

# PF\_RING User Guide

Linux High Speed Packet Capture

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## 2. Introduction

PF\_RING is a high speed packet capture library that turns a commodity PC into an efficient and cheap network measurement box suitable for both packet and active traffic analysis and manipulation. Moreover, PF\_RING opens totally new markets as it enables the creation of efficient application such as traffic balancers or packet filters in a matter of lines of codes.

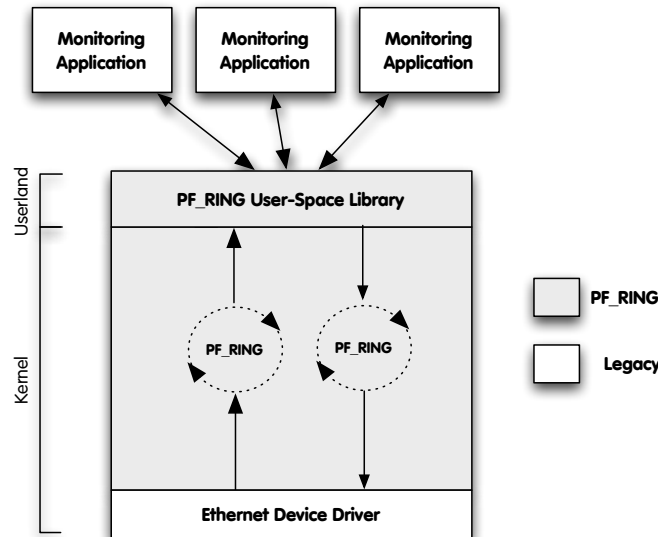
This manual is divided in two parts:

- PF\_RING installation and configuration.
- PF\_RING SDK.

### 2.1. What's New with PF\_RING User's Guide?

- Release 5.5.2 (Jan 2013)
  - Updated guide to PF\_RING version 5.5.2
- Release 5.4.6 (Aug 2012)
  - Updated guide to PF\_RING version 5.4.6
- Release 5.4.0 (May 2012)
  - Updated guide to PF\_RING version 5.4.0
  - New libzero for zero-copy flexible packet processing on top of DNA.
- Release 5.3.1 (March 2012)
  - Updated guide to PF\_RING version 5.3.1
- Release 5.2.1 (January 2012)
  - Updated guide to PF\_RING version 5.2.1
  - New API functions for managing hardware clocks and timestamps.
  - New kernel plugin callbacks.
- Release 5.1 (September 2011)
  - Updated guide to PF\_RING version 5.1.0
- Release 4.7.1 (July 2011)
  - Updated guide to PF\_RING version 4.7.1
  - Described PF\_RING modular library and some modules (DAG, DNA)
- Release 4.6.1 (March 2011)
  - Updated guide to PF\_RING version 4.6.1
- Release 4.6 (February 2011)
  - Updated guide to PF\_RING version 4.6.0.
- Release 1.1 (January 2008)
  - Described PF\_RING plugins architecture.
- Release 1.0 (January 2008)
  - Initial PF\_RING users guide.

### 3. Welcome to PF\_RING



PF\_RING's architecture is depicted in the figure below.

The main building blocks are:

- The accelerated kernel module that provides low-level packet copying into the PF\_RING rings.
- The user-space PF\_RING SDK that provides transparent PF\_RING-support to user-space applications.
- Specialized PF\_RING-aware drivers (optional) that allow to further enhance packet capture by efficiently copying packets from the driver to PF\_RING without passing through the kernel data structures. Please note that PF\_RING can operate with any NIC driver, but for maximum performance it is necessary to use these specialized drivers that can be found into the kernel/ directory part of the PF\_RING distribution. Note that the way drivers pass packets to PF\_RING is selected when the PF\_RING kernel module is loaded by means of the `transparent_mode` parameter.

PF\_RING implements a new socket type (named PF\_RING) on which user-space applications can speak with the PF\_RING kernel module. Applications can obtain a PF\_RING handle, and issue API calls that are described later in this manual. A handle can be bound to a:

- Physical network interface.
- A RX queue, only on multi-queue network adapters.
- To the 'any' virtual interface that means packets received/sent on all system interfaces are accepted.

As specified above, packets are read from a memory ring allocated at creation time. Incoming packets are copied by the kernel module to the ring, and read by the user-space applications. No per-packet memory allocation/deallocation is performed. Once a packet has been read from the ring, the space used in the ring for storing the packet just read will be used for accommodating future packets. This means that applications willing to keep a packet archive, must store themselves the packets just read as the PF\_RING will not preserve them.

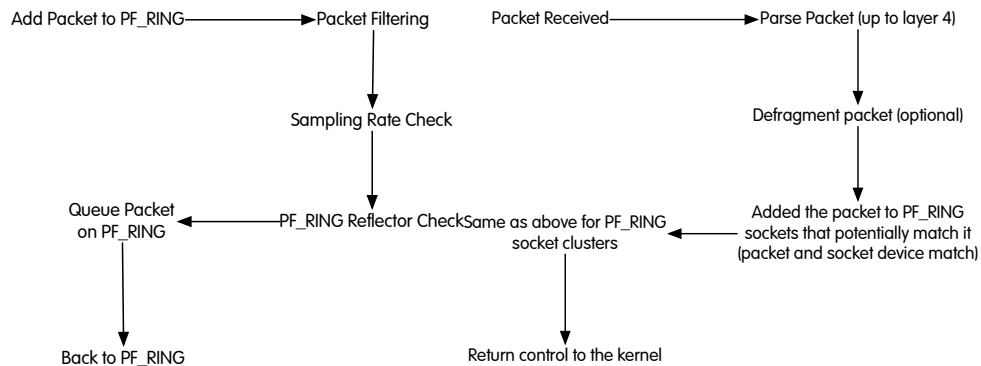
#### 3.1. Packet Filtering

PF\_RING supports both legacy BPF filters (i.e. those supported by pcap-based applications such as tcpdump), and also two additional types of filters (named wildcard and precise filters, depending on the fact that some or all filter elements are specified) that provide developers a wide choice of options. Filters are evaluated inside the PF\_RING module thus in kernel. Some modern adapters such as Intel 82599-

based on Silicom Redirector NICs, support hardware-based filters that are also supported by PF\_RING via specified API calls (e.g. `pfring_add_hw_rule`). PF\_RING filters (except hw filters) can have an action specified, for telling to the PF\_RING kernel module what action needs to be performed when a given packet matches the filter. Actions include pass/don't pass the filter to the user space application, stop evaluating the filter chain, or reflect packet. In PF\_RING, packet reflection is the ability to transmit (unmodified) the packet matching the filter onto a network interface (this except the interface on which the packet has been received). The whole reflection functionality is implemented inside the PF\_RING kernel module, and the only activity requested to the user-space application is the filter specification without any further packet processing.

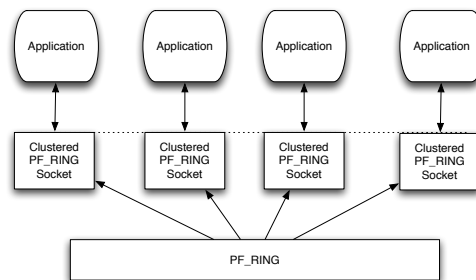
### 3.2. Packet Journey

The packet journey in PF\_RING is quite long before being queued into a PF\_RING ring.



### 3.3. Packet Clustering

PF\_RING can also increase the performance of packet capture applications by implementing two mechanisms named balancing and clustering. These mechanisms allow applications, willing to partition the set of packets to handle, to handle a portion of the whole packet stream while sending all the remaining packets to the other members of the cluster. This means that different applications opening PF\_RING sockets can bind them to a specific cluster Id (via `pfring_set_cluster`) for joining the forces and each analyze a portion of the packets.



The way packets are partitioned across cluster sockets is specified in the cluster policy that can be either per-flow (i.e. all the packets belonging to the same tuple `<proto, ip src/dst, port src/dst>`) that is the default or round-robin. This means that if you select per-flow balancing, all the packets belonging to the same flow (i.e. the 5-tuple specified above) will go to the same application, whereas with round-robin all the apps will receive the same amount of packets but there is no guarantee that packets belonging to the same queue will be received by a single application. So in one hand per-flow balancing allows you

to preserve the application logic as in this case the application will receive a subset of all packets but this traffic will be consistent. On the other hand if you have a specific flow that takes most of the traffic, then the application that will handle such flow will be over-flooded by packets and thus the traffic will not be heavily balanced.



## 4. PF\_RING Driver Families

As previously stated, PF\_RING can work both on top of standard NIC drivers, or on top of specialized drivers. The PF\_RING kernel module is the same, but based on the drivers being used some functionality and performance are different.

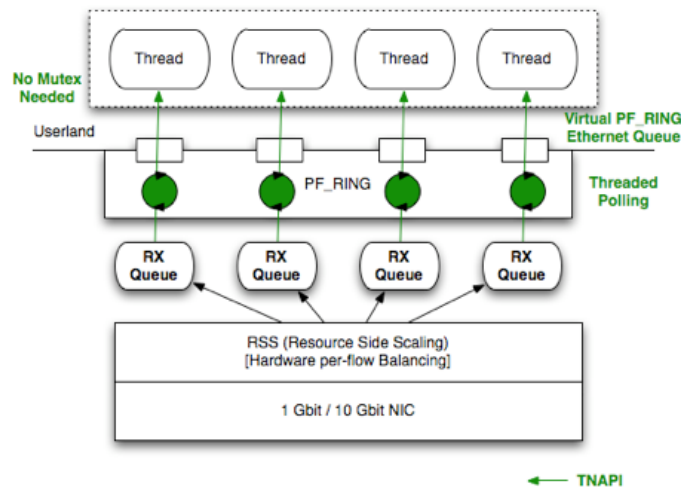
### 4.1. PF\_RING-aware Drivers

These drivers (available on PF\_RING/driver/PF\_RING-aware) are designed to improve packet capture by pushing packets directly to PF\_RING without going through the standard Linux packet dispatching mechanisms. With these drivers you can use the `transparent_mode` with values 1, or 2 (see below on this document for details).

In addition to PF\_RING aware drivers, for some selected adapters, it is possible to use other driver types that further increase packet capture.

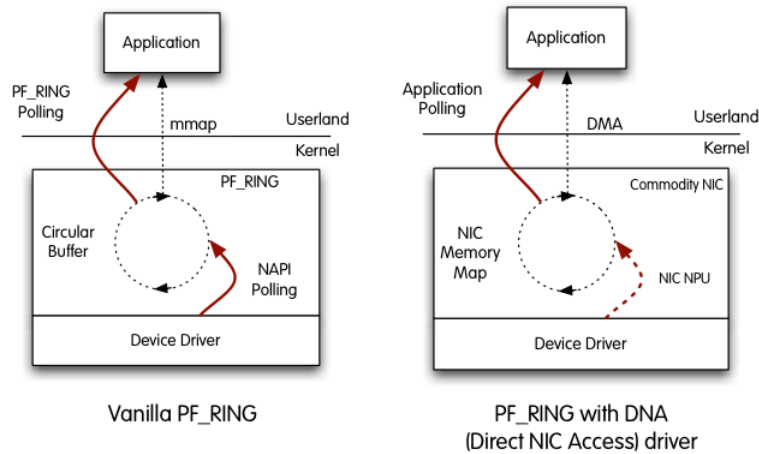
### 4.2. TNAPI

The first family of drivers is named TNAPI (Threaded NAPI), that allow packets to be pushed more efficiently into PF\_RING by means of kernel threads activated directly by the TNAPI driver. The TNAPI drivers are designed for improving packet capture, and thus they cannot be used to transmit packets as the TX path is disabled.



### 4.3.DNA

For those users that who need maximum packet capture speed with 0% CPU utilization for copying packets to the host (i.e. the NAPI polling mechanism is not used), it is also possible to use a different type of driver named DNA, that allows packets to be read directly from the network interface by simultaneously bypassing both the Linux kernel and the PF\_RING module in a zero-copy fashion.



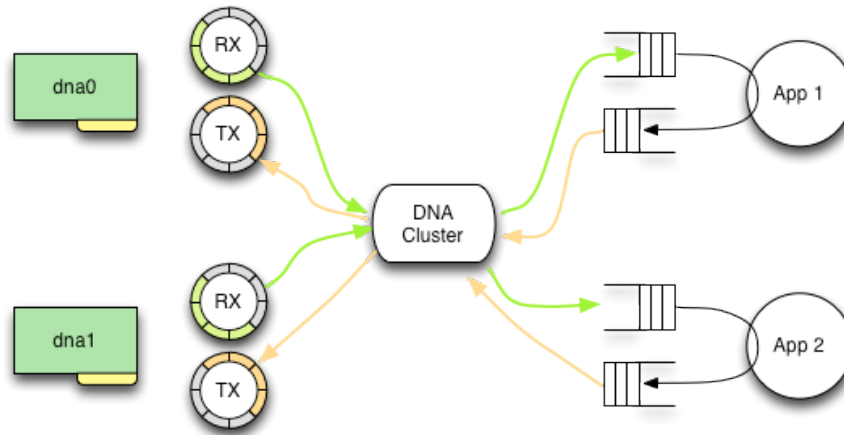
In DNA both RX and TX operations are supported. As the kernel is bypassed, some PF\_RING functionality are missing, and they include:

- In kernel packet filtering (BPF and PF\_RING filters)
- PF\_RING kernel plugins have no effect.

## 5.Libzero for DNA

As most applications need complex packet processing features, starting with PF\_RING 5.4.0 a library named libzero has been introduced, sitting on top of the low-level DNA interface and implementing zero-copy packet processing. The libzero provides two main components: the DNA Cluster and the DNA Bouncer.

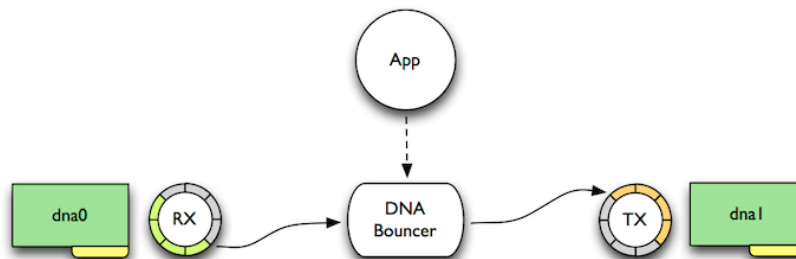
### 5.1.DNA Cluster



The DNA Cluster implements packet clustering, so that all applications belonging to the same cluster can share incoming packets using a flexible balancing function and transmit packets all in zero-copy. In essence is a custom implementation of RSS, that allows to distribute packets across queues inside network adapters. The cluster allows users to define their dispatching function for filtering, distributing and duplicating packets towards multiple threads and applications.

### 5.2.DNA Bouncer

The DNA Bouncer switches packets across two interfaces in zero-copy, leaving the user the ability to specify a function that can decide, packet-by-packet, whether a given packet has to be forwarded or not.



Forwarding can be mono-directional (thus in case you want to implement bridging, two bouncer threads, one per direction, need to be instantiated) or bi-directional.

## 6. PF\_RING Installation

When you download PF\_RING you fetch the following components:

- The PF\_RING user-space SDK.
- An enhanced version of the libpcap library that transparently takes advantage of PF\_RING if installed, or fallback to the standard behavior if not installed.
- The PF\_RING kernel module.
- PF\_RING aware drivers for different chips of various vendors.

PF\_RING is downloaded by means of SVN as explained in <http://www.ntop.org/get-started/download/>.

The PF\_RING source code layout is the following:

- doc/
- drivers/
- kernel/
- Makefile
- README
- README.DNA
- README.FIRST
- userland/
- vPF\_RING/

You can compile the entire tree typing make (as normal, non-root, user) from the main directory.

### 6.1. Linux Kernel Module Installation

In order to compile the PF\_RING kernel module you need to have the linux kernel headers (or kernel source) installed.

```
$ cd <PF_RING_PATH>/kernel
$ make
```

Note that:

- the kernel module installation (via make install) requires super user (root) capabilities.
- For some Linux distributions a kernel installation/compilation package is provided.
- As of PF\_RING 4.x you NO LONGER NEED to patch the linux kernel as in previous PF\_RING versions.

## 7. Running PF\_RING

Before using any PF\_RING application the pf\_ring kernel module should be loaded (as superuser):

```
# insmod <PF_RING PATH>/kernel/pf_ring.ko [transparent_mode=0|1|2]
[ min_num_slots=x ][ enable_tx_capture=1|0 ] [ enable_ip_defrag=1|0 ] [ quick_mode=1|
0 ]
```

Note:

- transparent\_mode=0 (default)  
Packets are received via the standard Linux interface. Any driver can use this mode.
- transparent\_mode=1(Both vanilla and PF\_RING-aware drivers)  
Packets are memcpyl() to PF\_RING and also to the standard Linux path.
- transparent\_mode=2 (PF\_RING -aware drivers only)  
Packets are ONLY memcpyl() to PF\_RING and not to the standard Linux path (i.e. tcpdump won't see anything).

**IMPORTANT:** Do NOT use transparent\_mode 1 and 2 with vanilla drivers as it will result in no packet capture.

The higher is the transparent\_mode value, the faster it gets packet capture.

Other parameters:

- min\_num\_slots  
Min number of ring slots (default — 4096).
- enable\_tx\_capture  
Set to 1 to capture outgoing packets, set to 0 to disable capture outgoing packets (default — RX +TX).
- enable\_ip\_defrag  
Set to 1 to enable IP defragmentation, only rx traffic is defragmented.
- quick\_mode  
Set to 1 to run at full speed but with up to one socket per interface.

### 7.1. Checking PF\_RING Device Configuration

When PF\_RING is activated, a new entry /proc/net/pf\_ring is created.

```
# ls /proc/net/pf_ring/
dev  info  plugins_info
```

```
# cat /proc/net/pf_ring/info
PF_RING Version      : 5.5.3
Total rings          : 0
```

```
Standard (non DNA) Options
Ring slots           : 4096
Slot version         : 15
Capture TX           : Yes [RX+TX]
IP Defragment        : No
Socket Mode          : Standard
Transparent mode      : Yes [mode 0]
```

```
Total plugins           : 2
Cluster Fragment Queue  : 0
Cluster Fragment Discard : 0
```

PF\_RING allows users to install plugins for handling custom traffic. Those plugins are also registered in the `pf_ring` /proc tree and can be listed by typing the `plugins_info` file.

```
# cat /proc/net/pf_ring/plugins_info
ID      Plugin
2       sip [SIP protocol analyzer]
12      rtp [RTP protocol analyzer]
```

## 7.2. Libpfiring and Libpcap Installation

Both `libpfiring` (userspace PF\_RING library) and `libpcap` are distributed in source format. They can be compiled as follows:

```
$ cd <PF_RING PATH>/userland/lib
$ ./configure
$ make
$ sudo make install
$ cd ../libpcap
$ ./configure
$ make
```

Note that the `lib` is reentrant hence it's necessary to link your PF\_RING-enabled applications also against the `-lpthread` library.

### IMPORTANT

Legacy statically-linked pcap-based applications need to be recompiled against the new PF\_RING-enabled `libpcap.a` in order to take advantage of PF\_RING. Do not expect to use PF\_RING without recompiling your existing application.

## 7.3. Application Examples

If you are new to PF\_RING, you can start with some examples. The `userland/examples` folder is rich of ready-to-use PF\_RING applications:

```
$ cd <PF_RING PATH>/userland/examples
$ ls *.c
alldevs.c                pfcount_aggregator.c    pffilter_test.c
dummy_plugin_pfcount.c   pfcount_bundle.c        pflatency.c
interval.c               pfcount_dummy_plugin.c  pfmap.c
pcap2nspcap.c            pfcount_multichannel.c  pfsend.c
pcount.c                 pfdnabounce.c           pfsystest.c
pfbounce.c               pfdnacluster_master.c   pfutils.c
pfbridge.c               pfdnacluster_mt_rss_frwd.c pfwrite.c
pfcount.c                pfdnacluster_multithread.c preflect.c
```

```
pfcount_82599.c          pfdump.c
$ make
```

For instance, pfcount allows you to receive packets printing some statistics:

```
# ./pfcount -i dna0
Using PF_RING v.5.5.3
...
=====
Absolute Stats: [64415543 pkts rcvd][0 pkts dropped]
Total Pkts=64415543/Dropped=0.0 %
64'415'543 pkts - 5'410'905'612 bytes [4'293'748.94 pkt/sec - 2'885.39
Mbit/sec]
=====
Actual Stats: 14214472 pkts [1'000.03 ms][14'214'017.15 pps/9.55 Gbps]
=====
```

Another example is pfsend, which allows you to send packets (synthetic packets, or optionally a .pcap file can be used) at a specific rate:

```
# ./pfsend -f 64byte_packets.pcap -n 0 -i dna0 -r 5
...
TX rate: [current 7'508'239.00 pps/5.05 Gbps][average 7'508'239.00 pps/
5.05 Gbps][total 7'508'239.00 pkts]
```

## 7.4. PF\_RING Additional Modules

As of version 4.7, the PF\_RING library has a new modular architecture, making it possible to use additional components other than the standard PF\_RING kernel module. These components are compiled inside the library according to the supports detected by the configure script.

Currently, the set of additional modules includes:

- DAG module.  
This module adds native support for Endace DAG cards in PF\_RING. In order to use this module it's necessary to have the dag library (4.x or later) installed and to link your PF\_RING-enabled application using the -ldag flag.
- DNA module.  
This module can be used to open a device in DNA mode, if you own a supported card and a DNA driver. Please note that the PF\_RING kernel module must be loaded before the the DNA driver. With DNA you can dramatically increase the packet capture and transmission speed as the kernel layer is bypassed and applications can communicate directly with drivers.  
Currently these DNA-aware drivers are available:
  - ▶ e1000e
  - ▶ igb
  - ▶ ixgbe

The drivers are part of the PF\_RING distribution and can be found in drivers/DNA/.

With all the drivers you can achieve wire rate at any packet size, both for RX and TX. You can test RX using the pfcount application, and TX using the pfsend application.

Note that in case of TX, the transmission speed is limited by the RX performance. This is because when the receiver cannot keep-up with the capture speed, the ethernet NIC sends ethernet PAUSE frames back to the sender to slow it down. If you want to ignore these frames and thus send at full speed, you need to disable autonegotiation and ignore them (`ethtool -A dnaX autoneg off rx off tx off`).

- Link Aggregation ("multi") module.  
This module can be used to aggregate multiple interfaces in order to capture packets from all of them opening a single PF\_RING socket. For example it is possible to open a ring with device name "multi:ethX;ethY;ethZ".
- Userspace RING ("userspace") module.  
This module allows an application to send packets to another process leveraging on the standard PF\_RING API by creating virtual devices (e.g. `usrX`, where X is a unique identifier for the userspace ring). In order to do this, the sending application has to open a ring by using as device name "userspace:usrX" (where "userspace:" identifies the Userspace RING module), while the receiving application has to open a ring in the standard way by using as device name "usrX".
- Libzero consumer ("dnacluster") module.  
This module can be used to attach to a DNA Cluster allowing the application to send and receive packets leveraging on the standard PF\_RING API. The sending application has to open a ring by using as device name "dnacluster:X@Y" where X is the cluster identifier and Y is the consumer identifier, or "dnacluster:X" for auto-assigning the consumer identifier.
- Linux TCP/IP Stack injection ("stack") module.  
This module can be used to inject/capture packets to/from the Linux TCP/IP Stack, simulating the arrival/sending of those packets on an interface. The application has to open a ring by using as device name "stack:dnaX" where dnaX is the interface bound to the packets injected into the stack. In order to inject a packet to the stack `pfring_send()` has to be used, in order to capture outgoing packets `pfring_rcv()` has to be used.



## 8. PF\_RING for Application Developers

Conceptually PF\_RING is a simple yet powerful technology that enables developers to create high-speed traffic monitor and manipulation applications in a small amount of time. This is because PF\_RING shields the developer from inner kernel details that are handled by a library and kernel driver. This way developers can dramatically save development time focusing on the application they are developing without paying attention to the way packets are sent and received.

This chapter covers:

- The PF\_RING API.
- Extensions to the libpcap library for supporting legacy applications.

### 8.1. The PF\_RING API

The PF\_RING internal data structures should be hidden to the user who can manipulate packets and devices only by means of the available API defined in the include file `pfring.h` that comes with PF\_RING.

### 8.2. Return Codes

By convention, the library returns negative values for errors and exceptions. Non-negative codes indicate success. In case return code have another meaning, then they are described inside the corresponding function.

### 8.3. PF\_RING Device Name Convention

In PF\_RING device names are the same as libpcap and ifconfig. So `eth0` and `eth5` are valid names you can use in PF\_RING. You can specify also a virtual device named 'any' that instructs PF\_RING to capture packets from all available network devices.

As previously explained, with PF\_RING you can use both the drivers that come with your Linux distribution (thus that are not PF\_RING-specific), or some PF\_RING-aware drivers (you can find them into the `drivers/` directory of PF\_RING) that push PF\_RING packets much more efficiently than vanilla drivers. If you own a modern multi-queue NIC running with a PF\_RING-aware driver (e.g. the Intel 10 Gbit adapter), PF\_RING allows you to capture packet from the whole device (i.e. capture packets regardless of the RX queue on which the packet has been received, `ethX` for instance) or from a specific queue (e.g. `ethX@Y`). Supposing to have an adapter with `Z` queues, the queue Id `Y`, must be in range `0..Z-1`. In case you specify a queue that does not exist, no packets will be captured.

As stated in the previous chapter, PF\_RING 4.7 has a modular architecture. In order to indicate to the library which module we are willing to use, it is possible to prepend the module name to the device name, separated by a colon (e.g. `dna:dnaX@Y` for the dna module, `dag:dagX:Y` for the dag module, `"multi:ethA@X;ethB@Y;ethC@Z"` for the Link Aggregation module, `"dnacluster:A@X"` for the Cluster consumer module).

## 8.4.PF\_RING: SOCKET Initialization

```
pfring* pfring_open(char *device_name, u_int32_t caplen, u_int flags)
```

This call is used to initialize a PF\_RING socket hence obtain a handle of type struct pfring that can be used in subsequent calls. Note that:

- You can use physical (e.g. ethX) and virtual (e.g. tapX) devices, RX-queues (e.g. ethX@Y), and additional modules (e.g. dna:dnaX@Y, dag:dagX:Y, "multi:ethA@X;ethB@Y;ethC@Z", "dnacluster:A@X", "stack:dnaX").
- You need super-user capabilities in order to open a device.

Input parameters:

device\_name

Symbolic name of the PF\_RING-aware device we're attempting to open (e.g. eth0).

caplen

Maximum packet capture len (also known as snaplen).

flags

It allows several options to be specified on a compact format using bitmaps:

- PF\_RING\_REENTRANT  
The device is open in reentrant mode. This is implemented by means of semaphores and it results in slightly worse performance. Use reentrant mode only for multithreaded applications.
- PF\_RING\_LONG\_HEADER  
If used, PF\_RING does not fill the field extended\_hdr of struct pfring\_pkthdr. If set, the extended\_hdr field is also properly filled. In case you do not need extended information, set this value to 0 in order to speedup the operation.
- PF\_RING\_PROMISC  
The device is open in promiscuous mode.
- PF\_RING\_DNA\_SYMMETRIC\_RSS  
Set the hw RSS function to symmetric mode (both directions of the same flow go to the same hw queue). Supported by DNA drivers only. This option is also available with the PF\_RING-aware libpcap via the PCAP\_PF\_RING\_DNA\_RSS environment variable.
- PF\_RING\_TIMESTAMP  
Force PF\_RING to set the timestamp on received packets (usually it is not set when using zero-copy, for optimizing performance).
- PF\_RING\_HW\_TIMESTAMP  
Enable hw timestamping, when available.
- PF\_RING\_DNA\_FIXED\_RSS\_Q\_0  
Set hw RSS to send all traffic to queue 0. Other queues can be selected using hw filters (DNA cards with hw filtering only).
- PF\_RING\_STRIP\_HW\_TIMESTAMP  
Strip hw timestamp from the packet.
- PF\_RING\_DO\_NOT\_PARSE  
Disable packet parsing also when 1-copy is used.
- PF\_RING\_DO\_NOT\_TIMESTAMP  
Disable packet timestamping also when 1-copy is used.

Return value:

On success a handle is returned, NULL otherwise.

```
u_int8_t pfring_open_multichannel(char *device_name,  
                                   u_int32_t caplen, u_int flags,  
                                   pfring* ring[MAX_NUM_RX_CHANNELS])
```

This call is similar to `pfring_open()` with the exception that in case of a multi RX-queue NIC, instead of opening a single ring for the whole device, several individual rings are open (one per RX-queue).

Input parameters:

`device_name`

Symbolic name of the PF\_RING-aware device we're attempting to open (e.g. `eth0`). No queue name hash to be specified, but just the main device name

`caplen`

Maximum packet capture len (also known as `snaplen`).

`flags`

See `pfring_open()` for details.

`ring`

A pointer to an array of rings that will contain the opened ring pointers.

Return value:

The last index of the ring array that contain a valid ring pointer.

## 8.5. PF\_RING: Device Termination

```
void pfring_close(pfring *ring)
```

This call is used to terminate an PF\_RING device previously open. Note that you must always close a device before leaving an application. If unsure, you can close a device from a signal handler.

Input parameters:

ring

The PF\_RING handle that we are attempting to close.

## 8.6. PF\_RING: Read Incoming Packets

```
int pfring_recv(pfring *ring, u_char** buffer, u_int buffer_len, struct pfring_pkthdr *hdr,  
               u_int8_t wait_for_incoming_packet)
```

This call returns an incoming packet when available.

Input parameters:

ring

The PF\_RING handle where we perform the check.

buffer

A memory area allocated by the caller where the incoming packet will be stored. Note that this parameter is a pointer to a pointer, in order to enable zero-copy implementations (buffer\_len must be set to 0).

buffer\_len

The length of the memory area above. Note that the incoming packet is cut if it is too long for the allocated area. A length of 0 indicates to use the zero-copy optimization, when available.

hdr

A memory area where the packet header will be copied.

wait\_for\_incoming\_packet

If 0 we simply check the packet availability, otherwise the call is blocked until a packet is available. This option is also available with the PF\_RING-aware libpcap via the PCAP\_PF\_RING\_ACTIVE\_POLL environment variable.

Return value:

0 in case of no packet being received (non-blocking), 1 in case of success, -1 in case of error.

```
int pfring_rcv_parsed(pfring *ring, u_char** buffer, u_int buffer_len, struct
pfring_pkthdr *hdr, u_int8_t wait_for_incoming_packet, u_int8_t level, u_int8_t
add_timestamp, u_int8_t add_hash)
```

Same of `pfring_rcv()`, with additional parameters to force packet parsing.

Input parameters not present in `pfring_rcv()`:

`level`

The header level where to stop parsing.

`add_timestamp`

Add the timestamp.

`add_hash`

Compute an IP-based bidirectional hash.

```
int pfring_loop(pfring *ring, pfringProcessPacket loop, const u_char *user_bytes,  
u_int8_t wait_for_packet)
```

This call processes packets until pfring\_breakloop() is called or an error occurs.

Input parameters:

ring  
The PF\_RING handle.

loop  
A callback to be called for each received packet. The parameters passed to this routine are: a pointer to a struct pfring\_pkthdr, a pointer to the packet memory, and a pointer to user\_bytes.

user\_bytes  
A pointer to user's data which is passed to the callback.

wait\_for\_packet  
If 0 active wait is used to check the packet availability.

Return value:

A non-negative number if pfring\_breakloop() is called. A negative number in case of error.



```
int pfring_next_pkt_time(pfring *ring, struct timespec *ts)
```

This call returns the arrival time of the next incoming packet, when available.

Input parameters:

ring  
The PF\_RING handle where we perform the check.

ts  
The struct where the time will be stored.

Return value:

0 in case of success, a negative number in case of error.

```
int pfring_next_pkt_raw_timestamp(pfring *ring, u_int64_t *timestamp_ns)
```

This call returns the raw timestamp of the next incoming packet, when available. This is available with adapters supporting rx hardware timestamping only.

Input parameters:

ring  
The PF\_RING handle where we perform the check.

timestamp\_ns  
Where the timestamp will be stored.

Return value:

0 in case of success, a negative number in case of error.

## 8.7. PF\_RING: Ring Clusters

```
int pfring_set_cluster(pfring *ring, u_int clusterId, cluster_type the_type)
```

This call allows a ring to be added to a cluster that can spawn across address spaces. On a nutshell when two or more sockets are clustered they share incoming packets that are balanced on a per-flow manner. This technique is useful for exploiting multicore systems or for sharing packets in the same address space across multiple threads.

Clustering is also available with the PF\_RING-aware libpcap via the PCAP\_PF\_RING\_CLUSTER\_ID environment variable (Round-Robin by default, per-flow via the PCAP\_PF\_RING\_USE\_CLUSTER\_PER\_FLOW environment variable).

Input parameters:

ring

The PF\_RING handle to be cluster.

clusterId

A numeric identifier of the cluster to which the ring will be bound.

the\_type

The cluster type (2-tuple, 4-tuple, 5-tuple, tcp only 5-tuple, 6-tuple flow or Round-Robin).

Return value:

Zero if success, a negative value otherwise.

```
int pfring_remove_from_cluster(pfring *ring);
```

This call allows a ring to be removed from a previous joined cluster.

Input parameters:

ring  
The PF\_RING handle to be cluster.

clusterId  
A numeric identifier of the cluster to which the ring will be bound.

Return value:

Zero if success, a negative value otherwise.

## 8.8. PF\_RING: Packet Reflection

Packet reflection is the ability to bridge packets in kernel without sending them to userspace and back. You can specify packet reflection inside the filtering rules.

```
typedef struct {  
    ...  
    char reflector_device_name[REFLECTOR_NAME_LEN];  
    ...  
} filtering_rule;
```

In the `reflector_device_name` you need to specify a device name (e.g. `eth0`) on which packets matching the filter will be reflected. Make sure NOT to specify as reflection device the same device name on which you capture packets, as otherwise you will create a packet loop.

## 8.9. PF\_RING: Packet Sampling

```
int pfring_set_sampling_rate(pfring *ring, u_int32_t rate)
```

Implement packet sampling directly into the kernel. Note that this solution is much more efficient than implementing it in user-space. Sampled packets are only those that pass all filters (if any)

Input parameters:

ring

The PF\_RING handle on which sampling is applied.

rate

The sampling rate. Rate of X means that 1 packet out of X is forwarded. This means that a sampling rate of 1 disables sampling

Return value:

Zero if success, a negative value otherwise.

## 8.10. PF\_RING: Packet Filtering

PF\_RING allows filtering packets in two ways: precise (a.k.a. hash filtering) or wildcard filtering. Precise filtering is used when it is necessary to track a precise 6-tuple connection <vlan Id, protocol, source IP, source port, destination IP, destination port>. Wildcard filtering is used instead whenever a filter can have wildcards on some of its fields (e.g. match all UDP packets regardless of their destination). If some field is set to zero it will not participate in filter calculation.

### 8.10.1. PF\_RING: Wildcard Filtering

```
int pfring_add_filtering_rule(pfring *ring, filtering_rule* rule_to_add)
```

Add a filtering rule to an existing ring. Each rule will have a unique rule Id across the ring (i.e. two rings can have rules with the same id).

Input parameters:

ring

The PF\_RING handle on which the rule will be added.

rule\_to\_add

The rule to add as defined in the last chapter of this document.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_remove_filtering_rule(pfring *ring, u_int16_t rule_id)
```

Remove a previously added filtering rule.

Input parameters:

ring  
The PF\_RING handle on which the rule will be removed.

rule\_id  
The id of a previously added rule that will be removed.

Return value:

Zero if success, a negative value otherwise (e.g. the rule does not exist).



```
int pfring_get_filtering_rule_stats(pfring *ring, u_int16_t rule_id,  
                                   char* stats, u_int *stats_len)
```

Read statistics of a hash filtering rule.

Input parameters:

ring

The PF\_RING handle from which stats will be read.

rule\_id

The rule id that identifies the rule for which stats are read.

stats

A buffer allocated by the user that will contain the rule statistics. Please make sure that the buffer is large enough to contain the statistics. Such buffer will contain number of received and dropped packets.

stats\_len

The size (in bytes) of the stats buffer.

Return value:

Zero if success, a negative value otherwise (e.g. the rule does not exist).

```
int pfring_purge_idle_rules(pfring *ring, u_int16_t inactivity_sec);
```

Remove filtering rules inactive for the specified number of seconds.

Input parameters:

ring  
The PF\_RING handle on which the rules will be removed.

inactivity\_sec  
The inactivity threshold.

Return value:

Zero if success, a negative value otherwise.

### 8.10.2.PF\_RING: Hash Filtering

```
int pfring_handle_hash_filtering_rule(pfring *ring, hash_filtering_rule* rule_to_add,  
                                     u_char add_rule)
```

Add or remove a hash filtering rule.

Input parameters:

ring

The PF\_RING handle from which stats will be read.

rule\_to\_add

The rule that will be added/removed as defined in the last chapter of this document. All rule parameters should be defined in the filtering rule (no wildcards).

add\_rule

If set to a positive value the rule is added, if zero the rule is removed.

Return value:

Zero if success, a negative value otherwise (e.g. the rule to be removed does not exist).

All rule parameters should be defined in the filtering rule (no wildcards).

```
int pfring_get_hash_filtering_rule_stats(pfring *ring,  
                                         hash_filtering_rule* rule,  
                                         char* stats, u_int *stats_len)
```

Read statistics of a hash filtering rule.

Input parameters:

ring

The PF\_RING handle on which the rule will be added/removed.

rule

The rule for which stats are read. This needs to be the same rule that has been previously added.

stats

A buffer allocated by the user that will contain the rule statistics. Please make sure that the buffer is large enough to contain the statistics. Such buffer will contain number of received and dropped packets.

stats\_len

The size (in bytes) of the stats buffer.

Return value:

Zero if success, a negative value otherwise (e.g. the rule to be removed does not exist).

```
int pfring_purge_idle_hash_rules(pfring *ring, u_int16_t inactivity_sec);
```

Remove hash filtering rules inactive for the specified number of seconds.

Input parameters:

ring  
The PF\_RING handle on which the rules will be removed.

inactivity\_sec  
The inactivity threshold.

Return value:

Zero if success, a negative value otherwise.

### 8.10.3.PF\_RING: BPF Filtering

As of version 5.1, it is possible to set BPF filters through the PF\_RING API. In order to do this, it's necessary to enable (this is the default) BPF support at compile time and link PF\_RING-enabled applications against the -lpcap library (it is possible to disable the BPF support with "cd userland/lib/; ./configure --disable-bpf; make" to avoid linking libpcap).

```
int pfring_set_bpf_filter(pfring *ring, char* filter_buffer)
```

Set a BPF filter to an existing ring.

Input parameters:

ring  
The PF\_RING handle on which the filter will be set.

filter\_buffer  
The filter to set.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_remove_bpf_filter(pfring *ring)
```

Remove the BPF filter.

Input parameters:

ring  
The PF\_RING handle.

Return value:

Zero if success, a negative value otherwise.

## 8.11. PF\_RING: In-NIC Packet Filtering

Some multi-queue modern network adapters feature "packet steering" capabilities. Using them it is possible to instruct the hardware NIC to assign selected packets to a specific RX queue. If the specified queue has an id that exceeds the maximum queueid, such packet is discarded thus acting as a hardware firewall filter.

NOTE: Kernel packet filtering is not supported by DNA.

```
int pfiring_add_hw_rule(pfiring *ring, hw_filtering_rule *rule)
```

Sets a specified filtering rule into the NIC. Note that no PF\_RING filter is added, but only a NIC filter.

Input parameters:

ring

The PF\_RING handle on which the rule will be added.

rule

The filtering rule to be set in the NIC as defined in the last chapter of this document. All rule parameters should be defined, and if set to zero they do not participate to filtering.

Return value:

Zero if success, a negative value otherwise (e.g. the rule to be added has wrong format or if the NIC to which this ring is bound does not support hardware filters).



```
int pfring_remove_hw_rule(pfring *ring, hw_filtering_rule *rule)
```

Remove the specified filtering rule from the NIC.

Input parameters:

ring  
The PF\_RING handle on which the rule will be removed.

rule  
The filtering rule to be removed from the NIC.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_filtering_mode(pfring *ring, filtering_mode mode)
```

Sets the filtering mode (software only, hardware only, both software and hardware) in order to implicitly add/remove hardware rules by means of the same API functionality used for software (wildcard and hash) rules.

Input parameters:

ring  
The PF\_RING handle on which the rule will be removed.

mode  
The filtering mode.

Return value:

Zero if success, a negative value otherwise.

## 8.12. PF\_RING: Filtering Policy

```
int pfring_toggle_filtering_policy(pfring *ring, u_int8_t rules_default_accept_policy)
```

Set the default filtering policy. This means that if no rule is matching the incoming packet the default policy will decide if the packet is forwarded to user space or dropped. Note that filtering rules are limited to a ring, so each ring can have a different set of rules and default policy.

Input parameters:

ring

The PF\_RING handle on which the rule will be added/removed.

rules\_default\_accept\_policy

If set to a positive value the default policy is accept (i.e. forward packets to user space), drop otherwise.

Return value:

Zero if success, a negative value otherwise.

### 8.13. PF\_RING: Packet Transmission

Depending on the driver being used, packet transmission happens differently:

- Vanilla and PF\_RING aware drivers: PF\_RING does not accelerate the TX so the standard Linux transmission facilities are used. Do not expect speed advantage when using PF\_RING on this mode.
- TNAPI: packet transmission is not supported.
- DNA: line rate transmission is supported.

```
int pfiring_send(pfiring *ring, u_char *pkt, u_int pkt_len, u_int8_t flush_packet)
```

Although PF\_RING has been optimized for RX, it is also possible to send packets (TX). This function allows to send a raw packet (i.e. it is sent on wire as specified). This packet must be fully specified (the MAC address up) and it will be transmitted as-is without any further manipulation.

Input parameters:

ring

The PF\_RING handle on which the packet has to be sent.

pkt

The buffer containing the packet to send.

pkt\_len

The length of the pkt buffer.

flush\_packet

1 = Flush possible transmission queues. If set to 0, you will decrease your CPU usage but at the cost of sending packets in trains and thus at larger latency.

Return value:

The number of bytes sent if success, a negative value otherwise.

```
int pfring_send_ifindex(pfring *ring, u_char *pkt, u_int pkt_len, u_int8_t flush_packet,  
int if_index)
```

Same of `pfring_send()`, with the possibility to specify the outgoing interface index.

Input parameters not present in `pfring_send()`:

- `if_index`

- The interface index assigned to the outgoing device.

```
int pfring_send_get_time(pfring *ring, u_char *pkt, u_int pkt_len, struct timespec *ts)
```

This function allows to send a raw packet returning the exact time (ns) it has been sent on the wire. Note that this is available when the adapter supports tx hardware timestamping only and might affect performance.

Input parameters not present in `pfring_send()`:

`ts`

The struct where the tx timestamp will be stored.

```
int pfring_send_last_rx_packet(pfring *ring, int tx_interface_id)
```

Send the last received packet to the specified device. This is an optimization working with standard PF\_RING only.

Input parameters:

ring

The PF\_RING handle on which the packet has been received.

tx\_interface\_id

The outgoing interface index.

Return value:

Zero if success, a negative value otherwise.

## 8.14. PF\_RING: Miscellaneous Functions

```
int pfring_enable_ring(pfring *ring)
```

When a ring is created, it is not enabled (i.e. incoming packets are dropped) until the above function is called.

Input parameters:

- ring  
The PF\_RING handle to enable.

Return value:

- Zero if success, a negative value otherwise (e.g. the ring cannot be enabled).



```
int pfring_disable_ring(pfring *ring)
```

Disable a ring.

Input parameters:

ring  
The PF\_RING handle to disable.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_stats(pfring *ring, pfring_stat *stats)
```

Read ring statistics (packets received and dropped).

Input parameters:

ring  
The PF\_RING handle.

stats  
A user-allocated buffer on which stats (number of received and dropped packets) will be stored.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_application_stats(pfring *ring, char *stats)
```

Set custom application statistics.

Input parameters:

ring  
The PF\_RING handle.

stats  
The application stats.

Return value:

Zero if success, a negative value otherwise.

```
char* pfring_get_appl_stats_file_name(pfring *ring, char *path, u_int path_len)
```

Return the filename where the application statistics can be read.

Input parameters:

ring  
The PF\_RING handle.

path  
A user-allocated buffer on which the stats filename will be stored.

path\_len  
The path len.

Return value:

The path if success, NULL otherwise.

```
int pfring_version(pfring *ring, u_int32_t *version)
```

Read the ring version. Note that if the ring version is 3.7 the returned ring version is 0x030700.

Input parameters:

ring  
The PF\_RING handle to enable.

version  
A user-allocated buffer on which ring version will be copied.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_direction(pfring *ring, packet_direction direction)
```

Tell PF\_RING to consider only those packets matching the specified direction. If the application does not call this function, all the packets (regardless of the direction, either RX or TX) are returned.

Input parameters:

ring

The PF\_RING handle to enable.

direction

The packet direction (RX, TX or both RX and TX).

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_socket_mode(pfring *ring, socket_mode mode)
```

Tell PF\_RING if the application needs to send and/or receive packets to/from the socket.

Input parameters:

ring  
The PF\_RING handle to enable.

mode  
The socket mode (send, receive or both send and receive).

Return value:

Zero if success, a negative value otherwise.

```
int pfring_poll(pfring *ring, u_int wait_duration)
```

Performs passive wait on a PF\_RING socket, similar to the standard poll(), taking care of data structures synchronization.

Input parameters:

ring  
The PF\_RING socket to poll.

wait\_duration  
The poll timeout in msec.

Return value:

Zero if success, a negative value otherwise.



```
int pfring_set_poll_watermark(pfring *ring, u_int16_t watermark)
```

Whenever a user-space application has to wait until incoming packets arrive, it can instruct PF\_RING not to return from poll() call unless at least "watermark" packets have been returned. A low watermark value such as 1, reduces the latency of poll() but likely increases the number of poll() calls. A high watermark (it cannot exceed 50% of the ring size, otherwise the PF\_RING kernel module will top its value) instead reduces the number of poll() calls but slightly increases the packet latency. The default value for the watermark (i.e. if user-space applications do not manipulate its value via this call) is 128.

Input parameters:

ring  
The PF\_RING handle to enable.

watermark  
The packet poll watermark.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_tx_watermark(pfring *ring, u_int16_t watermark)
```

Set the number of packets that have to be enqueued in the egress queue before being sent on the wire.

Input parameters:

ring  
The PF\_RING handle to enable.

watermark  
The tx watermark.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_poll_duration(pfring *ring, u_int duration)
```

Set the poll timeout when passive wait is used.

Input parameters:

ring  
The PF\_RING handle to enable.

duration  
The poll timeout in msec.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_application_name(pfring *ring, char *name)
```

Tell PF\_RING the name of the application (usually argv[0]) that uses this ring. This information is used to identify the application when accessing the files present in the PF\_RING /proc filesystem.

This is also available with the PF\_RING-aware libpcap via the PCAP\_PF\_RING\_APPNAME environment variable.

Example

```
> cat /proc/net/pf_ring/16614-eth0.0
Bound Device      : eth0
Slot Version      : 13 [4.7.1]
Active            : 1
Sampling Rate     : 1
Appl. Name        : pfcoun
IP Defragment     : No
....
```

Input parameters:

ring

The PF\_RING handle to enable.

name

The name of the application using this ring.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_get_bound_device_address(pfring *ring, u_char mac_address[6])
```

Returns the MAC address of the device bound to the socket.

Input parameters:

ring  
The PF\_RING handle to query.

mac\_address  
The memory area where the MAC address will be copied.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_get_bound_device_id(pfring *ring, int* device_id)
```

Returns the MAC address of the device bound to the socket.

Input parameters:

ring  
The PF\_RING handle to query.

mac\_address  
The memory area where the MAC address will be copied.

Return value:

Zero if success, a negative value otherwise.

`u_int8_t pfring_get_num_rx_channels(pfring *ring)`

Returns the number of RX channels (also known as RX queues) of the ethernet interface to which this ring is bound.

Input parameters:

ring  
The PF\_RING handle to query.

Return value:

The number of RX channels, or 1 (default) in case this information is unknown.

`int pfring_get_selectable_fd(pfring *ring)`

Returns the file descriptor associated to the specified ring. This number can be used in function calls such as `poll()` and `select()` for passively waiting for incoming packets.

Input parameters:

ring  
The PF\_RING handle to query.

Return value:

A number that can be used as reference to this ring, in function calls that require a selectable file descriptor.



`int pfring_enable_rss_rehash(pfring *ring)`

Tells PF\_RING to rehash incoming packets using a bi-directional hash function.

This is also available with the PF\_RING-aware libpcap via the PCAP\_PF\_RING\_RSS\_REHASH environment variable.

Input parameters:

ring  
The PF\_RING handle to query.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_get_device_clock(pfring *ring, struct timespec *ts)
```

Reads the time from the device hardware clock, when the adapter supports hardware timestamping.

Input parameters:

ring  
The PF\_RING handle.

ts  
The struct where time will be stored.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_set_device_clock(pfring *ring, struct timespec *ts)
```

Sets the time in the device hardware clock, when the adapter supports hardware timestamping.

Input parameters:

ring  
The PF\_RING handle.

ts  
The time to be set.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_adjust_device_clock(pfring *ring, struct timespec *offset, int8_t sign)
```

Adjust the time in the device hardware clock with an offset, when the adapter supports hardware timestamping.

Input parameters:

ring  
The PF\_RING handle.

offset  
The time offset.

sign  
The offset sign.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_enable_hw_timestamp(pfring *ring, char *device_name, u_int8_t enable_rx,  
u_int8_t enable_tx)
```

Enables rx and tx hardware timestamping, when the adapter supports it.

Input parameters:

ring  
The PF\_RING handle.

device\_name  
The name of the device where timestamping will be enabled.

enable\_rx  
Flag to enable rx timestamping.

enable\_tx  
Flag to enable tx timestamping.

Return value:

Zero if success, a negative value otherwise.

```
int pfring_parse_pkt(u_char *pkt, struct pfring_pkthdr *hdr, u_int8_t level,  
                    u_int8_t add_timestamp, u_int8_t add_hash)
```

Parse a packet.

It expects that the hdr memory is either zeroed or contains valid values for the current packet, in order to avoid parsing twice the same packet headers. This is implemented by controlling the l3\_offset and l4\_offset fields, indicating that respectively the L2 and L3 layers have been parsed when other than zero.

Input parameters:

pkt

The packet buffer.

hdr

The header to be filled.

level

The header level where to stop parsing.

add\_timestamp

Add the timestamp.

add\_hash

Compute an IP-based bidirectional hash.

Return value:

A non-negative number indicating the topmost header level on success, a negative value otherwise.

## 8.15. The C++ PF\_RING interface

The C++ interface (see. PF\_RING/userland/c++/) is equivalent to the C interface. No major changes have been made and all the methods have the same name as C. For instance:

- C: `int pfring_stats(pfring *ring, pfring_stat *stats);`
- C++: `inline int get_stats(pfring_stat *stats);`

## 9. libzero for DNA

This library implements a zero-copy Inter Process Communication, so that it can be used both in multi-thread and multi-process applications. As reported in the introduction it provides two main components: the DNA Cluster and the DNA Bouncer.

### 9.1. The DNA Cluster

The DNA Cluster implements packet clustering, so that all applications belonging to the same cluster can share incoming packets in zero-copy using a user-defined balancing function. Applications can also transmit packets in zero-copy. Each application reads/sends packets from/to a "slave" socket.

A master thread/application is responsible of dispatching incoming packets to the slaves by using an user-defined balancing function (the default one is a bidirectional IP-based hashing function). It can also act as a fan-out, delivering the same packet to multiple slave threads/applications, without the slowest consumer to affect the performance of faster ones.

The cluster allows application to process packets "with holes" (i.e. do not process packets in sequence), moving to the next incoming packet even though the previous one has not been processed yet.

#### 9.1.1. The Master API

```
pfring_dna_cluster* dna_cluster_create(u_int32_t cluster_id, u_int32_t num_apps,
u_int32_t flags)
```

Create a new DNA Cluster handle. The cluster just created has no ring associated.

Input parameters:

cluster\_id

The cluster identifier.

num\_apps

The number of slave applications/threads.

flags

A mask for enabling additional extensions:

- DNA\_CLUSTER\_DIRECT\_FORWARDING: enable the "direct forwarding" for transmitting incoming packets to an outgoing interface according to the return values of the distribution function.
- DNA\_CLUSTER\_NO\_ADDITIONAL\_BUFFERS: disable allocation of "pfring\_pkt\_buff" (see "The Slave API" Section), reducing memory usage.
- DNA\_CLUSTER\_HUGEPAGES: enable memory allocation via hugepages.

Return value:

The cluster handle.



```
int dna_cluster_low_level_settings(pfring_dna_cluster *handle, u_int32_t
slave_rx_queue_len, u_int32_t slave_tx_queue_len, u_int32_t
slave_additional_buffers);
```

Changes the default values for the number of rx/tx queue slots and additional buffers (experts only).

Input parameters:

handle  
The DNA Cluster handle.

slave\_rx\_queue\_len  
The number of slots in the slave rx queue.

slave\_tx\_queue\_len  
The number of slots in the slave tx queue.

slave\_additional\_buffers  
The maximum number of extra buffers a slave can allocate (see "The Slave API" Section).

Return value:

Zero if success, a negative value otherwise.

```
int dna_cluster_register_ring(pfring_dna_cluster *handle, pfring *ring)
```

Add a PF\_RING socket to the DNA Cluster.

Input parameters:

handle  
The DNA Cluster handle.

ring  
The PF\_RING handle.

Return value:

Zero if success, a negative value otherwise.

```
void dna_cluster_set_cpu_affinity(pfring_dna_cluster *handle, u_int32_t rx_core_id,  
u_int32_t tx_core_id)
```

Bind the RX and TX master threads to the given core ids. In clusters, threads are used to poll (RX) and send (TX) cluster packets. This function is used to specify thread affinity across cores.

Input parameters:

handle  
The DNA Cluster handle.

rx\_core\_id  
The core id for the RX thread.

tx\_core\_id  
The core id for the TX thread.

```
int dna_cluster_set_mode(pf_ring_dna_cluster *handle, socket_mode mode)
```

Set the cluster mode: receive (TX only), send (RX and TX), or both receive and send (RX and TX).

Input parameters:

handle  
The DNA Cluster handle.

mode  
The cluster mode.

Return value:

Zero if success, a negative value otherwise.

```
void dna_cluster_set_distribution_function(pfring_dna_cluster *handle,  
pfring_dna_cluster_distribution_func func)
```

Set the packet distribution function (the default function is a bidirectional IP-based hash function). This call allows developers to specify their own custom function.

Input parameters:

handle  
The DNA Cluster handle.

func  
The distribution function.

```
void dna_cluster_set_wait_mode(pfring_dna_cluster *handle, u_int32_t active_wait)
```

Set the ingress packet wait mode: passive (poll) or active wait.

Input parameters:

handle  
The DNA Cluster handle.

active\_wait  
A boolean value: 0 for passive mode, 1 for active mode.

Return value:

Zero if success, a negative value otherwise.

```
int dna_cluster_enable(pfring_dna_cluster *handle)
```

Enable the cluster.

Input parameters:

handle  
The DNA Cluster handle.

Return value:

Zero if success, a negative value otherwise.

```
int dna_cluster_disable(pfring_dna_cluster *handle)
```

Disable the cluster.

Input parameters:

handle  
The DNA Cluster handle.

Return value:

Zero if success, a negative value otherwise.



```
int dna_cluster_stats(pf_ring_dna_cluster *handle, u_int64_t *tot_rx_packets, u_int64_t
*tot_tx_packets, u_int64_t *tot_rx_processed)
```

Return cluster statistics.

Input parameters:

handle

The DNA Cluster handle.

tot\_rx\_packets

Total amount of received packets.

tot\_tx\_packets

Total amount of sent packets.

tot\_rx\_processed

Total amount of packets processed by the slaves.

Return value:

Zero if success, a negative value otherwise.

```
void dna_cluster_destroy(pfring_dna_cluster *handle)
```

Destroy the cluster, and close the bound PF\_RING sockets.

Input parameters:

handle  
The DNA Cluster handle.

Return value:

Zero if success, a negative value otherwise.

### 9.1.1.The Slave API

A DNA Cluster slave thread/application uses a superset of the PF\_RING API, granting backward compatibility with all existing applications. Later on this document you can find the differences between the two sets.

```
pfring_pkt_buff* pfring_alloc_pkt_buff(pfring *ring)
```

Return a packet buffer handle. The memory is allocated by PF\_RING into the kernel and it is managed by PF\_RING (i.e. no free!) on this memory) using the pfring\_XXX\_XXX calls.

Input parameters:

ring  
The PF\_RING handle.

Return value:

The buffer handle just returned.

```
void pfring_release_pkt_buff(pfring *ring, pfring_pkt_buff *pkt_handle)
```

Free a packet buffer handle previously allocated by `pfring_alloc_pkt_buff`.

Input parameters:

ring  
The PF\_RING handle.

pkt\_handle  
The buffer handle.

```
int pfring_rcv_pkt_buff(pfring *ring, pfring_pkt_buff *pkt_handle, struct pfring_pkthdr
*hdr, u_int8_t wait_for_incoming_packet)
```

Receive a packet filling the buffer pointed by pkt\_handle instead of returning a new buffer. In a nutshell, the returned packet is put on the passed function argument.

Input parameters:

ring  
The PF\_RING handle.

pkt\_handle  
The buffer handle where the incoming packets will be placed.

hdr  
The PF\_RING header.

wait\_for\_incoming\_packet  
If 0 we simply check the packet availability, otherwise the call is blocked until a packet is available.

Return value:

0 in case of no packet being received (non-blocking), 1 in case of success, -1 in case of error.

```
int pfring_send_pkt_buff(pfring *ring, pfring_pkt_buff *pkt_handle, u_int8_t  
flush_packet)
```

Send the packet pointed by the pkt\_handle buffer handle. Note: this function resets the content of the buffer handle so if you need to keep its content, make sure you copy the data before you call it.

Input parameters:

ring  
The PF\_RING handle.

pkt\_handle  
The buffer handle.

flush\_packet  
Flush possible transmission queues.

Return value:

The number of bytes sent if success, a negative value otherwise.

```
u_char* pfring_get_pkt_buff_data(pfring *ring, pfring_pkt_buff *pkt_handle)
```

Return a pointer to the buffer pointed by the packet buffer handle.

Input parameters:

ring  
The PF\_RING handle.

pkt\_handle  
The buffer handle.

Return value:

The pointer to the packet buffer.

```
void pfring_set_pkt_buff_len(pfring *ring, pfring_pkt_buff *pkt_handle, u_int32_t len)
```

Sets the length of the packet. This function call is not necessary unless you want to custom set the packet length, instead of using the size from the received packet.

Input parameters:

ring  
The PF\_RING handle.

pkt\_handle  
The buffer handle.

len  
The packet len.



```
void pfring_set_pkt_buff_ifindex(pfring *ring, pfring_pkt_buff *pkt_handle, int if_index)
```

Binds the buffer handle (handling a packet) to an interface id. This function call is useful to specify the egress interface index.

Input parameters:

ring  
The PF\_RING handle.

pkt\_handle  
The buffer handle.

if\_index  
The interface id.

```
void pfring_add_pkt_buff_ifindex(pfring *ring, pfring_pkt_buff *pkt_handle, int if_index)
```

Adds an interface id to the bound interface ids of the buffer handle. This is used to specify the egress interfaces (fan-out) of a packet buffer.

Input parameters:

ring  
The PF\_RING handle.

pkt\_handle  
The buffer handle.

if\_index  
The interface id.

```
void pfring_register_zerocopy_tx_ring(pfring *ring, pfring *tx_ring)
```

Attach a DNA socket to a DNA Cluster, allowing an application receiving packets from a cluster to send them in zero-copy to a DNA interface/queue.

Input parameters:

ring  
The PF\_RING handle (DNA Cluster slave/consumer).

tx\_ring  
The (tx) DNA socket that have to be attached to the cluster.

## 9.2.DNA Bouncer

The DNA Bouncer switches packets across two interfaces in zero-copy, leaving the user the ability to specify a function that can decide, packet-by-packet, whether a given packet has to be forwarded or not. The bouncer is able to work in mode-directional mode, meaning that packets are copied only on one direction (ingress to egress rings, if you need a bi-directional copy you need to create two bouncer threads/applications), or bi-directional mode.

### 9.2.1.The DNA Bouncer API

```
pfring_dna_bouncer *pfring_dna_bouncer_create(pfring *ingress_ring, pfring *egress_ring)
```

Create a new DNA Bouncer handle.

Input parameters:

    ingress\_ring

    The socket where packets will be read.

    egress\_ring

    The socket where packets will be sent.

Return value:

    The DNA Bouncer handle.

```
int pfring_dna_bouncer_set_mode(pfring_dna_bouncer *handle, dna_bouncer_mode  
mode)
```

Set the DNA Bouncer mode to one-way (default) or two-way.

Input parameters:

    handle  
    The DNA Bouncer handle.

    mode  
    The mode: `one_way_mode` or `two_way_mode`.

Return value:

    Zero if success, a negative value otherwise.

```
int    pfring_dna_bouncer_loop(pfring_dna_bouncer *handle,  
pfring_dna_bouncer_decision_func func, const u_char *user_bytes, u_int8_t  
wait_for_packet)
```

Enable the DNA Bouncer.

Input parameters:

handle

The DNA Bouncer handle.

func

The packet processing function.

user\_bytes

A pointer to user data.

wait\_for\_packet

If 0 active wait is used to check the packet availability.

Return value:

Zero if success, a negative value otherwise.

```
void pfring_dna_bouncer_breakloop(pfring_dna_bouncer *handle)
```

Stop the bouncer.

Input parameters:

handle

The DNA Bouncer handle.

```
void pfring_dna_bouncer_destroy(pfring_dna_bouncer *handle)
```

Destroy the bouncer and close the bound PF\_RING sockets.

Input parameters:

handle

The DNA Bouncer handle.



## 9.3.Code Snippets for Common Use Cases

### 9.3.1.DNA Cluster: receive a packet and put it aside

```
pfring_pkt_buff *pkt_handle = pfring_alloc_pkt_buff(ring);

if (pkt_handle != NULL) {

    rc = pfring_recv_pkt_buff(ring, pkt_handle, &hdr, wait_for_packet);

    if (rc > 0) {
        /* put the packet aside and do something later on */
        enqueue_packet(pkt_handle);
    }
}

pkt_handle = dequeue_packet();

/* do something with the packet and release it */
buffer = pfring_get_pkt_buff_data(ring, pkt_handle);
pfring_release_pkt_buff(ring, pkt_handle);
```

### 9.3.2.DNA Cluster: receive a packet and send it in zero-copy

```
pfring_pkt_buff *pkt_handle = pfring_alloc_pkt_buff(ring);

if (pkt_handle != NULL) {

    rc = pfring_rcv_pkt_buff(ring, pkt_handle, &hdr, wait_for_packet);

    if (rc > 0) {
        if (forward_packet_to_another_interface) {
            pfring_set_pkt_buff_ifindex(ring[thread_id], pkt_handle, if_index);
        } else {
            /* bounce packet on the rx interface (already set in pkt_handle) */
        }

        pfring_send_pkt_buff(ring[thread_id], pkt_handle, 0);
    }
}
```

### 9.3.3.DNA Cluster: replace the default balancing function with a custom function

```

int hash_distribution_function(const u_char *buffer,
                             const u_int16_t buffer_len,
                             const u_int32_t num_slaves,
                             u_int32_t *id_mask,
                             u_int32_t *hash) {

    u_int32_t slave_idx;

    /* computing a bidirectional software hash */
    *hash = custom_hash_function(buffer, buffer_len);

    /* balancing on hash */
    slave_idx = (*hash) % num_slaves;
    *id_mask = (1 << slave_idx);
    return DNA_CLUSTER_PASS;
}

dna_cluster_set_distribution_function(dna_cluster_handle,
                                     hash_distribution_function);

```

### 9.3.4.DNA Cluster: replace the default balancing function with a fan-out function

```
int fanout_distribution_function(const u_char *buffer,
                               const u_int16_t buffer_len,
                               const u_int32_t num_slaves,
                               u_int32_t *id_mask,
                               u_int32_t *hash) {
    u_int32_t n_zero_bits = 32 - num_slaves;

    /* returning slave id bitmap */
    *id_mask = ((0xFFFFFFFF << n_zero_bits) >> n_zero_bits);
    return DNA_CLUSTER_PASS;
}

dna_cluster_set_distribution_function(dna_cluster_handle,
                                     fanout_distribution_function);
```

### 9.3.5.DNA Cluster: send an incoming packet directly without passing through a slave

```

int hash_distribution_function(const u_char *buffer,
                             const u_int16_t buffer_len,
                             const u_int32_t num_slaves,
                             u_int32_t *id_mask,
                             u_int32_t *hash) {
    u_int32_t socket_idx = get_out_socket_index();

    *id_mask = (1 << socket_idx);
    return DNA_CLUSTER_FRWD;
}

pfring_dna_cluster *dna_cluster_handle;
dna_cluster_handle = dna_cluster_create(cluster_id,
                                       num_threads,
                                       DNA_CLUSTER_DIRECT_FORWARDING);
int dna_cluster_set_mode(dna_cluster_handle, send_and_recv_mode);
dna_cluster_set_distribution_function(dna_cluster_handle,
                                     hash_distribution_function);

```

## 10. Writing PF\_RING Plugins

Since version 3.7, developers can write plugins in order to delegate to PF\_RING activities like:

- Packet payload parsing
- Packet content filtering
- In-kernel traffic statistics computation.

In order to clarify the concept, imagine that you need to develop an application for VoIP traffic monitoring. In this case it's necessary to:

- parse signaling packets (e.g. SIP or IAX) so that those that only packets belonging to interesting peers are forwarded.
- compute voice statistics into PF\_RING and report to user space only the statistics, not the packets.

In this case a developer can code two plugins so that PF\_RING can be used as an advanced traffic filter and a way to speed-up packet processing by avoiding packets to cross the kernel boundaries when not needed.

The rest of the chapter explains how to implement a plugin and how to call it from user space.

### 10.1. Implementing a PF\_RING Plugin

Inside the directory `kernel/net/ring/plugins/` there is a simple plugin called `dummy_plugin` that shows how to implement a simple plugin. Let's explore the code.

Each plugin is implemented as a Linux kernel module. Each module must have two entry points, `module_init` and `module_exit`, that are called when the module is insert and removed. The `module_init` function, in the `dummy_plugin` example, implement by the function `dummy_plugin_init()`, is responsible for registering the plugin by calling the `register_plugin()` function. The parameter passed to the registration function is a data structure of type `'struct pfring_plugin_registration'` that contains:

- `plugin_id`  
A unique integer plugin Id.
- `pfring_plugin_filter_skb`  
A pointer to a function called whenever a packet needs to be filtered. This function is called after `pfring_plugin_handle_skb()`.
- `pfring_plugin_handle_skb`  
A pointer to a function called whenever an incoming packet is received.
- `pfring_plugin_get_stats`  
A pointer to a function called whenever a user wants to read statistics from a filtering rule that has set this plugin as action.
- `pfring_plugin_purge_idle`  
A pointer to a function called whenever a user wants to purge a filtering rule that has set this plugin as action.
- `pfring_plugin_free_rule_mem`  
A pointer to a function called when a filtering rule that has set this plugin as action is removed.
- `pfring_plugin_free_ring_mem`  
A pointer to a function called when the plugin is unregistered (`rmmod`) or a ring using the plugin is removed. Free here any global memory allocated by the plugin during its operations.
- `pfring_plugin_add_rule`  
A pointer to a function called when a user has set for this plugin a filtering rule with behavior `forward_packet_add_rule_and_stop_rule_evaluation`. In case of a packet match, this function is called.

- `pfring_plugin_add_rule`

A pointer to a function called when a user has set for this plugin a filtering rule with behavior `forward_packet_del_rule_and_stop_rule_evaluation`.

A developer can choose not to implement all the above functions, but in this case the plugin will be limited in functionality (e.g. if `pfring_plugin_filter_skb` is set to NULL filtering is not supported).

## 10.2. PF\_RING Plugin: Handle Incoming Packets

```
static int plugin_handle_skb( struct pf_ring_socket *pfr,
                           sw_filtering_rule_element *rule,
                           sw_filtering_hash_bucket *hash_rule,
                           struct pfring_pkthdr *hdr,
                           struct sk_buff *skb, int displ,
                           u_int16_t filter_plugin_id,
                           struct parse_buffer **parse_memory,
                           rule_action_behaviour *behaviour)
```

This function is called whenever an incoming packet (RX or TX) is received. This function typically updates rule statistics. Note that if the developer has set this plugin as filter plugin, then the packet has:

- already been parsed
- passed a rule payload filter (if set).

Input parameters:

rule

A pointer to a wildcard rule (if this plugin has been set on a wildcard rule) or NULL (if this plugin has been set to a hash rule).

hash\_rule

A pointer to a hash rule (if this plugin has been set on a hash rule) or NULL (if this plugin has been set to a wildcard rule). Note if rule is NULL, hash\_rule is not, and vice-versa.

hdr

A pointer to a pcap packet header for the received packet. Please note that:

- the packet is already parsed
- the header is an extended pcap header containing parsed packet header metadata.

skb

A sk\_buff datastructure used in Linux to carry packets inside the kernel.

filter\_plugin\_id

The id of the plugin that has parsed packet payload (not header that is already stored into hdr). if the filter\_plugin\_id is the same as the id of the dummy\_plugin then this packet has already been parsed by this plugin and the parameter filter\_rule\_memory\_storage points to the payload parsed memory.

parse\_memory

Pointer to a data structure containing parsed packet payload information that has been parsed by the plugin identified by the parameter filter\_plugin\_id. Note that:

- only one plugin can parse a packet.
- the parsed memory is allocated dynamically (i.e. via kmalloc) by plugin\_filter\_skb and freed by the PF\_RING core.

Return value:



Zero if success, a negative value otherwise.

### 10.3. PF\_RING Plugin: Filter Incoming Packets

```
int plugin_filter_skb( struct pf_ring_socket *pfr,
                     sw_filtering_rule_element *rule,
                     struct pfring_pkthdr *hdr,
                     struct sk_buff *skb, int displ,
                     struct parse_buffer ** parse_memory)
```

This function is called whenever a previously parsed packet (via `plugin_handle_skb`) incoming packet (RX or TX) needs to be filtered. In this case the packet is parsed, parsed information is returned and the return value indicates whether the packet has passed the filter.

Input parameters:

`rule`

A pointer to a wildcard rule that contains a payload filter to apply to the packet.

`hdr`

A pointer to a pcap packet header for the received packet. Please note that:

- the packet is already parsed
- the header is an extended pcap header containing parsed packet header metadata.

`skb`

A `sk_buff` data structure used in Linux to carry packets inside the kernel.

Output parameters:

`parse_memory`

A pointer to a memory area allocated by the function, that will contain information about the parsed packet payload.

Return value:

Zero if the packet has not matched the rule filter, a positive value otherwise.

## 10.4. PF\_RING Plugin: Read Packet Statistics

```
int plugin_plugin_get_stats( struct pf_ring_socket *pfr,  
                           filtering_rule_element *rule,  
                           filtering_hash_bucket *hash_rule,  
                           u_char* stats_buffer,  
                           u_int stats_buffer_len)
```

This function is called whenever a user space application wants to read statics about a filtering rule.

Input parameters:

rule

A pointer to a wildcard rule (if this plugin has been set on a wildcard rule) or NULL (if this plugin has been set to a hash rule).

hash\_rule

A pointer to a hash rule (if this plugin has been set on a hash rule) or NULL (if this plugin has been set to a wildcard rule). Note if rule is NULL, hash\_rule is not, and vice-versa.

stats\_buffer

A pointer to a buffer where statistics will be copied..

stats\_buffer\_len

Length in bytes of the stats\_buffer.

Return value:

The length of the rule stats, or zero in case of error.

## 10.5. Using a PF\_RING Plugin

A PF\_RING based application, can take advantage of plugins when filtering rules are set. The `filtering_rule` data structure is used to both set a rule and specify a plugin associated to it.

```
filtering_rule rule;

rule.rule_id = X;
....
rule.plugin_action.plugin_id = MY_PLUGIN_ID;
```

When the `plugin_action.plugin_id` is set, whenever a packet matches the header portion of the rule, then the `MY_PLUGIN_ID` plugin (if registered) is called and the `plugin_filter_skb()` and `plugin_handle_skb()` are called.

If the developer is willing to filter a packet before `plugin_handle_skb()` is called, then extra `filtering_rule` fields need to be set. For instance suppose to implement a SIP filter plugin and to instrument it so that only the packets with INVITE are returned. The following lines of code show how to do this.

```
struct sip_filter *filter = (struct sip_filter*)
    rule.extended_fields.filter_plugin_data;

rule.extended_fields.filter_plugin_id = SIP_PLUGIN_ID;
filter->method = method_invite;
filter->caller[0] = '\0'; /* Any caller */
filter->called[0] = '\0'; /* Any called */
filter->call_id[0] = '\0'; /* Any call-id */
```

As explained before, the `pfring_add_filtering_rule()` function is used to register filtering rules.

## 11. PF\_RING Data Structures

Below are described some relevant PF\_RING data structures.

```
typedef struct {
    u_int16_t rule_id; /* Rules are processed in order from
                        lowest to highest id */

    rule_action_behaviour rule_action; /* What to do in case of match */
    u_int8_t balance_id, balance_pool; /* If balance_pool > 0, then pass the
                                        packet above only if the
                                        (hash(proto, sip, sport, dip, dport) %
                                        balance_pool) = balance_id */

    u_int8_t locked; /* Do not purge */
    u_int8_t bidirectional; /* Swap peers (Default: mono) */
    filtering_rule_core_fields core_fields;
    filtering_rule_extended_fields extended_fields;
    filtering_rule_plugin_action plugin_action;
    char reflector_device_name[REFLECTOR_NAME_LEN];

    filtering_internals internals; /* PF_RING internal fields */
} filtering_rule;

typedef struct {
    u_int8_t smac[ETH_ALEN], dmac[ETH_ALEN]; /* Use '0' (zero-ed MAC address) for
                                                any MAC address. This is applied
                                                to both source and destination */

    u_int16_t vlan_id; /* Use '0' for any vlan */
    u_int8_t proto; /* Use 0 for 'any' protocol */
    ip_addr shost, dhost; /* User '0' for any host. This is applied
                           to both source and destination. */

    ip_addr shost_mask, dhost_mask; /* IPv4/6 network mask */
    u_int16_t sport_low, sport_high; /* All ports between port_low...port_high
                                      means 'any' port */
    u_int16_t dport_low, dport_high; /* All ports between port_low...port_high
                                      means 'any' port */
} filtering_rule_core_fields;

typedef struct {
    char payload_pattern[32]; /* If strlen(payload_pattern) > 0, the
                              packet payload must match the specified
                              pattern */

    u_int16_t filter_plugin_id; /* If > 0 identifies a plugin to which the
                                datastructure below will be passed for
                                matching */

    char filter_plugin_data[FILTER_PLUGIN_DATA_LEN];
    /* Opaque datastructure that is interpreted by the
       specified plugin and that specifies a filtering
       criteria to be checked for match. Usually this data
       is re-casted to a more meaningful datastructure
       */
} filtering_rule_extended_fields;
```

```

typedef enum {
    forward_packet_and_stop_rule_evaluation = 0,
    dont_forward_packet_and_stop_rule_evaluation,
    execute_action_and_continue_rule_evaluation,
    execute_action_and_stop_rule_evaluation,
    forward_packet_add_rule_and_stop_rule_evaluation, /* auto-filled hash rule or
                                                    via plugin_add_rule() */
    forward_packet_del_rule_and_stop_rule_evaluation, /* plugin_del_rule() only */
    reflect_packet_and_stop_rule_evaluation,
    reflect_packet_and_continue_rule_evaluation,
    bounce_packet_and_stop_rule_evaluation,
    bounce_packet_and_continue_rule_evaluation
} rule_action_behaviour;

typedef struct {
    u_int16_t rule_id;
    u_int16_t vlan_id;
    u_int8_t  proto;
    ip_addr host_peer_a, host_peer_b;
    u_int16_t port_peer_a, port_peer_b;
    rule_action_behaviour rule_action; /* What to do in case of match */
    filtering_rule_plugin_action plugin_action;
    char reflector_device_name[REFLECTOR_NAME_LEN];
    filtering_internals internals; /* PF_RING internal fields */
} hash_filtering_rule;

typedef struct {
    u_int64_t recv, drop;
} pfring_stat;

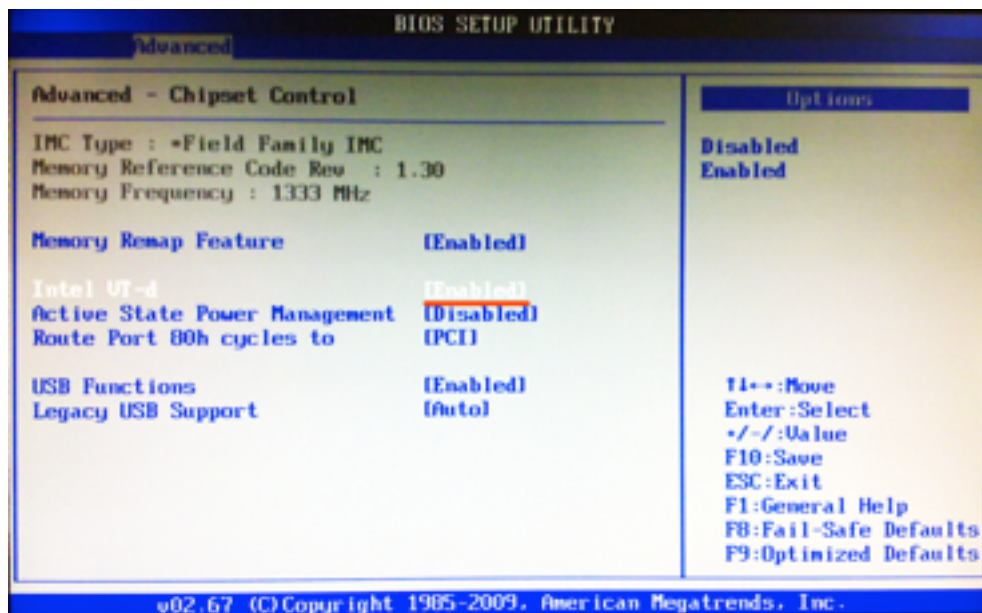
```

## 12. PF\_RING DNA On Virtual Machines

Section 5.4 contains a brief introduction to the PF\_RING DNA module, which allows you to manipulate packets at 10 Gbit wire speed for any packet size. Thanks to Virtualization Technologies based on IOMMUs (Intel VT-d or AMD IOMMU), it is now possible to assign a device to a given guest operating system, benefiting from the PF\_RING DNA module within a VM (Virtual Machine). The following sections show how to configure VMware and KVM (the Linux-native virtualization system). XEN users can use similar system configurations.

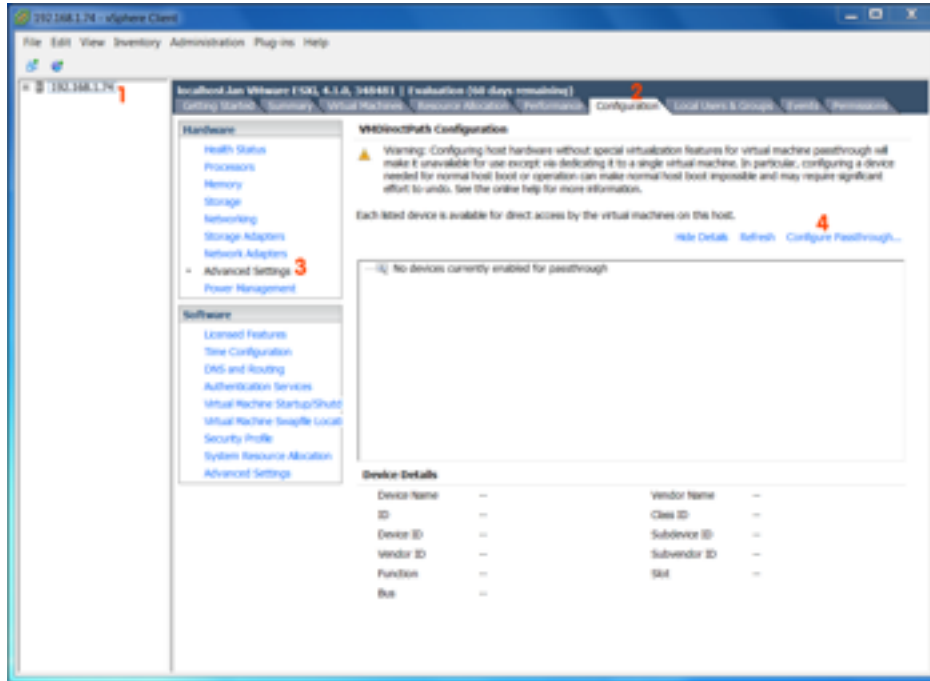
### 12.1. BIOS Configuration

First of all, make sure that your motherboard supports the PCI passthrough and check that it is enabled in your BIOS.

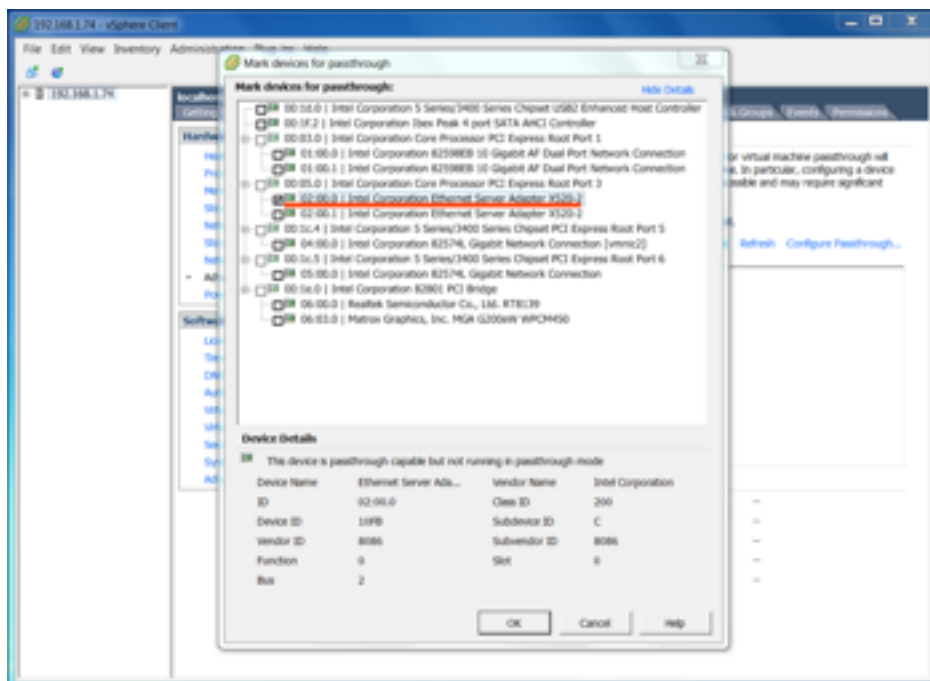


## 12.2.VMware ESX Configuration

In order to configure the PCI passthrough in VMware, open the vSphere Client and connect to the server. Select the server, go to "Configuration", "Advanced Settings", "Configure Passthrough".



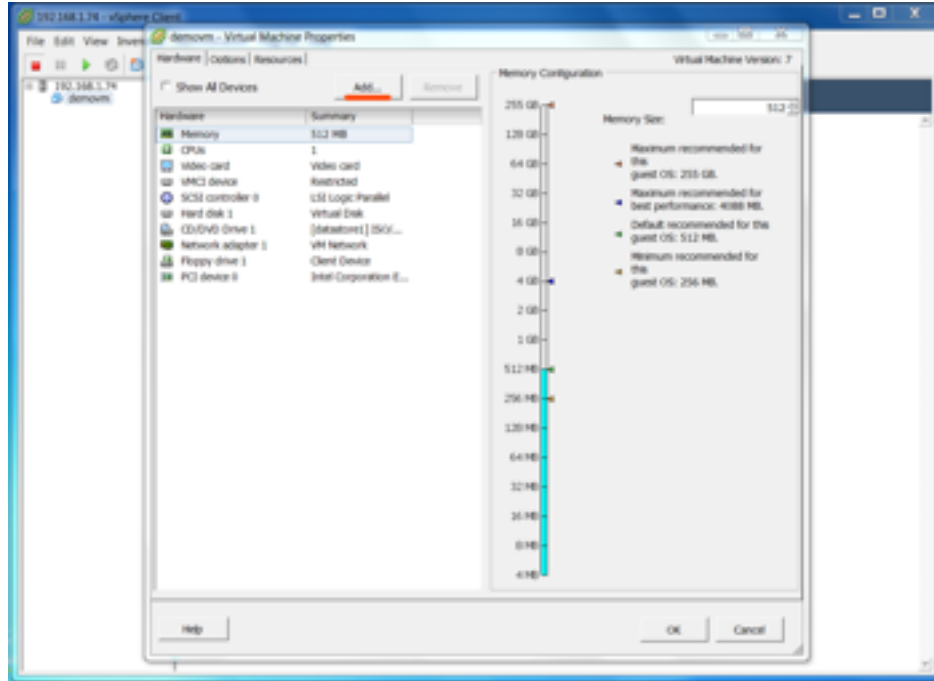
Select the devices you want to assign to the VMs.



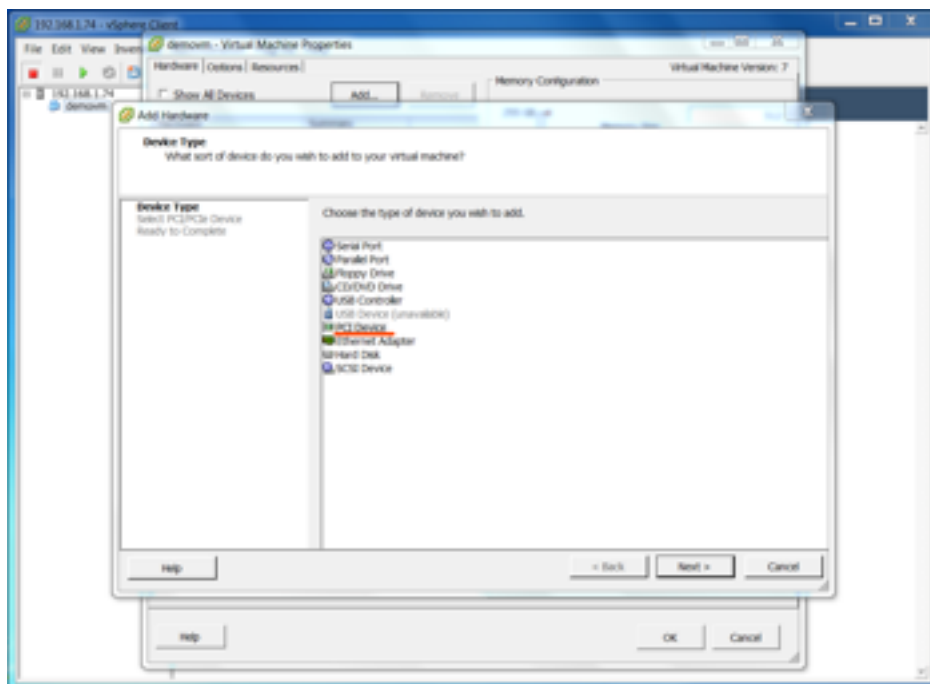


Reboot the server.

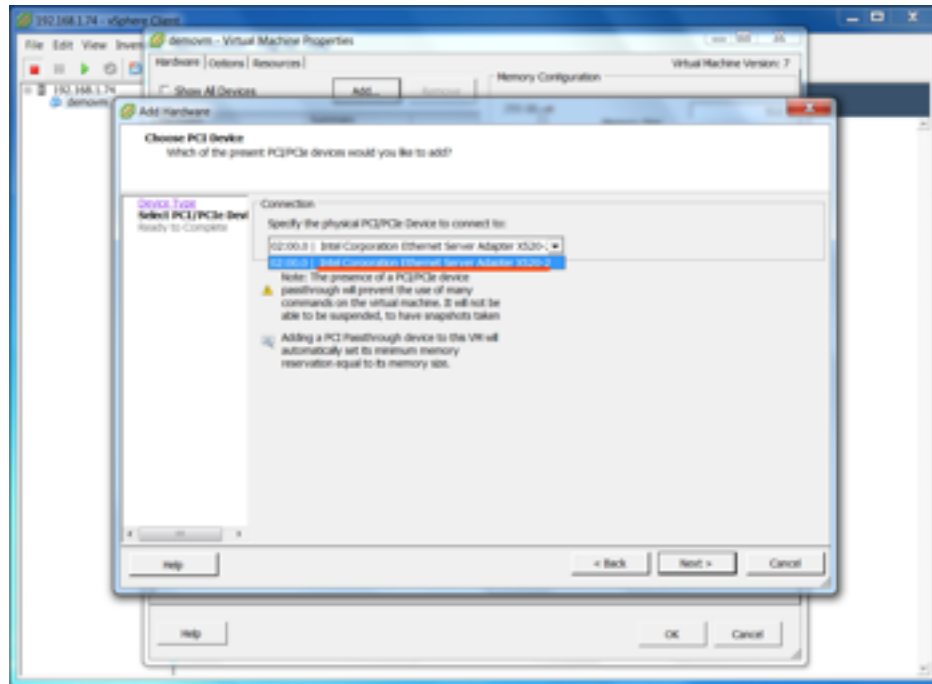
After the reboot, make sure that the VMs where the PCI device will be assigned is in the off state. Open the VM settings, and click on "Add..." in the "Hardware" tab.



Select "PCI Device".



Select the device to assign to the VM.



Boot the VM and install PF\_RING with the DNA driver as in the native case.

## 12.3. KVM Configuration

In order to configure the PCI passthrough with KVM, make sure you have enabled these options in your kernel:

Bus options (PCI etc.)

[\*] Support for DMA Remapping Devices

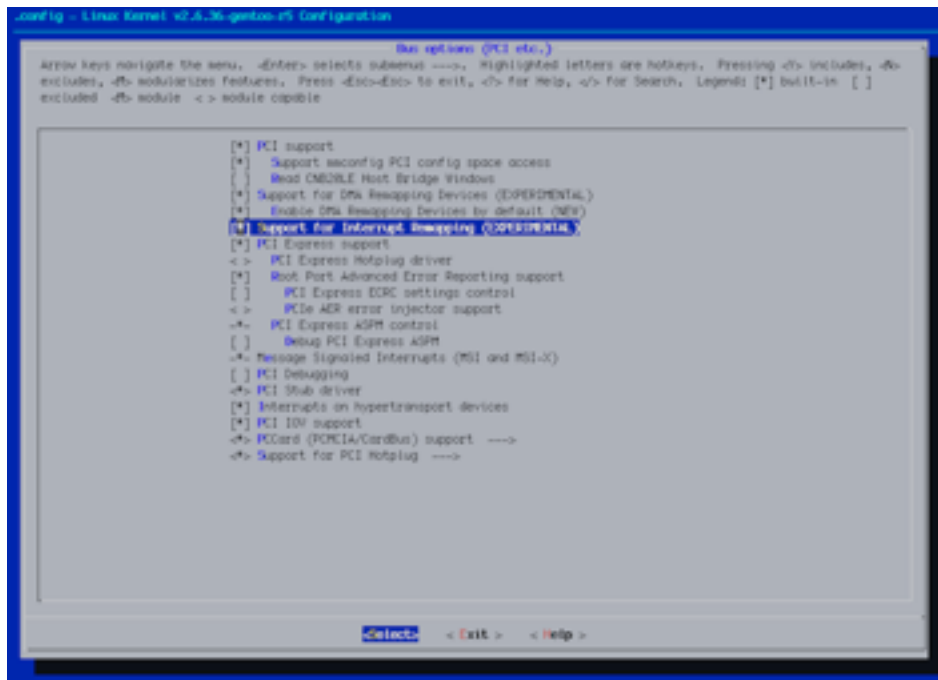
[\*] Enable DMA Remapping Devices

[\*] Support for Interrupt Remapping

<\*> PCI Stub driver

```
$ cd /usr/src/linux
```

```
$ make menuconfig
```



```
$ make
```

```
$ make modules_install
```

```
$ make install
```

(or use your distribution-specific way)

Pass "intel\_iommu=on" as kernel parameter. For instance, if you are using grub, edit your /boot/grub/menu.lst this way:

```
title Linux 2.6.36
root (hd0,0)
kernel /boot/kernel-2.6.36 root=/dev/sda3 intel_iommu=on
```

Unbind the device you want to assign to the VM from the host kernel driver.

```
$ lspci -n
..
02:00.0 0200: 8086:10fb (rev 01)
..
$ echo "8086 10fb" > /sys/bus/pci/drivers/pci-stub/new_id
$ echo 0000:02:00.0 > /sys/bus/pci/devices/0000:02:00.0/driver/unbind
$ echo 0000:02:00.0 > /sys/bus/pci/drivers/pci-stub/bind
```

Load KVM and start the VM.

```
$ modprobe kvm
$ modprobe kvm-intel
$ /usr/local/kvm/bin/qemu-system-x86_64 -m 512 -boot c \
    -drive file=virtual_machine.img,if=virtio,boot=on \
    -device pci-assign,host=02:00.0
```

Install and run PF\_RING with the DNA driver as in the native case.