as part of this section.

3. An application resource can also be defined by referencing it. Referencing a resource takes place by simply using its name as part of the value assigned to a variable in any configuration file section. In this case, the resource is registered with all its parameters having their default values. Optionally, a section with the resource name can be added to the configuration file to fine tune some or all of the resource parameters.

   Example: in section `PIPELINE3`, variable `pktq_in` includes `SWQ5` as part of its list, which results in defining a software queue named `SWQ5`; when there is no `SWQ5` section present in the configuration file, `SWQ5` gets registered with default parameters.

31.5.4 PIPELINE section

Table 31.2: Configuration file PIPELINE section (1/2)

Section	Description	Optional	Range	Default value
type	Pipeline type. Defines the functionality to be executed.	NO	See "List of pipeline types"	N/A
core	CPU core to run the current pipeline.	YES	See "CPU Core notation"	CPU socket 0, core 0, hyper-thread 0
pktq_in	Packet queues to serve as input ports for the current pipeline instance. The acceptable packet queue types are: `RXQ`, `SWQ`, `TM` and `SOURCE`. First device in this list is used as pipeline input port 0, second as pipeline input port 1, etc.	YES	List of input packet queue IDs	Empty list
pktq_out	Packet queues to serve as output ports for the current pipeline instance. The acceptable packet queue types are: `TXQ`, `SWQ`, `TM` and `SINK`. First device in this list is used as pipeline output port 0, second as pipeline output port 1, etc.	YES	List of output packet queue IDs.	Empty list

Table 31.3: Configuration file PIPELINE section (2/2)

Section	Description	Optional	Range	Default value
msgq_in	Input message queues. These queues contain request messages that need to be handled by the current pipeline instance. The type and format of request messages is defined by the pipeline type. For each pipeline instance, there is an input message queue defined implicitly, whose name is: `MSGQ-REQ-<PIPELINE_ID>`. This message queue should not be mentioned as part of msgq_in list.	YES	List of message queue IDs	Empty list
msgq_out	Output message queues. These queues are used by the current pipeline instance to write response messages as result of request messages being handled. The type and format of response messages is defined by the pipeline type. For each pipeline instance, there is an output message queue defined implicitly, whose name is: `MSGQ-RSP-<PIPELINE_ID>`. This message queue should not be mentioned as part of msgq_out list.	YES	List of message queue IDs	Empty list
timer_period	Time period, measured in milliseconds, for handling the input message queues.	YES	milliseconds	1 ms
<any other>	Arguments to be passed to the current pipeline instance. Format of the arguments, their type, whether each argument is optional or mandatory and its default value (when optional) are defined by the pipeline type. The value of the arguments is applicable to the current pipeline instance only.	Depends on pipeline type	Depends on pipeline type	Depends on pipeline type

CPU core notation

The CPU Core notation is:

```
<CPU core> ::= [s|S<CPU socket ID>][c|C]<CPU core ID>[h|H]
```

For example:

```
CPU socket 0, core 0, hyper-thread 0: 0, c0, s0c0

CPU socket 0, core 0, hyper-thread 1: 0h, c0h, s0c0h

CPU socket 3, core 9, hyper-thread 1: s3c9h
```

31.5.5 MEMPOOL section

Table 31.4: Configuration file MEMPOOL section

Section	Description	Optional	Type	Default value
buffer_size	Buffer size (in bytes) for the current buffer pool.	YES	uint32_t	2048 + sizeof(struct rte_mbuf) + HEADROOM
pool_size	Number of buffers in the current buffer pool.	YES	uint32_t	32K
cache_size	Per CPU thread cache size (in number of buffers) for the current buffer pool.	YES	uint32_t	256
cpu	CPU socket ID where to allocate memory for the current buffer pool.	YES	uint32_t	0

31.5.6 LINK section

Table 31.5: Configuration file LINK section

Section entry	Description	Optional	Type	Default value
arp_q	NIC RX queue where ARP packets should be filtered.	YES	0 .. 127	0 (default queue)
tcp_syn_local_q	NIC RX queue where TCP packets with SYN flag should be filtered.	YES	0 .. 127	0 (default queue)
ip_local_q	NIC RX queue where IP packets with local destination should be filtered. When TCP, UDP and SCTP local queues are defined, they take higher priority than this queue.	YES	0 .. 127	0 (default queue)
tcp_local_q	NIC RX queue where TCP packets with local destination should be filtered.	YES	0 .. 127	0 (default queue)
udp_local_q	NIC RX queue where TCP packets with local destination should be filtered.	YES	0 .. 127	0 (default queue)
sctp_local_q	NIC RX queue where TCP packets with local destination should be filtered.	YES	0 .. 127	0 (default queue)
promisc	Indicates whether current link should be started in promiscuous mode.	YES	YES/NO	YES

31.5.7 RXQ section

Table 31.6: Configuration file RXQ section

Section	Description	Optional	Type	Default value
mempool	Mempool to use for buffer allocation for current NIC RX queue. The mempool ID has to be associated with a valid instance defined in the mempool entry of the global section.	YES	uint32_t	MEMPOOL0
Size	NIC RX queue size (number of descriptors)	YES	uint32_t	128
burst	Read burst size (number of descriptors)	YES	uint32_t	32

31.5.8 TXQ section

Table 31.7: Configuration file TXQ section

Section	Description	Optional	Type	Default value
size	NIC TX queue size (number of descriptors)	YES	uint32_t power of 2 > 0	512
burst	Write burst size (number of descriptors)	YES	uint32_t power of 2 0 < burst < size	32
dropless	When dropless is set to NO, packets can be dropped if not enough free slots are currently available in the queue, so the write operation to the queue is non- blocking. When dropless is set to YES, packets cannot be dropped if not enough free slots are currently available in the queue, so the write operation to the queue is blocking, as the write operation is retried until enough free slots become available and all the packets are successfully written to the queue.	YES	YES/NO	NO
n_retries	Number of retries. Valid only when dropless is set to YES. When set to 0, it indicates unlimited number of retries.	YES	uint32_t	0

31.5.9 SWQ section

Table 31.8: Configuration file SWQ section

Section	Description	Optional	Type	Default value
size	Queue size (number of packets)	YES	uint32_t power of 2	256
burst_read	Read burst size (number of packets)	YES	uint32_t power of 2 0 < burst < size	32
burst_write	Write burst size (number of packets)	YES	uint32_t power of 2 0 < burst < size	32
dropless	When dropless is set to NO, packets can be dropped if not enough free slots are currently available in the queue, so the write operation to the queue is non- blocking. When dropless is set to YES, packets cannot be dropped if not enough free slots are currently available in the queue, so the write operation to the queue is blocking, as the write operation is retried until enough free slots become available and all the packets are successfully written to the queue.	YES	YES/NO	NO
n_retries	Number of retries. Valid only when dropless is set to YES. When set to 0, it indicates unlimited number of retries.	YES	uint32_t	0
cpu	CPU socket ID where to allocate memory for this SWQ.	YES	uint32_t	0

31.5.10 TM section

Table 31.9: Configuration file TM section

Section	Description	Optional	Type	Default value
Cfg	File name to parse for the TM configuration to be applied. The syntax of this file is described in the examples/qos_sched DPDK application documentation.	YES	string	tm_profile
burst_read	Read burst size (number of packets)	YES	uint32_t	64
burst_write	Write burst size (number of packets)	YES	uint32_t	32

31.5.11 SOURCE section

Table 31.10: Configuration file SOURCE section

Section	Description	Optional	Type	Default value
Mempool	Mempool to use for buffer allocation.	YES	uint32_t	MEMPOOL0
Burst	Read burst size (number of packets)		uint32_t	32

31.5.12 SINK section

Currently, there are no parameters to be passed to a sink device, so SINK section is not allowed.

31.5.13 MSGQ section

Table 31.11: Configuration file MSGQ section

Section	Description	Optional	Type	Default value
size	Queue size (number of packets)	YES	uint32_t != 0 power of 2	64
cpu	CPU socket ID where to allocate memory for the current queue.	YES	uint32_t	0

31.5.14 EAL section

The application generates the EAL parameters rather than reading them from the command line.

The CPU core mask parameter is generated based on the core entry of all PIPELINE sections. All the other EAL parameters can be set from this section of the application configuration file.

31.6 Library of pipeline types

31.6.1 Pipeline module

A pipeline is a self-contained module that implements a packet processing function and is typically implemented on top of the DPDK Packet Framework *librte_pipeline* library. The application provides a run-time mechanism to register different pipeline types.

Depending on the required configuration, each registered pipeline type (pipeline class) is instantiated one or several times, with each pipeline instance (pipeline object) assigned to one of the available CPU cores. Each CPU core can run one or more pipeline instances, which might be of same or different types. For more information of the CPU core threading model, please refer to the *Run-time* section.

Pipeline type

Each pipeline type is made up of a back-end and a front-end. The back-end represents the packet processing engine of the pipeline, typically implemented using the DPDK Packet Framework libraries, which reads packets from the input packet queues, handles them and eventually writes them to the output packet queues or drops them. The front-end represents the run-time configuration interface of the pipeline, which is exposed as CLI commands. The front-end communicates with the back-end through message queues.

Table 31.12: Pipeline back-end

Field name	Field type	Description
f_init	Function pointer	Function to initialize the back-end of the current pipeline instance. Typical work implemented by this function for the current pipeline instance: Memory allocation; Parse the pipeline type specific arguments; Initialize the pipeline input ports, output ports and tables, interconnect input ports to tables; Set the message handlers.
f_free	Function pointer	Function to free the resources allocated by the back-end of the current pipeline instance.
f_run	Function pointer	Set to NULL for pipelines implemented using the DPDK library librte_pipeline (typical case), and to non-NULL otherwise. This mechanism is made available to support quick integration of legacy code. This function is expected to provide the packet processing related code to be called as part of the CPU thread dispatch loop, so this function is not allowed to contain an infinite loop.
f_timer	Function pointer	Function to read the pipeline input message queues, handle the request messages, create response messages and write the response queues. The format of request and response messages is defined by each pipeline type, with the exception of some requests which are mandatory for all pipelines (e.g. ping, statistics).
f_track	Function pointer	See section Tracking pipeline output port to physical link

Table 31.13: Pipeline front-end

Field name	Field type	Description
f_init	Function pointer	Function to initialize the front-end of the current pipeline instance.
f_free	Function pointer	Function to free the resources allocated by the front-end of the current pipeline instance.
cmds	Array of CLI commands	Array of CLI commands to be registered to the application CLI for the current pipeline type. Even though the CLI is executed by a different pipeline (typically, this is the master pipeline), from modularity perspective is more efficient to keep the message client side (part of the front-end) together with the message server side (part of the back-end).

Tracking pipeline output port to physical link

Each pipeline instance is a standalone block that does not have visibility into the other pipeline instances or the application-level pipeline inter-connectivity. In some cases, it is useful for a pipeline instance to get application level information related to pipeline connectivity, such as to identify the output link (e.g. physical NIC port) where one of its output ports connected, either directly or indirectly by traversing other pipeline instances.

Tracking can be successful or unsuccessful. Typically, tracking for a specific pipeline instance is successful when each one of its input ports can be mapped to a single output port, meaning that all packets read from the current input port can only go out on a single output port. Depending on the pipeline type, some exceptions may be allowed: a small portion of the packets, considered exception packets, are sent out on an output port that is pre-configured for this purpose.

For pass-through pipeline type, the tracking is always successful. For pipeline types as flow classification, firewall or routing, the tracking is only successful when the number of output ports for the current pipeline instance is 1.

This feature is used by the IP routing pipeline for adding/removing implicit routes every time a link is brought up/down.

Table copies

Fast table copy: pipeline table used by pipeline for the packet processing task, updated through messages, table data structures are optimized for lookup operation.

Slow table copy: used by the configuration layer, typically updated through CLI commands, kept in sync with the fast copy (its update triggers the fast copy update). Required for executing advanced table queries without impacting the packet processing task, therefore the slow copy is typically organized using different criteria than the fast copy.

Examples:

- Flow classification: Search through current set of flows (e.g. list all flows with a specific source IP address);
- Firewall: List rules in descending order of priority;
- Routing table: List routes sorted by prefix depth and their type (local, remote, default);
- ARP: List entries sorted per output interface.

Packet meta-data

Packet meta-data field offsets provided as argument to pipeline instances are essentially defining the data structure for the packet meta-data used by the current application use-case. It is very useful to put it in the configuration file as a comment in order to facilitate the readability of the configuration file.

The reason to use field offsets for defining the data structure for the packet meta-data is due to the C language limitation of not being able to define data structures at run-time. Feature to consider: have the configuration file parser automatically generate and print the data structure defining the packet meta-data for the current application use-case.

Packet meta-data typically contains:

1. Pure meta-data: intermediate data per packet that is computed internally, passed between different tables of the same pipeline instance (e.g. lookup key for the ARP table

is obtained from the routing table), or between different pipeline instances (e.g. flow ID, traffic metering color, etc);

2. Packet fields: typically, packet header fields that are read directly from the packet, or read from the packet and saved (duplicated) as a working copy at a different location within the packet meta-data (e.g. Diffserv 5-tuple, IP destination address, etc).

Several strategies are used to design the packet meta-data, as described in the next subsections.

Store packet meta-data in a different cache line as the packet headers

This approach is able to support protocols with variable header length, like MPLS, where the offset of IP header from the start of the packet (and, implicitly, the offset of the IP header in the packet buffer) is not fixed. Since the pipelines typically require the specification of a fixed offset to the packet fields (e.g. Diffserv 5-tuple, used by the flow classification pipeline, or the IP destination address, used by the IP routing pipeline), the workaround is to have the packet RX pipeline copy these fields at fixed offsets within the packet meta-data.

As this approach duplicates some of the packet fields, it requires accessing more cache lines per packet for filling in selected packet meta-data fields (on RX), as well as flushing selected packet meta-data fields into the packet (on TX).

Example:

```
; struct app_pkt_metadata {
;   uint32_t ip_da;
;      uint32_t hash;
;      uint32_t flow_id;
;      uint32_t color;
; } __attribute__((__packed__));
;

[PIPELINE1]
; Packet meta-data offsets
ip_da_offset = 0;   Used by: routing
hash_offset = 4;    Used by: RX, flow classification
flow_id_offset = 8; Used by: flow classification, flow actions
color_offset = 12;  Used by: flow actions, routing
```

Overlay the packet meta-data in the same cache line with the packet headers

This approach is minimizing the number of cache line accessed per packet by storing the packet metadata in the same cache line with the packet headers. To enable this strategy, either some headroom is reserved for meta-data at the beginning of the packet headers cache line (e.g. if 16 bytes are needed for meta-data, then the packet headroom can be set to 128+16 bytes, so that NIC writes the first byte of the packet at offset 16 from the start of the first packet cache line), or meta-data is reusing the space of some packet headers that are discarded from the packet (e.g. input Ethernet header).

Example:

```
; struct app_pkt_metadata {
;     uint8_t headroom[RTE_PKTMBUF_HEADROOM]; /* 128 bytes (default) */
;     union {
;         struct {
;             struct ether_hdr ether; /* 14 bytes */
;               struct qinq_hdr qinq; /* 8 bytes */
;           };
;           struct {
;               uint32_t hash;
;               uint32_t flow_id;
;               uint32_t color;
;           };
;       };
;       struct ipv4_hdr ip; /* 20 bytes */
; } __attribute__((__packed__));
;
[PIPELINE2]
; Packet meta-data offsets
qinq_offset = 142;    Used by: RX, flow classification
ip_da_offset = 166;   Used by: routing
hash_offset = 128;    Used by: RX, flow classification
flow_id_offset = 132; Used by: flow classification, flow actions
color_offset = 136;   Used by: flow actions, routing
```

31.6.2 List of pipeline types

Table 31.14: List of pipeline types provided with the application

Name	Table(s)	Actions	Messages
Pass-through Note: depending on port type, can be used for RX, TX, IP fragmentation, IP reassembly or Traffic Management	Passthrough	1. Pkt metadata build 2. Flow hash 3. Pkt checks 4. Load balancing	1. Ping 2. Stats
Flow classification	Exact match • Key = byte array (source: pkt metadata) • Data = action dependent	1. Flow ID 2. Flow stats 3. Metering 4. Network Address 5. Translation (NAT)	1. Ping 2. Stats 3. Flow stats 4. Action stats 5. Flow add/ update/ delete 6. Default flow add/ update/ delete 7. Action update
Flow actions	Array • Key = Flow ID (source: pkt metadata) • Data = action dependent	1. Flow stats 2. Metering 3. Network Address 4. Translation (NAT)	1. Ping 2. Stats 3. Action stats 4. Action update
Firewall	ACL • Key = n-tuple (source: pkt headers) • Data = none	1. Allow/Drop	1. Ping 2. Stats 3. Rule add/ update/ delete 4. Default rule add/ update/ delete
IP routing	LPM (IPv4 or IPv6, depending on pipeline type) • Key = IP destination (source: pkt metadata) • Data = Dependent on actions and next hop type Hash table (for ARP, only when ARP is enabled) • Key = (Port ID, next hop IP address) (source: pkt meta-data) • Data: MAC address	1. TTL decrement and 2. IPv4 checksum 3. update 4. Header 5. encapsulation 6. (based on next hop 7. type)	1. Ping 2. Stats 3. Route add/ update/ delete 4. Default route add/ update/ delete 5. ARP entry add/ update/ delete 6. Default ARP entry add/ update/ delete

31.7 Command Line Interface (CLI)

31.7.1 Global CLI commands

Table 31.15: Global CLI commands

Command	Description	Syntax
run	Run CLI commands script file.	run <file> <file> = path to file with CLI commands to execute
quit	Gracefully terminate the application.	quit

31.7.2 CLI commands for link configuration

Table 31.16: List of run-time configuration commands for link configuration

Command	Description	Syntax
link config	Link configuration	link <link ID> config <IP address> <depth>
link up	Link up	link <link ID> up
link down	Link down	link <link ID> down
link ls	Link list	link ls

31.7.3 CLI commands common for all pipeline types

Table 31.17: CLI commands mandatory for all pipelines

Command	Description	Syntax
ping	Check whether specific pipeline instance is alive. The master pipeline sends a ping request message to given pipeline instance and waits for a response message back. Timeout message is displayed when the response message is not received before the timer expires.	p <pipeline ID> ping
stats	Display statistics for specific pipeline input port, output port or table.	p <pipeline ID> stats port in <port in ID> p <pipeline ID> stats port out <port out ID> p <pipeline ID> stats table <table ID>
input port enable	Enable given input port for specific pipeline instance.	p <pipeline ID> port in <port ID> enable
input port disable	Disable given input port for specific pipeline instance.	p <pipeline ID> port in <port ID> disable

31.7.4 Pipeline type specific CLI commands

The pipeline specific CLI commands are part of the pipeline type front-end.

CHAPTER

THIRTYTWO

TEST PIPELINE APPLICATION

The Test Pipeline application illustrates the use of the DPDK Packet Framework tool suite. Its purpose is to demonstrate the performance of single-table DPDK pipelines.

32.1 Overview

The application uses three CPU cores:

- Core A ("RX core") receives traffic from the NIC ports and feeds core B with traffic through SW queues.
- Core B ("Pipeline core") implements a single-table DPDK pipeline whose type is selectable through specific command line parameter. Core B receives traffic from core A through software queues, processes it according to the actions configured in the table entries that are hit by the input packets and feeds it to core C through another set of software queues.
- Core C ("TX core") receives traffic from core B through software queues and sends it to the NIC ports for transmission.

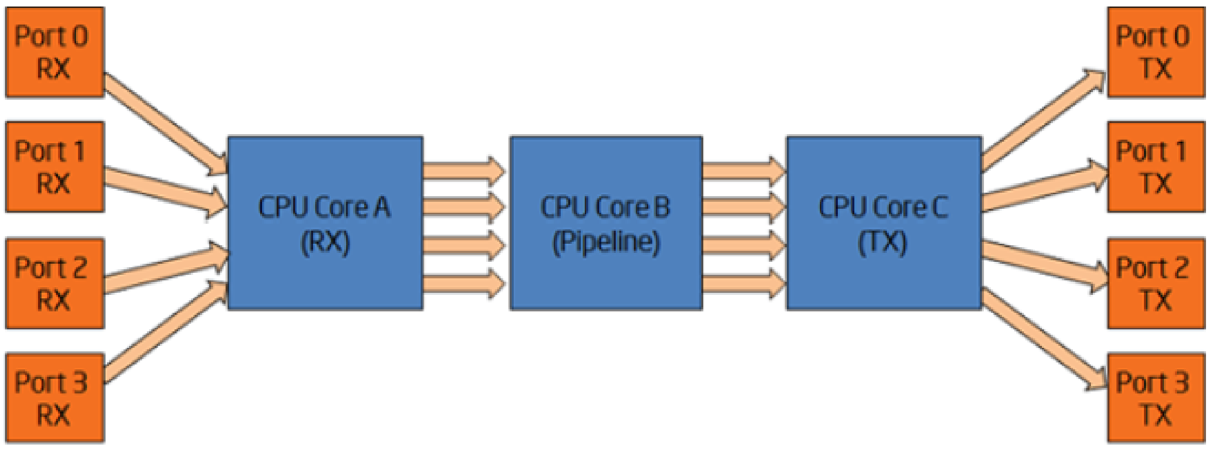


Fig. 32.1: Test Pipeline Application

32.2 Compiling the Application

1. Go to the app/test directory:

```
export RTE_SDK=/path/to/rte_sdk
cd ${RTE_SDK}/app/test/test-pipeline
```

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

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

3. Build the application:

```
make
```

32.3 Running the Application

32.3.1 Application Command Line

The application execution command line is:

```
./test-pipeline [EAL options] -- -p PORTMASK --TABLE_TYPE
```

The -c EAL CPU core mask option has to contain exactly 3 CPU cores. The first CPU core in the core mask is assigned for core A, the second for core B and the third for core C.

The PORTMASK parameter must contain 2 or 4 ports.

32.3.2 Table Types and Behavior

Table 32.1 describes the table types used and how they are populated.

The hash tables are pre-populated with 16 million keys. For hash tables, the following parameters can be selected:

- **Configurable key size implementation or fixed (specialized) key size implementation (e.g. hash-8-ext or hash-spec-8-ext).** The key size specialized implementations are expected to provide better performance for 8-byte and 16-byte key sizes, while the key-size-non-specialized implementation is expected to provide better performance for larger key sizes;
- **Key size (e.g. hash-spec-8-ext or hash-spec-16-ext).** The available options are 8, 16 and 32 bytes;
- **Table type (e.g. hash-spec-16-ext or hash-spec-16-lru).** The available options are ext (extendable bucket) or lru (least recently used).

Table 32.1: Table Types

#	TABLE_TYPE	Description of Core B Table	Pre-added Table Entries
1	none	Core B is not implementing a DPDK pipeline. Core B is implementing a pass-through from its input set of software queues to its output set of software queues.	N/A
2	stub	Stub table. Core B is implementing the same pass-through functionality as described for the “none” option by using the DPDK Packet Framework by using one stub table for each input NIC port.	N/A
3	hash-[spec]-8-lru	LRU hash table with 8-byte key size and 16 million entries.	16 million entries are successfully added to the hash table with the following key format: [4-byte index, 4 bytes of 0] The action configured for all table entries is “Sendto output port”, with the output port index uniformly distributed for the range of output ports. The default table rule (used in the case of a lookup miss) is to drop the packet. At run time, core A is creating the following lookup key and storing it into the packet meta data for core B to use for table lookup: [destination IPv4 address, 4 bytes of 0]
4	hash-[spec]-8-ext	Extendable bucket hash table with 8-byte key size and 16 million entries.	Same as hash-[spec]-8-lru table entries, above.
5	hash-[spec]-16-lru	LRU hash table with 16-byte key size and 16 million entries.	16 million entries are successfully added to the hash table with the following key format: [4-byte index, 12 bytes of 0] The action configured for all table entries is “Send to output port”, with the output port index uniformly distributed for the range of output ports. The default table rule (used in the case of a lookup miss) is to drop the packet. At run time, core A is creating the following lookup key and storing it into the packet meta data for core B to use for table lookup: [destination IPv4 address, 12 bytes of 0]
6	hash-	Extendable bucket hash table with	Same as hash-[spec]-16-lru table

32.3.3 Input Traffic

Regardless of the table type used for the core B pipeline, the same input traffic can be used to hit all table entries with uniform distribution, which results in uniform distribution of packets sent out on the set of output NIC ports. The profile for input traffic is TCP/IPv4 packets with:

- destination IP address as A.B.C.D with A fixed to 0 and B, C,D random
- source IP address fixed to 0.0.0.0
- destination TCP port fixed to 0
- source TCP port fixed to 0

CHAPTER

THIRTYTHREE

DISTRIBUTOR SAMPLE APPLICATION

The distributor sample application is a simple example of packet distribution to cores using the Data Plane Development Kit (DPDK).

33.1 Overview

The distributor application performs the distribution of packets that are received on an RX_PORT to different cores. When processed by the cores, the destination port of a packet is the port from the enabled port mask adjacent to the one on which the packet was received, that is, if the first four ports are enabled (port mask 0xf), ports 0 and 1 RX/TX into each other, and ports 2 and 3 RX/TX into each other.

This application can be used to benchmark performance using the traffic generator as shown in the figure below.

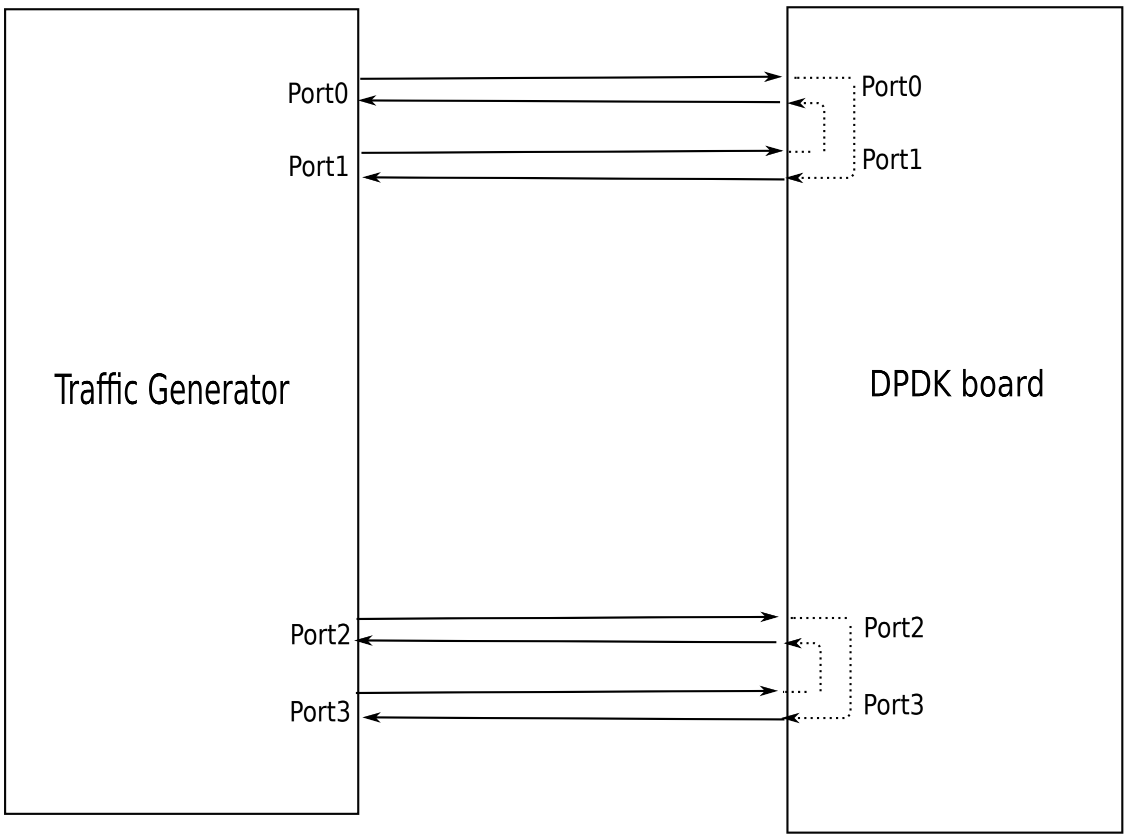


Fig. 33.1: Performance Benchmarking Setup (Basic Environment)

33.2 Compiling the Application

1. Go to the sample application directory:

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

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

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

   See the DPDK Getting Started Guide for possible RTE_TARGET values.

3. Build the application:

   ```
   make
   ```

33.3 Running the Application

1. The application has a number of command line options:

   ```
   ./build/distributor_app [EAL options] -- -p PORTMASK
   ```

   where,

   - -p PORTMASK: Hexadecimal bitmask of ports to configure

2. To run the application in linuxapp environment with 10 lcores, 4 ports, issue the command:

   ```
   $ ./build/distributor_app -c 0x4003fe -n 4 -- -p f
   ```

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

33.4 Explanation

The distributor application consists of three types of threads: a receive thread (lcore_rx()), a set of worker threads(lcore_worker()) and a transmit thread(lcore_tx()). How these threads work together is shown in Fig. 33.2 below. The main() function launches threads of these three types. Each thread has a while loop which will be doing processing and which is terminated only upon SIGINT or ctrl+C. The receive and transmit threads communicate using a software ring (rte_ring structure).

The receive thread receives the packets using rte_eth_rx_burst() and gives them to the distributor (using rte_distributor_process() API) which will be called in context of the receive thread itself. The distributor distributes the packets to workers threads based on the tagging of the packet - indicated by the hash field in the mbuf. For IP traffic, this field is automatically filled by the NIC with the “usr” hash value for the packet, which works as a per-flow tag.

More than one worker thread can exist as part of the application, and these worker threads do simple packet processing by requesting packets from the distributor, doing a simple XOR operation on the input port mbuf field (to indicate the output port which will be used later for packet transmission) and then finally returning the packets back to the distributor in the RX thread.

Meanwhile, the receive thread will call the distributor api rte_distributor_returned_pkts() to get the packets processed, and will enqueue them to a ring for transfer to the TX thread for transmission on the output port. The transmit thread will dequeue the packets from the ring and transmit them on the output port specified in packet mbuf.

Users who wish to terminate the running of the application have to press ctrl+C (or send SIGINT to the app). Upon this signal, a signal handler provided in the application will terminate all running threads gracefully and print final statistics to the user.

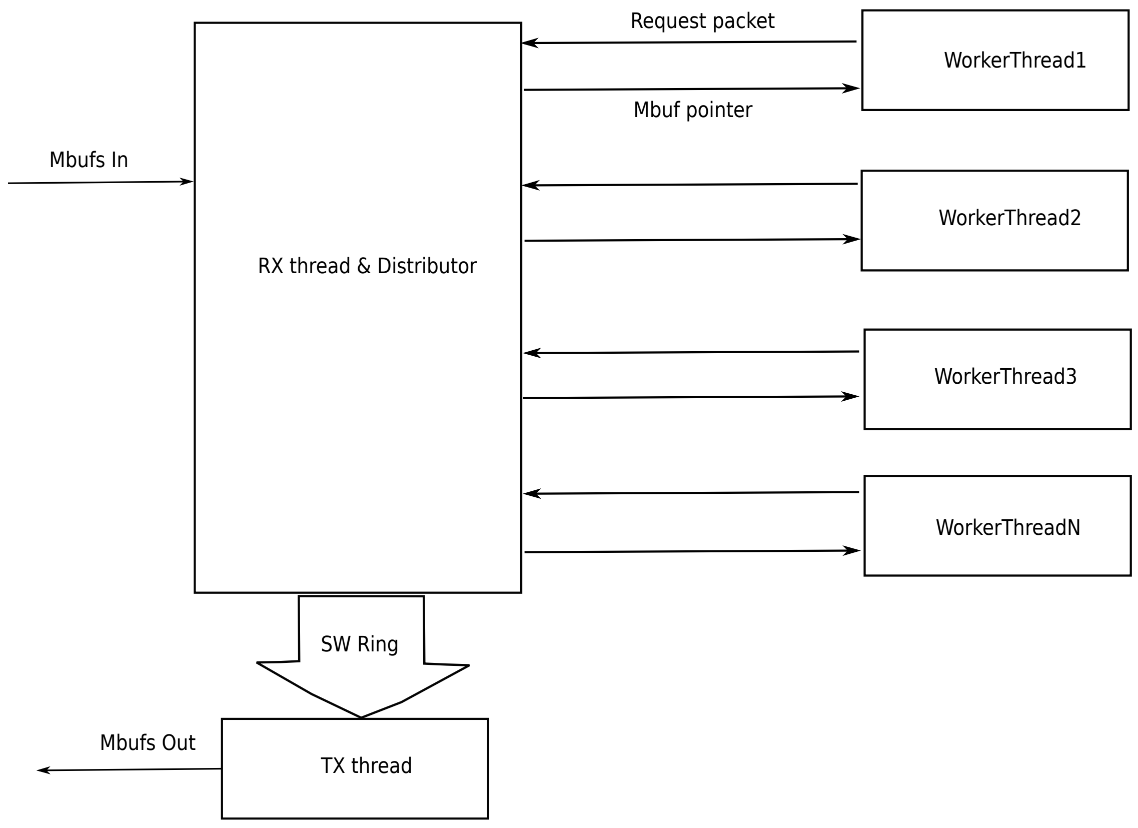


Fig. 33.2: Distributor Sample Application Layout

33.5 Debug Logging Support

Debug logging is provided as part of the application; the user needs to uncomment the line “#define DEBUG” defined in start of the application in main.c to enable debug logs.

33.6 Statistics

Upon SIGINT (or) ctrl+C, the print_stats() function displays the count of packets processed at the different stages in the application.

33.7 Application Initialization

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”.

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”.

Driver Initialization is done in same way as it is done in the L2 Forwarding Sample Application. See Section 9.4.3, “Driver Initialization”.

RX queue initialization is done in the same way as it is done in the L2 Forwarding Sample Application. See Section 9.4.4, “RX Queue Initialization”.

TX queue initialization is done in the same way as it is done in the L2 Forwarding Sample Application. See Section 9.4.5, “TX Queue Initialization”.

CHAPTER

THIRTYFOUR

VM POWER MANAGEMENT APPLICATION

34.1 Introduction

Applications running in Virtual Environments have an abstract view of the underlying hardware on the Host, in particular applications cannot see the binding of virtual to physical hardware. When looking at CPU resourcing, the pinning of Virtual CPUs(vCPUs) to Host Physical CPUs(pCPUS) is not apparent to an application and this pinning may change over time. Furthermore, Operating Systems on virtual machines do not have the ability to govern their own power policy; the Machine Specific Registers (MSRs) for enabling P-State transitions are not exposed to Operating Systems running on Virtual Machines(VMs).

The Virtual Machine Power Management solution shows an example of how a DPDK application can indicate its processing requirements using VM local only information(vCPU/lcore) to a Host based Monitor which is responsible for accepting requests for frequency changes for a vCPU, translating the vCPU to a pCPU via libvirt and affecting the change in frequency.

The solution is comprised of two high-level components:

1. Example Host Application

   Using a Command Line Interface(CLI) for VM->Host communication channel management allows adding channels to the Monitor, setting and querying the vCPU to pCPU pinning, inspecting and manually changing the frequency for each CPU. The CLI runs on a single lcore while the thread responsible for managing VM requests runs on a second lcore.

   VM requests arriving on a channel for frequency changes are passed to the librte_power ACPI cpufreq sysfs based library. The Host Application relies on both qemu-kvm and libvirt to function.

2. librte_power for Virtual Machines

   Using an alternate implementation for the librte_power API, requests for frequency changes are forwarded to the host monitor rather than the APCI cpufreq sysfs interface used on the host.

   The l3fwd-power application will use this implementation when deployed on a VM (see Chapter 11 “L3 Forwarding with Power Management Application”).

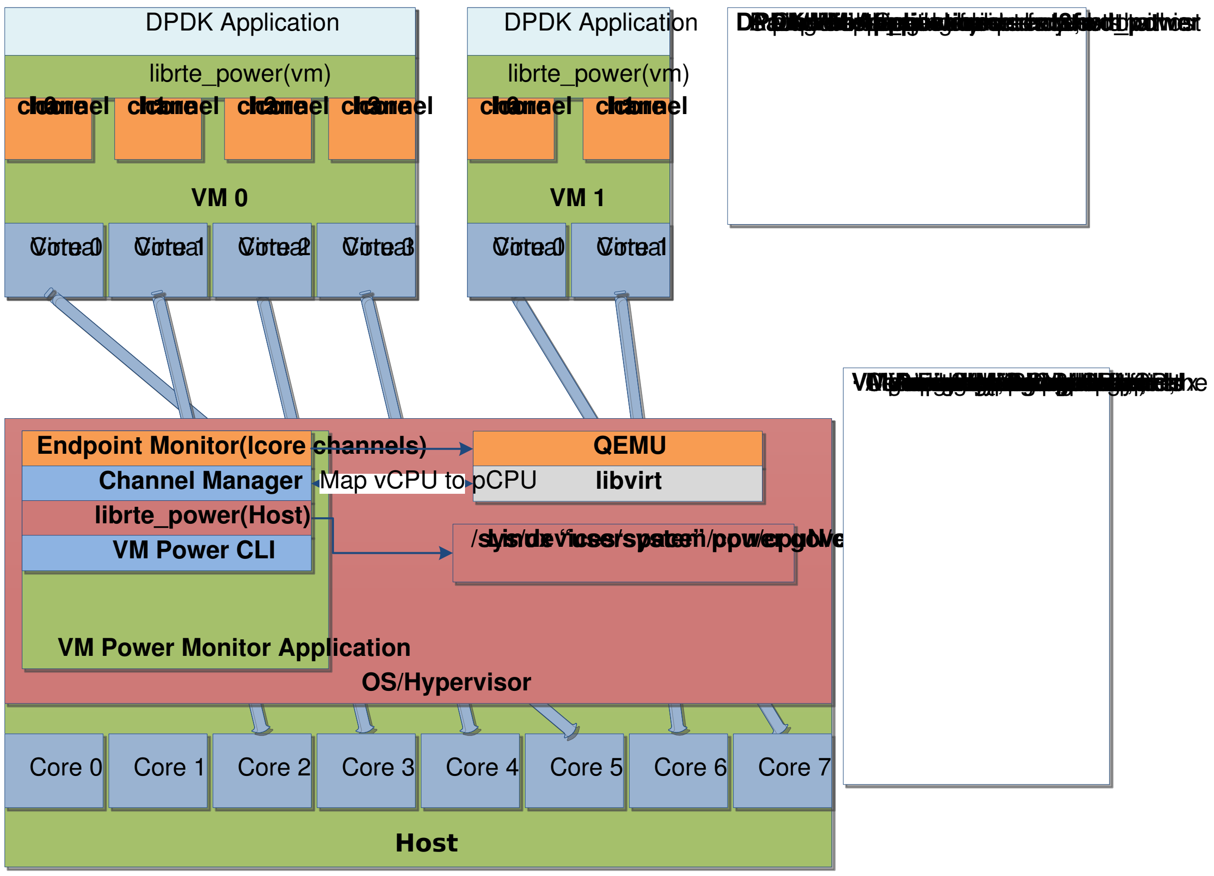


Fig. 34.1: Highlevel Solution

34.2 Overview

VM Power Management employs qemu-kvm to provide communications channels between the host and VMs in the form of Virtio-Serial which appears as a paravirtualized serial device on a VM and can be configured to use various backends on the host. For this example each Virtio-Serial endpoint on the host is configured as AF_UNIX file socket, supporting poll/select and epoll for event notification. In this example each channel endpoint on the host is monitored via epoll for EPOLLIN events. Each channel is specified as qemu-kvm arguments or as libvirt XML for each VM, where each VM can have a number of channels up to a maximum of 64 per VM, in this example each DPDK lcore on a VM has exclusive access to a channel.

To enable frequency changes from within a VM, a request via the librte_power interface is forwarded via Virtio-Serial to the host, each request contains the vCPU and power command(scale up/down/min/max). The API for host and guest librte_power is consistent across environments, with the selection of VM or Host Implementation determined at automatically at runtime based on the environment.

Upon receiving a request, the host translates the vCPU to a pCPU via the libvirt API before forwarding to the host librte_power.

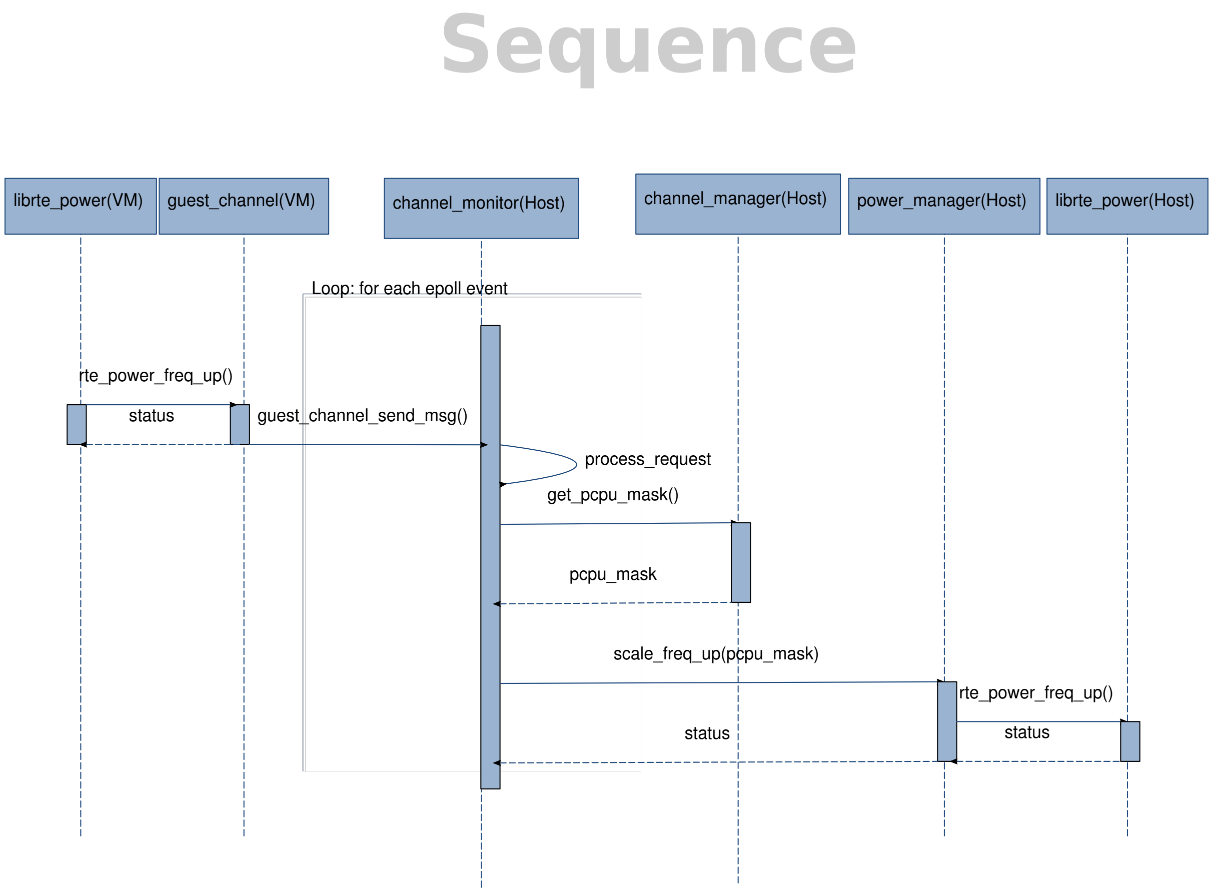


Fig. 34.2: VM request to scale frequency

34.2.1 Performance Considerations

While Haswell Microarchitecture allows for independent power control for each core, earlier Microarchtectures do not offer such fine grained control. When deployed on pre-Haswell platforms greater care must be taken in selecting which cores are assigned to a VM, for instance a core will not scale down until its sibling is similarly scaled.

34.3 Configuration

34.3.1 BIOS

Enhanced Intel SpeedStep® Technology must be enabled in the platform BIOS if the power management feature of DPDK is to be used. Otherwise, the sys file folder /sys/devices/system/cpu/cpu0/cpufreq will not exist, and the CPU frequency-based power management cannot be used. Consult the relevant BIOS documentation to determine how these settings can be accessed.

34.3.2 Host Operating System

The Host OS must also have the *apci_cpufreq* module installed, in some cases the *intel_pstate* driver may be the default Power Management environment. To enable *acpi_cpufreq* and disable *intel_pstate*, add the following to the grub Linux command line:

```
intel_pstate=disable
```

Upon rebooting, load the *acpi_cpufreq* module:

```
modprobe acpi_cpufreq
```

34.3.3 Hypervisor Channel Configuration

Virtio-Serial channels are configured via libvirt XML:

```
<name>{vm_name}</name>
<controller type='virtio-serial' index='0'>
  <address type='pci' domain='0x0000' bus='0x00' slot='0x06' function='0x0'/>
</controller>
<channel type='unix'>
  <source mode='bind' path='/tmp/powermonitor/{vm_name}.{channel_num}'/>
  <target type='virtio' name='virtio.serial.port.poweragent.{vm_channel_num}/>
  <address type='virtio-serial' controller='0' bus='0' port='{N}'/>
</channel>
```

Where a single controller of type *virtio-serial* is created and up to 32 channels can be associated with a single controller and multiple controllers can be specified. The convention is to use the name of the VM in the host path *{vm_name}* and to increment *{channel_num}* for each channel, likewise the port value *{N}* must be incremented for each channel.

Each channel on the host will appear in *path*, the directory */tmp/powermonitor/* must first be created and given qemu permissions

```
mkdir /tmp/powermonitor/
chown qemu:qemu /tmp/powermonitor
```

Note that files and directories within /tmp are generally removed upon rebooting the host and the above steps may need to be carried out after each reboot.

The serial device as it appears on a VM is configured with the *target* element attribute *name* and must be in the form of *virtio.serial.port.poweragent.{vm_channel_num}*, where *vm_channel_num* is typically the lcore channel to be used in DPDK VM applications.

Each channel on a VM will be present at */dev/virtio-ports/virtio.serial.port.poweragent.{vm_channel_num}*

34.4 Compiling and Running the Host Application

34.4.1 Compiling

1. export RTE_SDK=/path/to/rte_sdk
2. cd ${RTE_SDK}/examples/vm_power_manager
3. make

34.4.2 Running

The application does not have any specific command line options other than *EAL*:

```
./build/vm_power_mgr [EAL options]
```

The application requires exactly two cores to run, one core is dedicated to the CLI, while the other is dedicated to the channel endpoint monitor, for example to run on cores 0 & 1 on a system with 4 memory channels:

```
./build/vm_power_mgr -c 0x3 -n 4
```

After successful initialization the user is presented with VM Power Manager CLI:

```
vm_power>
```

Virtual Machines can now be added to the VM Power Manager:

```
vm_power> add_vm {vm_name}
```

When a {vm_name} is specified with the *add_vm* command a lookup is performed with libvirt to ensure that the VM exists, {vm_name} is used as an unique identifier to associate channels with a particular VM and for executing operations on a VM within the CLI. VMs do not have to be running in order to add them.

A number of commands can be issued via the CLI in relation to VMs:

Remove a Virtual Machine identified by {vm_name} from the VM Power Manager.

```
rm_vm {vm_name}
```

Add communication channels for the specified VM, the virtio channels must be enabled in the VM configuration(qemu/libvirt) and the associated VM must be active. {list} is a comma-separated list of channel numbers to add, using the keyword 'all' will attempt to add all channels for the VM:

```
add_channels {vm_name} {list}|all
```

Enable or disable the communication channels in {list}(comma-separated) for the specified VM, alternatively list can be replaced with keyword 'all'. Disabled channels will still receive packets on the host, however the commands they specify will be ignored. Set status to 'enabled' to begin processing requests again:

```
set_channel_status {vm_name} {list}|all enabled|disabled
```

Print to the CLI the information on the specified VM, the information lists the number of vCPUS, the pinning to pCPU(s) as a bit mask, along with any communication channels associated with each VM, along with the status of each channel:

```
show_vm {vm_name}
```

Set the binding of Virtual CPU on VM with name {vm_name} to the Physical CPU mask:

```
set_pcpu_mask {vm_name} {vcpu} {pcpu}
```

Set the binding of Virtual CPU on VM to the Physical CPU:

```
set_pcpu {vm_name} {vcpu} {pcpu}
```

Manual control and inspection can also be carried in relation CPU frequency scaling:

Get the current frequency for each core specified in the mask:

```
show_cpu_freq_mask {mask}
```

Set the current frequency for the cores specified in {core_mask} by scaling each up/down/min/max:

```
set_cpu_freq {core_mask} up|down|min|max
```

Get the current frequency for the specified core:

```
show_cpu_freq {core_num}
```

Set the current frequency for the specified core by scaling up/down/min/max:

```
set_cpu_freq {core_num} up|down|min|max
```

34.5 Compiling and Running the Guest Applications

For compiling and running l3fwd-power, see Chapter 11 “L3 Forwarding with Power Management Application”.

A guest CLI is also provided for validating the setup.

For both l3fwd-power and guest CLI, the channels for the VM must be monitored by the host application using the *add_channels* command on the host.

34.5.1 Compiling

1. export RTE_SDK=/path/to/rte_sdk
2. cd ${RTE_SDK}/examples/vm_power_manager/guest_cli
3. make

34.5.2 Running

The application does not have any specific command line options other than *EAL*:

```
./build/vm_power_mgr [EAL options]
```

The application for example purposes uses a channel for each lcore enabled, for example to run on cores 0,1,2,3 on a system with 4 memory channels:

```
./build/guest_vm_power_mgr -c 0xf -n 4
```

After successful initialization the user is presented with VM Power Manager Guest CLI:

```
vm_power(guest)>
```

To change the frequency of a lcore, use the set_cpu_freq command. Where {core_num} is the lcore and channel to change frequency by scaling up/down/min/max.

```
set_cpu_freq {core_num} up|down|min|max
```

CHAPTER

THIRTYFIVE

TEP TERMINATION SAMPLE APPLICATION

The TEP (Tunnel End point) termination sample application simulates a VXLAN Tunnel Endpoint (VTEP) termination in DPDK, which is used to demonstrate the offload and filtering capabilities of Intel® XL710 10/40 Gigabit Ethernet Controller for VXLAN packet. This sample uses the basic virtio devices management mechanism from vhost example, and also uses the us-vHost interface and tunnel filtering mechanism to direct a specified traffic to a specific VM. In addition, this sample is also designed to show how tunneling protocols can be handled.

35.1 Background

With virtualization, overlay networks allow a network structure to be built or imposed across physical nodes which is abstracted away from the actual underlining physical network connections. This allows network isolation, QOS, etc to be provided on a per client basis.

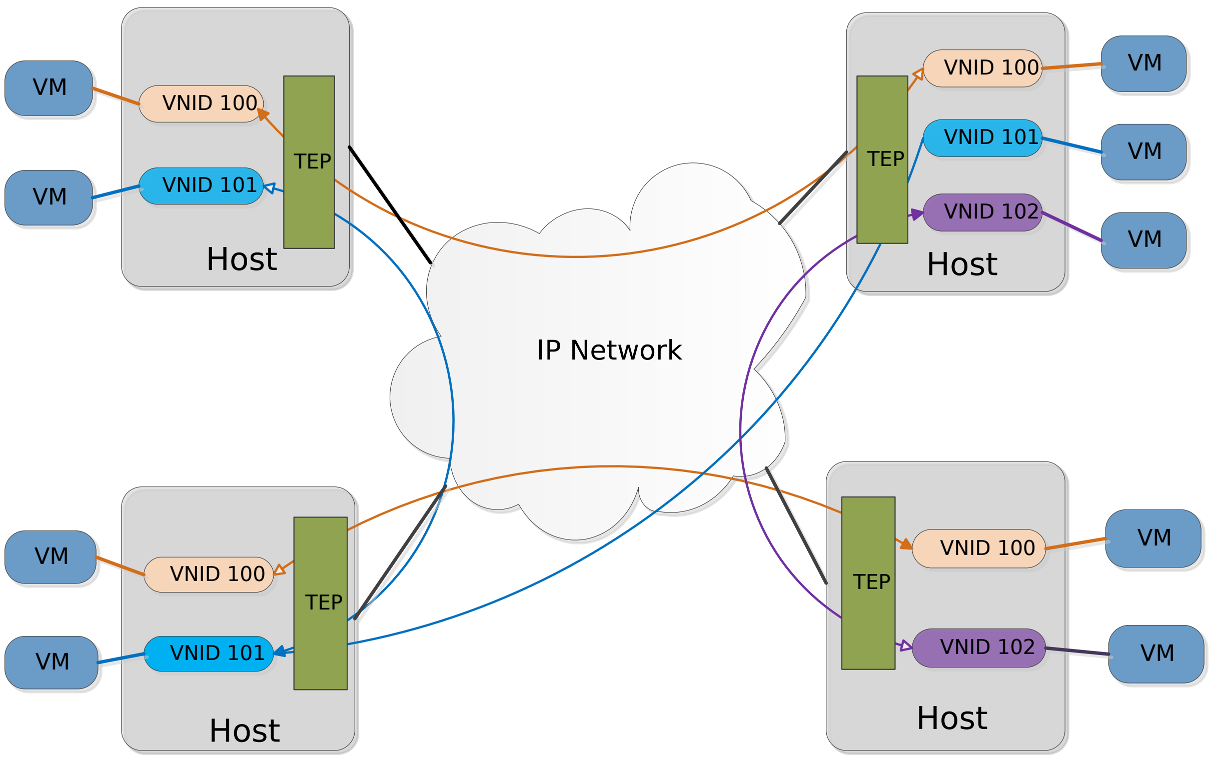


Fig. 35.1: Overlay Networking.

In a typical setup, the network overlay tunnel is terminated at the Virtual/Tunnel End Point

(VEP/TEP). The TEP is normally located at the physical host level ideally in the software switch. Due to processing constraints and the inevitable bottleneck that the switch becomes the ability to offload overlay support features becomes an important requirement. Intel® XL710 10/40 G Ethernet network card provides hardware filtering and offload capabilities to support overlay networks implementations such as MAC in UDP and MAC in GRE.

35.2 Sample Code Overview

The DPDK TEP termination sample code demonstrates the offload and filtering capabilities of Intel® XL710 10/40 Gigabit Ethernet Controller for VXLAN packet.

The sample code is based on vhost library. The vhost library is developed for user space Ethernet switch to easily integrate with vhost functionality.

The sample will support the followings:

- Tunneling packet recognition.
- The port of UDP tunneling is configurable
- Directing incoming traffic to the correct queue based on the tunnel filter type. The supported filter type are listed below.
  - Inner MAC and VLAN and tenant ID
  - Inner MAC and tenant ID, and Outer MAC
  - Inner MAC and tenant ID

  The tenant ID will be assigned from a static internal table based on the us-vhost device ID. Each device will receive a unique device ID. The inner MAC will be learned by the first packet transmitted from a device.
- Decapsulation of RX VXLAN traffic. This is a software only operation.
- Encapsulation of TX VXLAN traffic. This is a software only operation.
- Inner IP and inner L4 checksum offload.
- TSO offload support for tunneling packet.

The following figure shows the framework of the TEP termination sample application based on vhost-cuse.

35.3 Supported Distributions

The example in this section have been validated with the following distributions:

- Fedora* 18
- Fedora* 19
- Fedora* 20

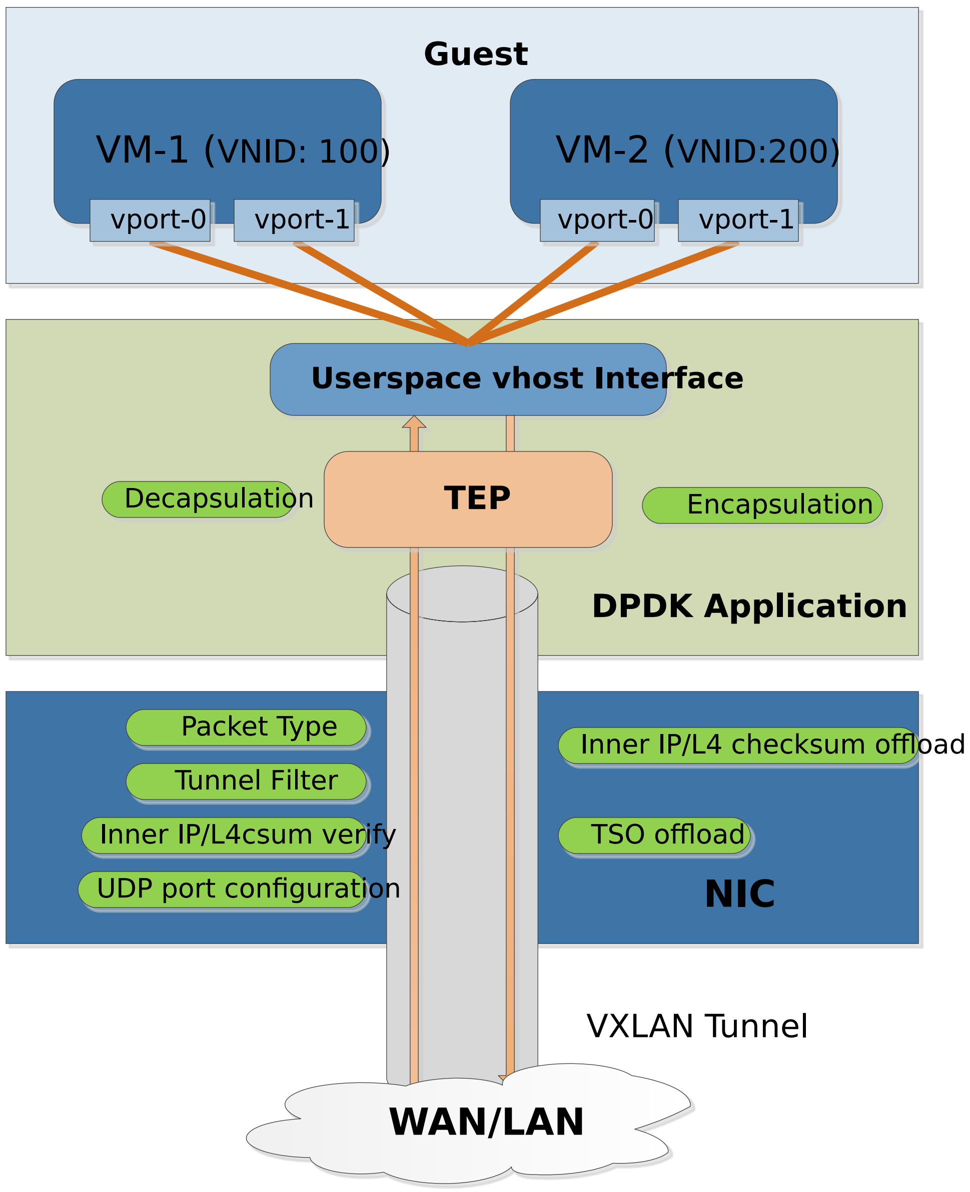


Fig. 35.2: TEP termination Framework Overview

35.4 Prerequisites

Refer to the guide in section 27.4 in the vhost sample.

35.5 Compiling the Sample Code

1. Compile vhost lib:

   To enable vhost, turn on vhost library in the configure file config/common_linuxapp.

   ```
   CONFIG_RTE_LIBRTE_VHOST=n
   ```

   vhost user is turned on by default in the configure file config/common_linuxapp. To enable vhost cuse, disable vhost user.

   ```
       CONFIG_RTE_LIBRTE_VHOST_USER=y

   After vhost is enabled and the implementation is selected, build the vhost library.
   ```

2. Go to the examples directory:

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

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

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

   See the DPDK Getting Started Guide for possible RTE_TARGET values.

4. Build the application:

   ```
   cd ${RTE_SDK}
   make config ${RTE_TARGET}
   make install ${RTE_TARGET}
   cd ${RTE_SDK}/examples/tep_termination
   make
   ```

5. Go to the eventfd_link directory(vhost cuse required):

   ```
   cd ${RTE_SDK}/lib/librte_vhost/eventfd_link
   ```

6. Build the eventfd_link kernel module(vhost cuse required):

   ```
   make
   ```

35.6 Running the Sample Code

1. Install the cuse kernel module(vhost cuse required):

   ```
   modprobe cuse
   ```

2. Go to the eventfd_link directory(vhost cuse required):

   ```
   export RTE_SDK=/path/to/rte_sdk
   cd ${RTE_SDK}/lib/librte_vhost/eventfd_link
   ```

3. Install the eventfd_link module(vhost cuse required):

   ```
   insmod ./eventfd_link.ko
   ```

4. Go to the examples directory:

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

5. Run the tep_termination sample code:

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
                -p 0x1 --dev-basename tep-termination --nb-devices 4
                --udp-port 4789 --filter-type 1
```

Note: Please note the huge-dir parameter instructs the DPDK to allocate its memory from the 2 MB page hugetlbfs.

35.6.1 Parameters

The same parameters with the vhost sample.

Refer to the guide in section 27.6.1 in the vhost sample for the meanings of 'Basename', 'Stats', 'RX Retry', 'RX Retry Number' and 'RX Retry Delay Time'.

Number of Devices.

The nb-devices option specifies the number of virtIO device. The default value is 2.

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
                --nb-devices 2
```

Tunneling UDP port.

The udp-port option is used to specify the destination UDP number for UDP tunneling packet. The default value is 4789.

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
                --nb-devices 2 --udp-port 4789
```

Filter Type.

The filter-type option is used to specify which filter type is used to filter UDP tunneling packet to a specified queue. The default value is 1, which means the filter type of inner MAC and tenant ID is used.

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
            --nb-devices 2 --udp-port 4789 --filter-type 1
```

TX Checksum.

The tx-checksum option is used to enable or disable the inner header checksum offload. The default value is 0, which means the checksum offload is disabled.

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
            --nb-devices 2 --tx-checksum
```

TCP segment size.

The tso-segsz option specifies the TCP segment size for TSO offload for tunneling packet. The default value is 0, which means TSO offload is disabled.

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
            --tx-checksum --tso-segsz 800
```

Decapsulation option.

The decap option is used to enable or disable decapsulation operation for received VXLAN packet. The default value is 1.

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
            --nb-devices 4 --udp-port 4789 --decap 1
```

Encapsulation option.

The encap option is used to enable or disable encapsulation operation for transmitted packet. The default value is 1.

```
user@target:~$ ./build/app/tep_termination -c f -n 4 --huge-dir /mnt/huge --
            --nb-devices 4 --udp-port 4789 --encap 1
```

35.7 Running the Virtual Machine (QEMU)

Refer to the guide in section 27.7 in the vhost sample.

35.8 Running DPDK in the Virtual Machine

Refer to the guide in section 27.8 in the vHost sample.

35.9 Passing Traffic to the Virtual Machine Device

For a virtio-net device to receive traffic, the traffic's Layer 2 header must include both the virtio-net device's MAC address. The DPDK sample code behaves in a similar manner to a learning switch in that it learns the MAC address of the virtio-net devices from the first transmitted packet. On learning the MAC address, the DPDK vhost sample code prints a message with the MAC address and tenant ID virtio-net device. For example:

```
DATA: (0) MAC_ADDRESS cc:bb:bb:bb:bb:bb and VNI 1000 registered
```

The above message indicates that device 0 has been registered with MAC address cc:bb:bb:bb:bb:bb and VNI 1000. Any packets received on the NIC with these values are placed on the devices receive queue.

CHAPTER

THIRTYSIX

DPDK_PROC_INFO APPLICATION

The dpdk_proc_info application is a Data Plane Development Kit (DPDK) application that runs as a DPDK secondary process and is capable of retrieving port statistics, resetting port statistics and printing DPDK memory information. This application extends the original functionality that was supported by dump_cfg.

36.1 Running the Application

The application has a number of command line options:

```
./$(RTE_TARGET)/app/dpdk_proc_info -- -m | [-p PORTMASK] [--stats | --xstats |
--stats-reset | --xstats-reset]
```

36.1.1 Parameters

-p PORTMASK: Hexadecimal bitmask of ports to configure.

–stats The stats parameter controls the printing of generic port statistics. If no port mask is specified stats are printed for all DPDK ports.

–xstats The stats parameter controls the printing of extended port statistics. If no port mask is specified xstats are printed for all DPDK ports.

–stats-reset The stats-reset parameter controls the resetting of generic port statistics. If no port mask is specified, the generic stats are reset for all DPDK ports.

–xstats-reset The xstats-reset parameter controls the resetting of extended port statistics. If no port mask is specified xstats are reset for all DPDK ports.

-m: Print DPDK memory information.

CHAPTER

THIRTYSEVEN

PTP CLIENT SAMPLE APPLICATION

The PTP (Precision Time Protocol) client sample application is a simple example of using the DPDK IEEE1588 API to communicate with a PTP master clock to synchronize the time on the NIC and, optionally, on the Linux system.

Note, PTP is a time syncing protocol and cannot be used within DPDK as a time-stamping mechanism. See the following for an explanation of the protocol: Precision Time Protocol.

37.1 Limitations

The PTP sample application is intended as a simple reference implementation of a PTP client using the DPDK IEEE1588 API. In order to keep the application simple the following assumptions are made:

- The first discovered master is the master for the session.
- Only L2 PTP packets are supported.
- Only the PTP v2 protocol is supported.
- Only the slave clock is implemented.

37.2 How the Application Works

The PTP synchronization in the sample application works as follows:

- Master sends *Sync* message - the slave saves it as T2.
- Master sends *Follow Up* message and sends time of T1.
- Slave sends *Delay Request* frame to PTP Master and stores T3.
- Master sends *Delay Response* T4 time which is time of received T3.

The adjustment for slave can be represented as:

adj = -[(T2-T1)-(T4 - T3)]/2

If the command line parameter `-T 1` is used the application also synchronizes the PTP PHC clock with the Linux kernel clock.

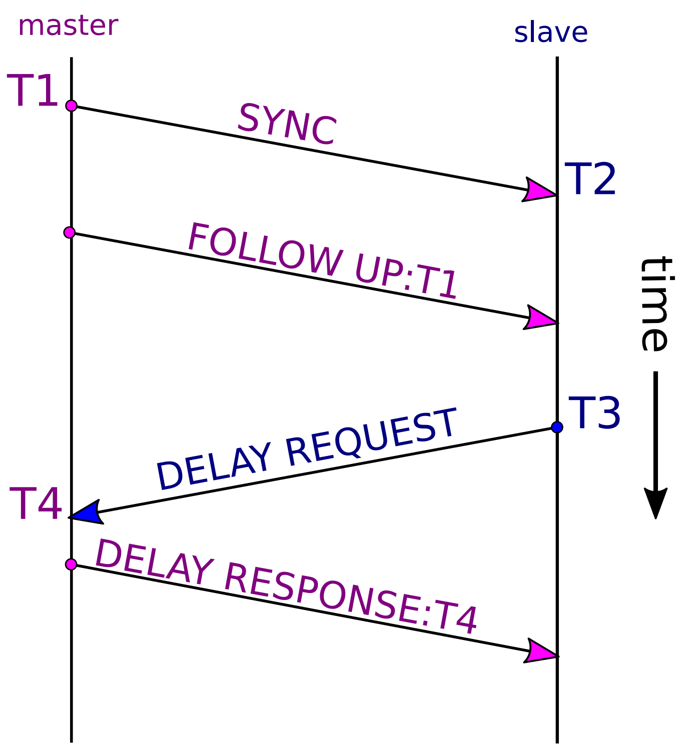


Fig. 37.1: PTP Synchronization Protocol

37.3 Compiling the Application

To compile the application, export the path to the DPDK source tree and edit the `config/common_linuxapp` configuration file to enable IEEE1588:

```
export RTE_SDK=/path/to/rte_sdk

# Edit  common_linuxapp and set the following options:
CONFIG_RTE_LIBRTE_IEEE1588=y
```

Set the target, for example:

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

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

Build the application as follows:

```
# Recompile DPDK.
make install T=$RTE_TARGET

# Compile the application.
cd ${RTE_SDK}/examples/ptpclient
make
```

37.4 Running the Application

To run the example in a `linuxapp` environment:

```
./build/ptpclient -c 2 -n 4 -- -p 0x1 -T 0
```

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

- `-p portmask`: Hexadecimal portmask.
- `-T 0`: Update only the PTP slave clock.
- `-T 1`: Update the PTP slave clock and synchronize the Linux Kernel to the PTP clock.

37.5 Code Explanation

The following sections provide an explanation of the main components of the code.

All DPDK library functions used in the sample code are prefixed with `rte_` and are explained in detail in the *DPDK API Documentation*.

37.5.1 The Main Function

The `main()` function performs the initialization and calls the execution threads for each lcore.

The first task is to initialize the Environment Abstraction Layer (EAL). The `argc` and `argv` arguments are provided to the `rte_eal_init()` function. The value returned is the number of parsed arguments:

```
int ret = rte_eal_init(argc, argv);
if (ret < 0)
    rte_exit(EXIT_FAILURE, "Error with EAL initialization\n");
```

And than we parse application specific arguments

```
argc -= ret;
argv += ret;

ret = ptp_parse_args(argc, argv);
if (ret < 0)
    rte_exit(EXIT_FAILURE, "Error with PTP initialization\n");
```

The `main()` also allocates a mempool to hold the mbufs (Message Buffers) used by the application:

```
mbuf_pool = rte_mempool_create("MBUF_POOL",
                               NUM_MBUFS * nb_ports,
                               MBUF_SIZE,
                               MBUF_CACHE_SIZE,
                               sizeof(struct rte_pktmbuf_pool_private),
                               rte_pktmbuf_pool_init, NULL,
                               rte_pktmbuf_init,      NULL,
                               rte_socket_id(),
                               0);
```

Mbufs are the packet buffer structure used by DPDK. They are explained in detail in the "Mbuf Library" section of the *DPDK Programmer's Guide*.

The `main()` function also initializes all the ports using the user defined `port_init()` function with portmask provided by user:

```
for (portid = 0; portid < nb_ports; portid++)
    if ((ptp_enabled_port_mask & (1 << portid)) != 0) {

        if (port_init(portid, mbuf_pool) == 0) {
            ptp_enabled_ports[ptp_enabled_port_nb] = portid;
            ptp_enabled_port_nb++;
        } else {
            rte_exit(EXIT_FAILURE, "Cannot init port %"PRIu8 "\n",
                    portid);
        }
    }
```

Once the initialization is complete, the application is ready to launch a function on an lcore. In this example `lcore_main()` is called on a single lcore.

```
lcore_main();
```

The `lcore_main()` function is explained below.

37.5.2 The Lcores Main

As we saw above the `main()` function calls an application function on the available lcores.

The main work of the application is done within the loop:

```
for (portid = 0; portid < ptp_enabled_port_nb; portid++) {

    portid = ptp_enabled_ports[portid];
    nb_rx = rte_eth_rx_burst(portid, 0, &m, 1);

    if (likely(nb_rx == 0))
        continue;

    if (m->ol_flags & PKT_RX_IEEE1588_PTP)
        parse_ptp_frames(portid, m);

    rte_pktmbuf_free(m);
}
```

Packets are received one by one on the RX ports and, if required, PTP response packets are transmitted on the TX ports.

If the offload flags in the mbuf indicate that the packet is a PTP packet then the packet is parsed to determine which type:

```
if (m->ol_flags & PKT_RX_IEEE1588_PTP)
     parse_ptp_frames(portid, m);
```

All packets are freed explicitly using `rte_pktmbuf_free()`.

The forwarding loop can be interrupted and the application closed using `Ctrl-C`.

37.5.3 PTP parsing

The `parse_ptp_frames()` function processes PTP packets, implementing slave PTP IEEE1588 L2 functionality.

```
void
parse_ptp_frames(uint8_t portid, struct rte_mbuf *m) {
    struct ptp_header *ptp_hdr;
    struct ether_hdr *eth_hdr;
    uint16_t eth_type;

    eth_hdr = rte_pktmbuf_mtod(m, struct ether_hdr *);
    eth_type = rte_be_to_cpu_16(eth_hdr->ether_type);
```

```
        if (eth_type == PTP_PROTOCOL) {
            ptp_data.m = m;
            ptp_data.portid = portid;
            ptp_hdr = (struct ptp_header *)(rte_pktmbuf_mtod(m, char *)
                        + sizeof(struct ether_hdr));

            switch (ptp_hdr->msgtype) {
            case SYNC:
                parse_sync(&ptp_data);
                break;
            case FOLLOW_UP:
                parse_fup(&ptp_data);
                break;
            case DELAY_RESP:
                parse_drsp(&ptp_data);
                print_clock_info(&ptp_data);
                break;
            default:
                break;
            }
        }
    }
```

There are 3 types of packets on the RX path which we must parse to create a minimal implementation of the PTP slave client:

- SYNC packet.
- FOLLOW UP packet
- DELAY RESPONSE packet.

When we parse the *FOLLOW UP* packet we also create and send a *DELAY_REQUEST* packet. Also when we parse the *DELAY RESPONSE* packet, and all conditions are met we adjust the PTP slave clock.

CHAPTER

THIRTYEIGHT

PERFORMANCE THREAD SAMPLE APPLICATION

The performance thread sample application is a derivative of the standard L3 forwarding application that demonstrates different threading models.

38.1 Overview

For a general description of the L3 forwarding applications capabilities please refer to the documentation of the standard application in L3 Forwarding Sample Application.

The performance thread sample application differs from the standard L3 forwarding example in that it divides the TX and RX processing between different threads, and makes it possible to assign individual threads to different cores.

Three threading models are considered:

1. When there is one EAL thread per physical core.
2. When there are multiple EAL threads per physical core.
3. When there are multiple lightweight threads per EAL thread.

Since DPDK release 2.0 it is possible to launch applications using the `--lcores` EAL parameter, specifying cpu-sets for a physical core. With the performance thread sample application its is now also possible to assign individual RX and TX functions to different cores.

As an alternative to dividing the L3 forwarding work between different EAL threads the performance thread sample introduces the possibility to run the application threads as lightweight threads (L-threads) within one or more EAL threads.

In order to facilitate this threading model the example includes a primitive cooperative scheduler (L-thread) subsystem. More details of the L-thread subsystem can be found in *The L-thread subsystem*.

Note: Whilst theoretically possible it is not anticipated that multiple L-thread schedulers would be run on the same physical core, this mode of operation should not be expected to yield useful performance and is considered invalid.

38.2 Compiling the Application

The application is located in the sample application folder in the `performance-thread` folder.

1. Go to the example applications folder

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

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

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

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

3. Build the application:

   make

38.3 Running the Application

The application has a number of command line options:

```
./build/l3fwd-thread [EAL options] --
    -p PORTMASK [-P]
    --rx(port,queue,lcore,thread)[,(port,queue,lcore,thread)]
    --tx(lcore,thread)[,(lcore,thread)]
    [--enable-jumbo] [--max-pkt-len PKTLEN]]  [--no-numa]
    [--hash-entry-num] [--ipv6] [--no-lthreads] [--stat-lcore lcore]
```

Where:

- `-p PORTMASK`: Hexadecimal bitmask of ports to configure.
- `-P`: optional, 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.
- `--rx (port,queue,lcore,thread)[,(port,queue,lcore,thread)]`: the list of NIC RX ports and queues handled by the RX lcores and threads. The parameters are explained below.
- `--tx (lcore,thread)[,(lcore,thread)]`: the list of TX threads identifying the lcore the thread runs on, and the id of RX thread with which it is associated. The parameters are explained below.
- `--enable-jumbo`: optional, enables jumbo frames.
- `--max-pkt-len`: optional, maximum packet length in decimal (64-9600).
- `--no-numa`: optional, disables numa awareness.
- `--hash-entry-num`: optional, specifies the hash entry number in hex to be setup.
- `--ipv6`: optional, set it if running ipv6 packets.
- `--no-lthreads`: optional, disables l-thread model and uses EAL threading model. See below.
- `--stat-lcore`: optional, run CPU load stats collector on the specified lcore.

The parameters of the `--rx` and `--tx` options are:

- `--rx` parameters

port	RX port
queue	RX queue that will be read on the specified RX port
lcore	Core to use for the thread
thread	Thread id (continuously from 0 to N)

- `--tx` parameters

lcore	Core to use for L3 route match and transmit
thread	Id of RX thread to be associated with this TX thread

The `l3fwd-thread` application allows you to start packet processing in two threading models: L-Threads (default) and EAL Threads (when the `--no-lthreads` parameter is used). For consistency all parameters are used in the same way for both models.

38.3.1 Running with L-threads

When the L-thread model is used (default option), lcore and thread parameters in `--rx/--tx` are used to affinitize threads to the selected scheduler.

For example, the following places every l-thread on different lcores:

```
l3fwd-thread -c ff -n 2 -- -P -p 3 \
             --rx="(0,0,0,0)(1,0,1,1)" \
             --tx="(2,0)(3,1)"
```

The following places RX l-threads on lcore 0 and TX l-threads on lcore 1 and 2 and so on:

```
l3fwd-thread -c ff -n 2 -- -P -p 3 \
             --rx="(0,0,0,0)(1,0,0,1)" \
             --tx="(1,0)(2,1)"
```

38.3.2 Running with EAL threads

When the `--no-lthreads` parameter is used, the L-threading model is turned off and EAL threads are used for all processing. EAL threads are enumerated in the same way as L-threads, but the `--lcores` EAL parameter is used to affinitize threads to the selected cpu-set (scheduler). Thus it is possible to place every RX and TX thread on different lcores.

For example, the following places every EAL thread on different lcores:

```
l3fwd-thread -c ff -n 2 -- -P -p 3 \
             --rx="(0,0,0,0)(1,0,1,1)" \
             --tx="(2,0)(3,1)" \
             --no-lthreads
```

To affinitize two or more EAL threads to one cpu-set, the EAL `--lcores` parameter is used.

The following places RX EAL threads on lcore 0 and TX EAL threads on lcore 1 and 2 and so on:

```
l3fwd-thread -c ff -n 2 --lcores="(0,1)@0,(2,3)@1" -- -P -p 3 \
             --rx="(0,0,0,0)(1,0,1,1)" \
             --tx="(2,0)(3,1)" \
             --no-lthreads
```

38.3.3 Examples

For selected scenarios the command line configuration of the application for L-threads and its corresponding EAL threads command line can be realized as follows:

1. Start every thread on different scheduler (1:1):

   ```
   l3fwd-thread -c ff -n 2 -- -P -p 3 \
                --rx="(0,0,0,0)(1,0,1,1)" \
                --tx="(2,0)(3,1)"
   ```

   EAL thread equivalent:

   ```
   l3fwd-thread -c ff -n 2 -- -P -p 3 \
                --rx="(0,0,0,0)(1,0,1,1)" \
                --tx="(2,0)(3,1)" \
                --no-lthreads
   ```

2. Start all threads on one core (N:1).

   Start 4 L-threads on lcore 0:

   ```
   l3fwd-thread -c ff -n 2 -- -P -p 3 \
                --rx="(0,0,0,0)(1,0,0,1)" \
                --tx="(0,0)(0,1)"
   ```

   Start 4 EAL threads on cpu-set 0:

   ```
   l3fwd-thread -c ff -n 2 --lcores="(0-3)@0" -- -P -p 3 \
                --rx="(0,0,0,0)(1,0,0,1)" \
                --tx="(2,0)(3,1)" \
                --no-lthreads
   ```

3. Start threads on different cores (N:M).

   Start 2 L-threads for RX on lcore 0, and 2 L-threads for TX on lcore 1:

   ```
   l3fwd-thread -c ff -n 2 -- -P -p 3 \
                --rx="(0,0,0,0)(1,0,0,1)" \
                --tx="(1,0)(1,1)"
   ```

   Start 2 EAL threads for RX on cpu-set 0, and 2 EAL threads for TX on cpu-set 1:

   ```
   l3fwd-thread -c ff -n 2 --lcores="(0-1)@0,(2-3)@1" -- -P -p 3 \
                --rx="(0,0,0,0)(1,0,1,1)" \
                --tx="(2,0)(3,1)" \
                --no-lthreads
   ```

38.4 Explanation

To a great extent the sample application differs little from the standard L3 forwarding application, and readers are advised to familiarize themselves with the material covered in the L3 Forwarding Sample Application documentation before proceeding.

The following explanation is focused on the way threading is handled in the performance thread example.

38.4.1 Mode of operation with EAL threads

The performance thread sample application has split the RX and TX functionality into two different threads, and the RX and TX threads are interconnected via software rings. With respect to these rings the RX threads are producers and the TX threads are consumers.

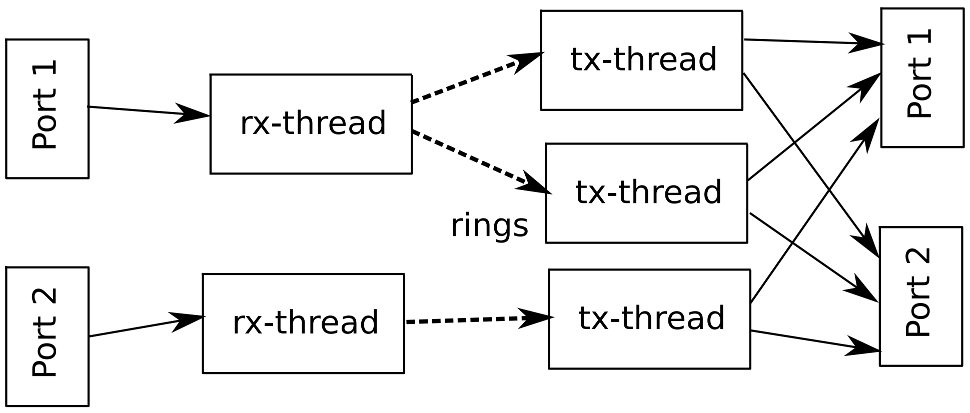
On initialization the TX and RX threads are started according to the command line parameters.

The RX threads poll the network interface queues and post received packets to a TX thread via a corresponding software ring.

The TX threads poll software rings, perform the L3 forwarding hash/LPM match, and assemble packet bursts before performing burst transmit on the network interface.

As with the standard L3 forward application, burst draining of residual packets is performed periodically with the period calculated from elapsed time using the timestamps counter.

The diagram below illustrates a case with two RX threads and three TX threads.



38.4.2 Mode of operation with L-threads

Like the EAL thread configuration the application has split the RX and TX functionality into different threads, and the pairs of RX and TX threads are interconnected via software rings.

On initialization an L-thread scheduler is started on every EAL thread. On all but the master EAL thread only a a dummy L-thread is initially started. The L-thread started on the master EAL thread then spawns other L-threads on different L-thread schedulers according the the command line parameters.

The RX threads poll the network interface queues and post received packets to a TX thread via the corresponding software ring.

The ring interface is augmented by means of an L-thread condition variable that enables the TX thread to be suspended when the TX ring is empty. The RX thread signals the condition whenever it posts to the TX ring, causing the TX thread to be resumed.

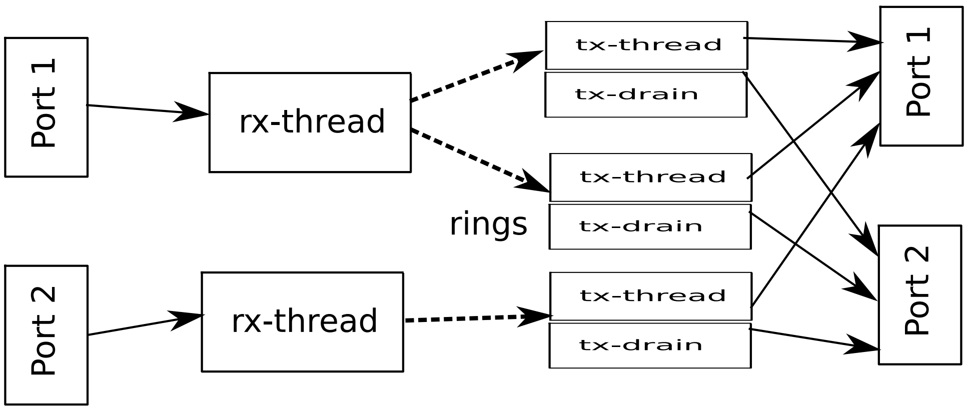
Additionally the TX L-thread spawns a worker L-thread to take care of polling the software rings, whilst it handles burst draining of the transmit buffer.

The worker threads poll the software rings, perform L3 route lookup and assemble packet bursts. If the TX ring is empty the worker thread suspends itself by waiting on the condition variable associated with the ring.

Burst draining of residual packets, less than the burst size, is performed by the TX thread which sleeps (using an L-thread sleep function) and resumes periodically to flush the TX buffer.

This design means that L-threads that have no work, can yield the CPU to other L-threads and avoid having to constantly poll the software rings.

The diagram below illustrates a case with two RX threads and three TX functions (each comprising a thread that processes forwarding and a thread that periodically drains the output buffer of residual packets).



38.4.3 CPU load statistics

It is possible to display statistics showing estimated CPU load on each core. The statistics indicate the percentage of CPU time spent: processing received packets (forwarding), polling queues/rings (waiting for work), and doing any other processing (context switch and other overhead).

When enabled statistics are gathered by having the application threads set and clear flags when they enter and exit pertinent code sections. The flags are then sampled in real time by a statistics collector thread running on another core. This thread displays the data in real time on the console.

This feature is enabled by designating a statistics collector core, using the `--stat-lcore` parameter.

38.5 The L-thread subsystem

The L-thread subsystem resides in the examples/performance-thread/common directory and is built and linked automatically when building the `l3fwd-thread` example.

The subsystem provides a simple cooperative scheduler to enable arbitrary functions to run as cooperative threads within a single EAL thread. The subsystem provides a pthread like API that is intended to assist in reuse of legacy code written for POSIX pthreads.

The following sections provide some detail on the features, constraints, performance and porting considerations when using L-threads.

38.5.1 Comparison between L-threads and POSIX pthreads

The fundamental difference between the L-thread and pthread models is the way in which threads are scheduled. The simplest way to think about this is to consider the case of a processor with a single CPU. To run multiple threads on a single CPU, the scheduler must frequently switch between the threads, in order that each thread is able to make timely progress. This is the basis of any multitasking operating system.

This section explores the differences between the pthread model and the L-thread model as implemented in the provided L-thread subsystem. If needed a theoretical discussion of preemptive vs cooperative multi-threading can be found in any good text on operating system design.

Scheduling and context switching

The POSIX pthread library provides an application programming interface to create and synchronize threads. Scheduling policy is determined by the host OS, and may be configurable. The OS may use sophisticated rules to determine which thread should be run next, threads may suspend themselves or make other threads ready, and the scheduler may employ a time slice giving each thread a maximum time quantum after which it will be preempted in favor of another thread that is ready to run. To complicate matters further threads may be assigned different scheduling priorities.

By contrast the L-thread subsystem is considerably simpler. Logically the L-thread scheduler performs the same multiplexing function for L-threads within a single pthread as the OS scheduler does for pthreads within an application process. The L-thread scheduler is simply the main loop of a pthread, and in so far as the host OS is concerned it is a regular pthread just like any other. The host OS is oblivious about the existence of and not at all involved in the scheduling of L-threads.

The other and most significant difference between the two models is that L-threads are scheduled cooperatively. L-threads cannot not preempt each other, nor can the L-thread scheduler preempt a running L-thread (i.e. there is no time slicing). The consequence is that programs implemented with L-threads must possess frequent rescheduling points, meaning that they must explicitly and of their own volition return to the scheduler at frequent intervals, in order to allow other L-threads an opportunity to proceed.

In both models switching between threads requires that the current CPU context is saved and a new context (belonging to the next thread ready to run) is restored. With pthreads this context switching is handled transparently and the set of CPU registers that must be preserved between context switches is as per an interrupt handler.

An L-thread context switch is achieved by the thread itself making a function call to the L-thread scheduler. Thus it is only necessary to preserve the callee registers. The caller is responsible to save and restore any other registers it is using before a function call, and restore them on return, and this is handled by the compiler. For `X86_64` on both Linux and BSD the System V calling convention is used, this defines registers RSP, RBP, and R12-R15 as callee-save registers (for more detailed discussion a good reference is X86 Calling Conventions).

Taking advantage of this, and due to the absence of preemption, an L-thread context switch is achieved with less than 20 load/store instructions.

The scheduling policy for L-threads is fixed, there is no prioritization of L-threads, all L-threads are equal and scheduling is based on a FIFO ready queue.

An L-thread is a struct containing the CPU context of the thread (saved on context switch) and other useful items. The ready queue contains pointers to threads that are ready to run. The L-thread scheduler is a simple loop that polls the ready queue, reads from it the next thread ready to run, which it resumes by saving the current context (the current position in the scheduler loop) and restoring the context of the next thread from its thread struct. Thus an L-thread is always resumed at the last place it yielded.

A well behaved L-thread will call the context switch regularly (at least once in its main loop) thus returning to the scheduler's own main loop. Yielding inserts the current thread at the back of the ready queue, and the process of servicing the ready queue is repeated, thus the system runs by flipping back and forth the between L-threads and scheduler loop.

In the case of pthreads, the preemptive scheduling, time slicing, and support for thread prioritization means that progress is normally possible for any thread that is ready to run. This comes at the price of a relatively heavier context switch and scheduling overhead.

With L-threads the progress of any particular thread is determined by the frequency of rescheduling opportunities in the other L-threads. This means that an errant L-thread monopolizing the CPU might cause scheduling of other threads to be stalled. Due to the lower cost of context switching, however, voluntary rescheduling to ensure progress of other threads, if managed sensibly, is not a prohibitive overhead, and overall performance can exceed that of an application using pthreads.

Mutual exclusion

With pthreads preemption means that threads that share data must observe some form of mutual exclusion protocol.

The fact that L-threads cannot preempt each other means that in many cases mutual exclusion devices can be completely avoided.

Locking to protect shared data can be a significant bottleneck in multi-threaded applications so a carefully designed cooperatively scheduled program can enjoy significant performance advantages.

So far we have considered only the simplistic case of a single core CPU, when multiple CPUs are considered things are somewhat more complex.

First of all it is inevitable that there must be multiple L-thread schedulers, one running on each EAL thread. So long as these schedulers remain isolated from each other the above assertions about the potential advantages of cooperative scheduling hold true.

A configuration with isolated cooperative schedulers is less flexible than the pthread model where threads can be affinitized to run on any CPU. With isolated schedulers scaling of applications to utilize fewer or more CPUs according to system demand is very difficult to achieve.

The L-thread subsystem makes it possible for L-threads to migrate between schedulers running on different CPUs. Needless to say if the migration means that threads that share data end up running on different CPUs then this will introduce the need for some kind of mutual exclusion system.

Of course `rte_ring` software rings can always be used to interconnect threads running on different cores, however to protect other kinds of shared data structures, lock free constructs or else explicit locking will be required. This is a consideration for the application design.

In support of this extended functionality, the L-thread subsystem implements thread safe mutexes and condition variables.

The cost of affinitizing and of condition variable signaling is significantly lower than the equivalent pthread operations, and so applications using these features will see a performance benefit.

Thread local storage

As with applications written for pthreads an application written for L-threads can take advantage of thread local storage, in this case local to an L-thread. An application may save and retrieve a single pointer to application data in the L-thread struct.

For legacy and backward compatibility reasons two alternative methods are also offered, the first is modelled directly on the pthread get/set specific APIs, the second approach is modelled on the `RTE_PER_LCORE` macros, whereby `PER_LTHREAD` macros are introduced, in both cases the storage is local to the L-thread.

38.5.2 Constraints and performance implications when using L-threads

API compatibility

The L-thread subsystem provides a set of functions that are logically equivalent to the corresponding functions offered by the POSIX pthread library, however not all pthread functions have a corresponding L-thread equivalent, and not all features available to pthreads are implemented for L-threads.

The pthread library offers considerable flexibility via programmable attributes that can be associated with threads, mutexes, and condition variables.

By contrast the L-thread subsystem has fixed functionality, the scheduler policy cannot be varied, and L-threads cannot be prioritized. There are no variable attributes associated with any L-thread objects. L-threads, mutexes and conditional variables, all have fixed functionality. (Note: reserved parameters are included in the APIs to facilitate possible future support for attributes).

The table below lists the pthread and equivalent L-thread APIs with notes on differences and/or constraints. Where there is no L-thread entry in the table, then the L-thread subsystem provides no equivalent function.

Table 38.1: [u'Pthread and equivalent L-thread APIs.']

Pthread function	L-thread function	Notes
pthread_barrier_destroy		
pthread_barrier_init		
pthread_barrier_wait		
pthread_cond_broadcast	lthread_cond_broadcast	See note 1
pthread_cond_destroy	lthread_cond_destroy	
pthread_cond_init	lthread_cond_init	
pthread_cond_signal	lthread_cond_signal	See note 1
pthread_cond_timedwait		
pthread_cond_wait	lthread_cond_wait	See note 5
pthread_create	lthread_create	See notes 2, 3
pthread_detach	lthread_detach	See note 4
pthread_equal		
pthread_exit	lthread_exit	
pthread_getspecific	lthread_getspecific	
pthread_getcpuclockid		

Continued on next page

Table 38.1 – continued from previous page

Pthread function	L-thread function	Notes
pthread_join	lthread_join	
pthread_key_create	lthread_key_create	
pthread_key_delete	lthread_key_delete	
pthread_mutex_destroy	lthread_mutex_destroy	
pthread_mutex_init	lthread_mutex_init	
pthread_mutex_lock	lthread_mutex_lock	See note 6
pthread_mutex_trylock	lthread_mutex_trylock	See note 6
pthread_mutex_timedlock		
pthread_mutex_unlock	lthread_mutex_unlock	
pthread_once		
pthread_rwlock_destroy		
pthread_rwlock_init		
pthread_rwlock_rdlock		
pthread_rwlock_timedrdlock		
pthread_rwlock_timedwrlock		
pthread_rwlock_tryrdlock		
pthread_rwlock_trywrlock		
pthread_rwlock_unlock		
pthread_rwlock_wrlock		
pthread_self	lthread_current	
pthread_setspecific	lthread_setspecific	
pthread_spin_init		See note 10
pthread_spin_destroy		See note 10
pthread_spin_lock		See note 10
pthread_spin_trylock		See note 10
pthread_spin_unlock		See note 10
pthread_cancel	lthread_cancel	
pthread_setcancelstate		
pthread_setcanceltype		
pthread_testcancel		
pthread_getschedparam		
pthread_setschedparam		
pthread_yield	lthread_yield	See note 7
pthread_setaffinity_np	lthread_set_affinity	See notes 2, 3, 8
	lthread_sleep	See note 9
	lthread_sleep_clks	See note 9

Note 1:

Neither lthread signal nor broadcast may be called concurrently by L-threads running on different schedulers, although multiple L-threads running in the same scheduler may freely perform signal or broadcast operations. L-threads running on the same or different schedulers may always safely wait on a condition variable.

Note 2:

Pthread attributes may be used to affinitize a pthread with a cpu-set. The L-thread subsystem does not support a cpu-set. An L-thread may be affinitized only with a single CPU at any time.

Note 3:

If an L-thread is intended to run on a different NUMA node than the node that creates the thread then, when calling `lthread_create()` it is advantageous to specify the destination core as a parameter of `lthread_create()`. See *Memory allocation and NUMA awareness* for details.

Note 4:

An L-thread can only detach itself, and cannot detach other L-threads.

Note 5:

A wait operation on a pthread condition variable is always associated with and protected by a mutex which must be owned by the thread at the time it invokes `pthread_wait()`. By contrast L-thread condition variables are thread safe (for waiters) and do not use an associated mutex. Multiple L-threads (including L-threads running on other schedulers) can safely wait on a L-thread condition variable. As a consequence the performance of an L-thread condition variables is typically an order of magnitude faster than its pthread counterpart.

Note 6:

Recursive locking is not supported with L-threads, attempts to take a lock recursively will be detected and rejected.

Note 7:

`lthread_yield()` will save the current context, insert the current thread to the back of the ready queue, and resume the next ready thread. Yielding increases ready queue backlog, see *Ready queue backlog* for more details about the implications of this.

N.B. The context switch time as measured from immediately before the call to `lthread_yield()` to the point at which the next ready thread is resumed, can be an order of magnitude faster that the same measurement for pthread_yield.

Note 8:

`lthread_set_affinity()` is similar to a yield apart from the fact that the yielding thread is inserted into a peer ready queue of another scheduler. The peer ready queue is actually a separate thread safe queue, which means that threads appearing in the peer ready queue can jump any backlog in the local ready queue on the destination scheduler.

The context switch time as measured from the time just before the call to `lthread_set_affinity()` to just after the same thread is resumed on the new scheduler can be orders of magnitude faster than the same measurement for `pthread_setaffinity_np()`.

Note 9:

Although there is no `pthread_sleep()` function, `lthread_sleep()` and `lthread_sleep_clks()` can be used wherever `sleep()`, `usleep()` or `nanosleep()` might ordinarily be used. The L-thread sleep functions suspend the current thread, start an `rte_timer` and resume the thread when the timer matures. The `rte_timer_manage()` entry point is called on every pass of the scheduler loop. This means that the worst case jitter on timer expiry is determined by the longest period between context switches of any running L-threads.

In a synthetic test with many threads sleeping and resuming then the measured jitter is typically orders of magnitude lower than the same measurement made for `nanosleep()`.

Note 10:

Spin locks are not provided because they are problematical in a cooperative environment, see *Locks and spinlocks* for a more detailed discussion on how to avoid spin locks.

Thread local storage

Of the three L-thread local storage options the simplest and most efficient is storing a single application data pointer in the L-thread struct.

The `PER_LTHREAD` macros involve a run time computation to obtain the address of the variable being saved/retrieved and also require that the accesses are de-referenced via a pointer. This means that code that has used `RTE_PER_LCORE` macros being ported to L-threads might need some slight adjustment (see *Thread local storage* for hints about porting code that makes use of thread local storage).

The get/set specific APIs are consistent with their pthread counterparts both in use and in performance.

Memory allocation and NUMA awareness

All memory allocation is from DPDK huge pages, and is NUMA aware. Each scheduler maintains its own caches of objects: lthreads, their stacks, TLS, mutexes and condition variables. These caches are implemented as unbounded lock free MPSC queues. When objects are created they are always allocated from the caches on the local core (current EAL thread).

If an L-thread has been affinitized to a different scheduler, then it can always safely free resources to the caches from which they originated (because the caches are MPSC queues).

If the L-thread has been affinitized to a different NUMA node then the memory resources associated with it may incur longer access latency.

The commonly used pattern of setting affinity on entry to a thread after it has started, means that memory allocation for both the stack and TLS will have been made from caches on the NUMA node on which the threads creator is running. This has the side effect that access latency will be sub-optimal after affinitizing.

This side effect can be mitigated to some extent (although not completely) by specifying the destination CPU as a parameter of `lthread_create()` this causes the L-thread's stack and TLS to be allocated when it is first scheduled on the destination scheduler, if the destination is a on another NUMA node it results in a more optimal memory allocation.

Note that the lthread struct itself remains allocated from memory on the creating node, this is unavoidable because an L-thread is known everywhere by the address of this struct.

Object cache sizing

The per lcore object caches pre-allocate objects in bulk whenever a request to allocate an object finds a cache empty. By default 100 objects are pre-allocated, this is defined by `LTHREAD_PREALLOC` in the public API header file lthread_api.h. This means that the caches constantly grow to meet system demand.

In the present implementation there is no mechanism to reduce the cache sizes if system demand reduces. Thus the caches will remain at their maximum extent indefinitely.

A consequence of the bulk pre-allocation of objects is that every 100 (default value) additional new object create operations results in a call to `rte_malloc()`. For creation of objects such as L-threads, which trigger the allocation of even more objects (i.e. their stacks and TLS) then this can cause outliers in scheduling performance.

If this is a problem the simplest mitigation strategy is to dimension the system, by setting the bulk object pre-allocation size to some large number that you do not expect to be exceeded. This means the caches will be populated once only, the very first time a thread is created.

Ready queue backlog

One of the more subtle performance considerations is managing the ready queue backlog. The fewer threads that are waiting in the ready queue then the faster any particular thread will get serviced.

In a naive L-thread application with N L-threads simply looping and yielding, this backlog will always be equal to the number of L-threads, thus the cost of a yield to a particular L-thread will be N times the context switch time.

This side effect can be mitigated by arranging for threads to be suspended and wait to be resumed, rather than polling for work by constantly yielding. Blocking on a mutex or condition variable or even more obviously having a thread sleep if it has a low frequency workload are all mechanisms by which a thread can be excluded from the ready queue until it really does need to be run. This can have a significant positive impact on performance.

Initialization, shutdown and dependencies

The L-thread subsystem depends on DPDK for huge page allocation and depends on the `rte_timer subsystem`. The DPDK EAL initialization and `rte_timer_subsystem_init()` **MUST** be completed before the L-thread sub system can be used.

Thereafter initialization of the L-thread subsystem is largely transparent to the application. Constructor functions ensure that global variables are properly initialized. Other than global variables each scheduler is initialized independently the first time that an L-thread is created by a particular EAL thread.

If the schedulers are to be run as isolated and independent schedulers, with no intention that L-threads running on different schedulers will migrate between schedulers or synchronize with L-threads running on other schedulers, then initialization consists simply of creating an L-thread, and then running the L-thread scheduler.

If there will be interaction between L-threads running on different schedulers, then it is important that the starting of schedulers on different EAL threads is synchronized.

To achieve this an additional initialization step is necessary, this is simply to set the number of schedulers by calling the API function `lthread_num_schedulers_set(n)`, where `n` is the number of EAL threads that will run L-thread schedulers. Setting the number of schedulers to a number greater than 0 will cause all schedulers to wait until the others have started before beginning to schedule L-threads.

The L-thread scheduler is started by calling the function `lthread_run()` and should be called from the EAL thread and thus become the main loop of the EAL thread.

The function `lthread_run()`, will not return until all threads running on the scheduler have exited, and the scheduler has been explicitly stopped by calling `lthread_scheduler_shutdown(lcore)` or `lthread_scheduler_shutdown_all()`.

All these function do is tell the scheduler that it can exit when there are no longer any running L-threads, neither function forces any running L-thread to terminate. Any desired application shutdown behavior must be designed and built into the application to ensure that L-threads complete in a timely manner.

Important Note: It is assumed when the scheduler exits that the application is terminating for good, the scheduler does not free resources before exiting and running the scheduler a subsequent time will result in undefined behavior.

38.5.3 Porting legacy code to run on L-threads

Legacy code originally written for a pthread environment may be ported to L-threads if the considerations about differences in scheduling policy, and constraints discussed in the previous sections can be accommodated.

This section looks in more detail at some of the issues that may have to be resolved when porting code.

pthread API compatibility

The first step is to establish exactly which pthread APIs the legacy application uses, and to understand the requirements of those APIs. If there are corresponding L-lthread APIs, and where the default pthread functionality is used by the application then, notwithstanding the other issues discussed here, it should be feasible to run the application with L-threads. If the legacy code modifies the default behavior using attributes then if may be necessary to make some adjustments to eliminate those requirements.

Blocking system API calls

It is important to understand what other system services the application may be using, bearing in mind that in a cooperatively scheduled environment a thread cannot block without stalling the scheduler and with it all other cooperative threads. Any kind of blocking system call, for example file or socket IO, is a potential problem, a good tool to analyze the application for this purpose is the `strace` utility.

There are many strategies to resolve these kind of issues, each with it merits. Possible solutions include:

- Adopting a polled mode of the system API concerned (if available).
- Arranging for another core to perform the function and synchronizing with that core via constructs that will not block the L-thread.
- Affinitizing the thread to another scheduler devoted (as a matter of policy) to handling threads wishing to make blocking calls, and then back again when finished.

Locks and spinlocks

Locks and spinlocks are another source of blocking behavior that for the same reasons as system calls will need to be addressed.

If the application design ensures that the contending L-threads will always run on the same scheduler then it its probably safe to remove locks and spin locks completely.

The only exception to the above rule is if for some reason the code performs any kind of context switch whilst holding the lock (e.g. yield, sleep, or block on a different lock, or on a condition variable). This will need to determined before deciding to eliminate a lock.

If a lock cannot be eliminated then an L-thread mutex can be substituted for either kind of lock.

An L-thread blocking on an L-thread mutex will be suspended and will cause another ready L-thread to be resumed, thus not blocking the scheduler. When default behavior is required, it can be used as a direct replacement for a pthread mutex lock.

Spin locks are typically used when lock contention is likely to be rare and where the period during which the lock may be held is relatively short. When the contending L-threads are running on the same scheduler then an L-thread blocking on a spin lock will enter an infinite loop stopping the scheduler completely (see *Infinite loops* below).

If the application design ensures that contending L-threads will always run on different schedulers then it might be reasonable to leave a short spin lock that rarely experiences contention in place.

If after all considerations it appears that a spin lock can neither be eliminated completely, replaced with an L-thread mutex, or left in place as is, then an alternative is to loop on a flag, with a call to `lthread_yield()` inside the loop (n.b. if the contending L-threads might ever run on different schedulers the flag will need to be manipulated atomically).

Spinning and yielding is the least preferred solution since it introduces ready queue backlog (see also *Ready queue backlog*).

Sleeps and delays

Yet another kind of blocking behavior (albeit momentary) are delay functions like `sleep()`, `usleep()`, `nanosleep()` etc. All will have the consequence of stalling the L-thread scheduler and unless the delay is very short (e.g. a very short nanosleep) calls to these functions will need to be eliminated.

The simplest mitigation strategy is to use the L-thread sleep API functions, of which two variants exist, `lthread_sleep()` and `lthread_sleep_clks()`. These functions start an rte_timer against the L-thread, suspend the L-thread and cause another ready L-thread to be resumed. The suspended L-thread is resumed when the rte_timer matures.

Infinite loops

Some applications have threads with loops that contain no inherent rescheduling opportunity, and rely solely on the OS time slicing to share the CPU. In a cooperative environment this will stop everything dead. These kind of loops are not hard to identify, in a debug session you will find the debugger is always stopping in the same loop.

The simplest solution to this kind of problem is to insert an explicit `lthread_yield()` or `lthread_sleep()` into the loop. Another solution might be to include the function performed by the loop into the execution path of some other loop that does in fact yield, if this is possible.

Thread local storage

If the application uses thread local storage, the use case should be studied carefully.

In a legacy pthread application either or both the `__thread` prefix, or the pthread set/get specific APIs may have been used to define storage local to a pthread.

In some applications it may be a reasonable assumption that the data could or in fact most likely should be placed in L-thread local storage.

If the application (like many DPDK applications) has assumed a certain relationship between a pthread and the CPU to which it is affinitized, there is a risk that thread local storage may have been used to save some data items that are correctly logically associated with the CPU, and others items which relate to application context for the thread. Only a good understanding of the application will reveal such cases.

If the application requires an that an L-thread is to be able to move between schedulers then care should be taken to separate these kinds of data, into per lcore, and per L-thread storage. In this way a migrating thread will bring with it the local data it needs, and pick up the new logical core specific values from pthread local storage at its new home.

38.5.4 Pthread shim

A convenient way to get something working with legacy code can be to use a shim that adapts pthread API calls to the corresponding L-thread ones. This approach will not mitigate any of the porting considerations mentioned in the previous sections, but it will reduce the amount of code churn that would otherwise been involved. It is a reasonable approach to evaluate L-threads, before investing effort in porting to the native L-thread APIs.

Overview

The L-thread subsystem includes an example pthread shim. This is a partial implementation but does contain the API stubs needed to get basic applications running. There is a simple "hello world" application that demonstrates the use of the pthread shim.

A subtlety of working with a shim is that the application will still need to make use of the genuine pthread library functions, at the very least in order to create the EAL threads in which the L-thread schedulers will run. This is the case with DPDK initialization, and exit.

To deal with the initialization and shutdown scenarios, the shim is capable of switching on or off its adaptor functionality, an application can control this behavior by the calling the function `pt_override_set()`. The default state is disabled.

The pthread shim uses the dynamic linker loader and saves the loaded addresses of the genuine pthread API functions in an internal table, when the shim functionality is enabled it performs the adaptor function, when disabled it invokes the genuine pthread function.

The function `pthread_exit()` has additional special handling. The standard system header file pthread.h declares `pthread_exit()` with `__attribute__((noreturn))` this is an optimization that is possible because the pthread is terminating and this enables the compiler to omit the normal handling of stack and protection of registers since the function is not expected to return, and in fact the thread is being destroyed. These optimizations are applied in both the callee and the caller of the `pthread_exit()` function.

In our cooperative scheduling environment this behavior is inadmissible. The pthread is the L-thread scheduler thread, and, although an L-thread is terminating, there must be a return to the scheduler in order that the system can continue to run. Further, returning from a function with attribute `noreturn` is invalid and may result in undefined behavior.

The solution is to redefine the `pthread_exit` function with a macro, causing it to be mapped to a stub function in the shim that does not have the `noreturn` attribute. This macro is defined in the file `pthread_shim.h`. The stub function is otherwise no different than any of the other stub functions in the shim, and will switch between the real `pthread_exit()` function or the `lthread_exit()` function as required. The only difference is that the mapping to the stub by macro substitution.

A consequence of this is that the file `pthread_shim.h` must be included in legacy code wishing to make use of the shim. It also means that dynamic linkage of a pre-compiled binary that did not include pthread_shim.h is not be supported.

Given the requirements for porting legacy code outlined in *Porting legacy code to run on L-threads* most applications will require at least some minimal adjustment and recompilation to run on L-threads so pre-compiled binaries are unlikely to be met in practice.

In summary the shim approach adds some overhead but can be a useful tool to help establish the feasibility of a code reuse project. It also is a fairly straightforward task to extend the shim if necessary.

Note: Bearing in mind the preceding discussions about the impact of making blocking calls then switching the shim in and out on the fly to invoke any pthread API this might block is something that should typically be avoided.

Building and running the pthread shim

The shim example application is located in the sample application in the performance-thread folder

To build and run the pthread shim example

1. Go to the example applications folder

   ```
   export RTE_SDK=/path/to/rte_sdk
   cd ${RTE_SDK}/examples/performance-thread/pthread_shim
   ```

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

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

   See the DPDK Getting Started Guide for possible RTE_TARGET values.

3. Build the application:

   ```
   make
   ```

4. To run the pthread_shim example

   ```
   lthread-pthread-shim -c core_mask -n number_of_channels
   ```

38.5.5 L-thread Diagnostics

When debugging you must take account of the fact that the L-threads are run in a single pthread. The current scheduler is defined by `RTE_PER_LCORE(this_sched)`, and the current lthread is stored at `RTE_PER_LCORE(this_sched)->current_lthread`. Thus on a breakpoint in a GDB session the current lthread can be obtained by displaying the pthread local variable `per_lcore_this_sched->current_lthread`.

Another useful diagnostic feature is the possibility to trace significant events in the life of an L-thread, this feature is enabled by changing the value of LTHREAD_DIAG from 0 to 1 in the file `lthread_diag_api.h`.

Tracing of events can be individually masked, and the mask may be programmed at run time. An unmasked event results in a callback that provides information about the event. The default callback simply prints trace information. The default mask is 0 (all events off) the mask can be modified by calling the function `lthread_diagniostic_set_mask()`.

It is possible register a user callback function to implement more sophisticated diagnostic functions. Object creation events (lthread, mutex, and condition variable) accept, and store in the created object, a user supplied reference value returned by the callback function.

The lthread reference value is passed back in all subsequent event callbacks, the mutex and APIs are provided to retrieve the reference value from mutexes and condition variables. This enables a user to monitor, count, or filter for specific events, on specific objects, for example to monitor for a specific thread signaling a specific condition variable, or to monitor on all timer events, the possibilities and combinations are endless.

The callback function can be set by calling the function `lthread_diagnostic_enable()` supplying a callback function pointer and an event mask.

Setting `LTHREAD_DIAG` also enables counting of statistics about cache and queue usage, and these statistics can be displayed by calling the function `lthread_diag_stats_display()`. This function also performs a consistency check on the caches and queues. The function should only be called from the master EAL thread after all slave threads have stopped and returned to the C main program, otherwise the consistency check will fail.

Figures