PF_RING User Guide

Linux High Speed Packet Capture

Version 6.0.0
Apr 2014

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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 6.0.0 (Apr 2014)
  - New PF_RING ZC API

- Release 5.4.0 (May 2012)
  - New libzero for zero-copy flexible packet processing on top of DNA.

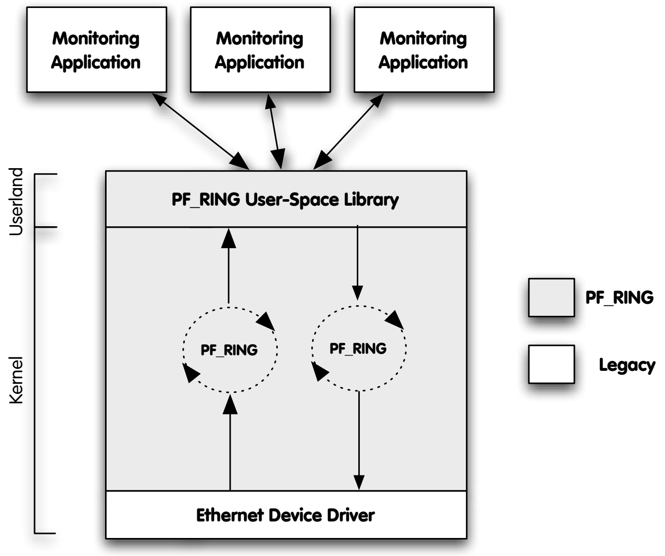
- Release 5.2.1 (January 2012)
  - New API functions for managing hardware clocks and timestamps.
  - New kernel plugin callbacks.

- Release 4.7.1 (July 2011)
  - Described PF_RING modular library and some modules (DAG, DNA)

- 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.

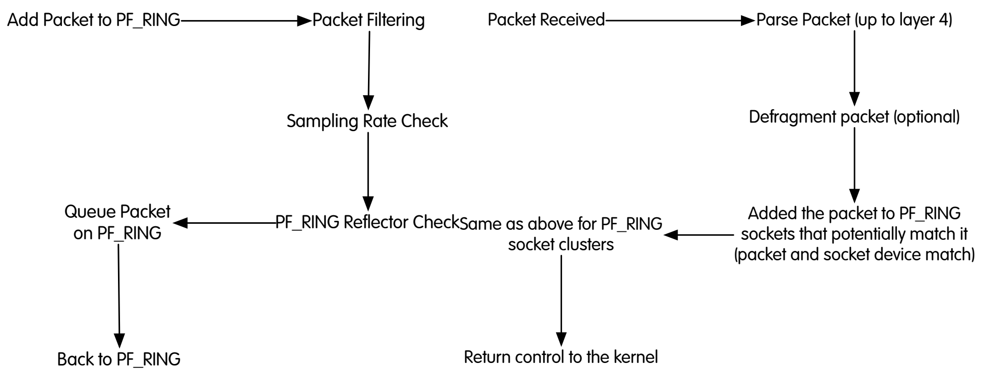
3.1.Packet Filtering

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 or 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.

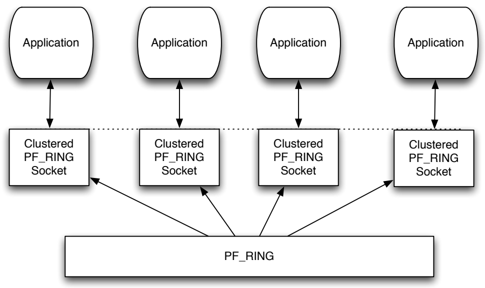
3.2.Packet Journey

The packet journey in PF_RING is quite long before being queued into a PF_RING ring.


Add Packet to PF_RING
Packet Filtering
Packet Received
Parse Packet (up to layer 4)
Sampling Rate Check
Defragment packet (optional)
Queue Packet on PF_RING
PF_RING Reflector Check
Same as above for PF_RING socket clusters
Added the packet to PF_RING sockets that potentially match it (packet and socket device match)
Back to PF_RING
Return control to the kernel

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.

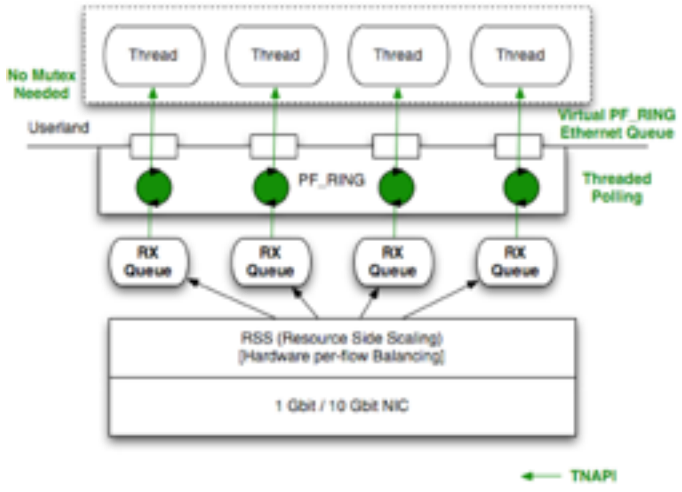
4.1.PF_RING-aware Drivers

These drivers (available in 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.

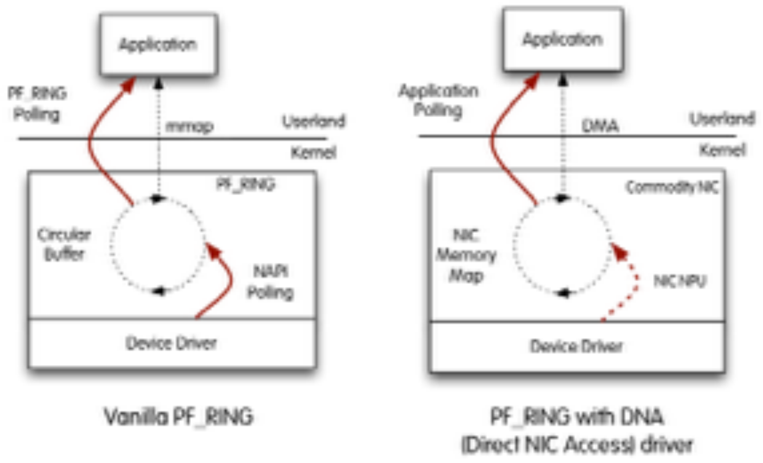
4.2.TNAPI

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.

4.4.PF_RING-aware with ZC support

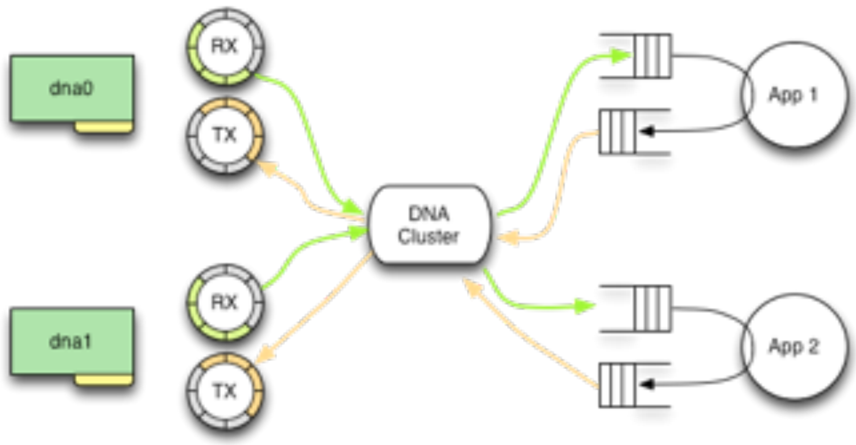
These drivers (available in PF_RING/driver/PF_RING-aware and identified by the '-zc' suffix) are standard PF_RING-aware drivers, with support for the new PF_RING ZC library. These drivers can be used as standard kernel drivers, with transparent_mode 1 or 2, or in zero-copy kernel-bypass mode (using the PF_RING ZC library) adding the prefix "zc:" to the interface name.

Once installed, the drivers operate as standard Linux drivers where you can do normal networking (e.g. ping or SSH). If you open a device in zero copy (e.g. pfcount -i zc:eth1) the device becomes unavailable to standard networking as it is accessed in zero-copy through kernel bypass, as happened with the predecessor DNA. Once the application accessing the device is closed, standard networking activities can take place again. An interface in ZC mode provides the same performance as DNA.

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.

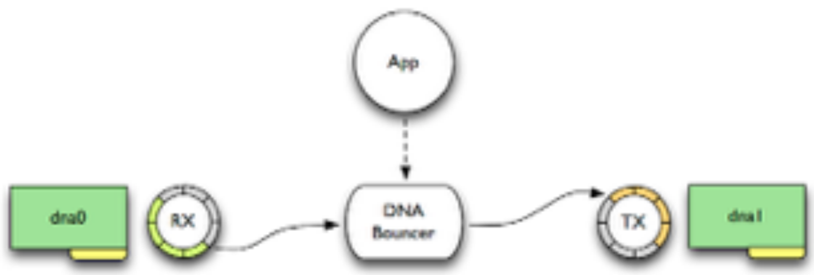
5.1.DNA Cluster



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 ZC

PF_RING ZC (Zero Copy) is a flexible packet processing framework that allows you to achieve 1/10 Gbit line-rate packet processing (both RX and TX) at any packet size. It implements zero-copy operations including patterns for inter-process and inter-VM (KVM) communications. It can be considered as the successor of DNA/LibZero that offers a single and consistent API implementing simple building blocks (queue, worker and pool) that can be used from threads, applications and virtual machines.

The following example shows how to create an aggregator+balancer application in 6 lines of code.

```
zc = pfring_zc_create_cluster(ID, MTU, MAX_BUFFERS, NULL);
for (i = 0; i < num_devices; i++)
 inzq[i] = pfring_zc_open_device(zc, devices[i], rx_only);
for (i = 0; i < num_slaves; i++)
  outzq[i] = pfring_zc_create_queue(zc, QUEUE_LEN);
zw = pfring_zc_run_balancer(inzq, outzq, num_devices,
num_slaves, NULL, NULL, !wait_for_packet, core_id);
```

PF_RING ZC comes with a new generation of PF_RING aware drivers that can be used both in kernel or bypass mode. Once installed, the drivers operate as standard Linux drivers where you can do normal networking (e.g. ping or SSH). When used from PF_RING they are quicker than vanilla drivers, as they interact directly with it. If you open a device using a PF_RING-aware driver in zero copy (e.g. pfcount -i zc:eth1) the device becomes unavailable to standard networking as it is accessed in zero-copy through kernel bypass, as happened with the predecessor DNA. Once the application accessing the device is closed, standard networking activities can take place again.

PF_RING ZC allows you to forward (both RX and TX) packets in zero-copy for a KVM Virtual Machine without using techniques such as PCIe passthrough. Thanks to the dynamic creation of ZC devices on VMs, you can capture/send traffic in zero-copy from your VM without having to patch the KVM code, or start KVM after your ZC devices have been created. In essence now you can do 10 Gbit line rate to your KVM using the same command you would use on a physical host, without changing a single line of code.

In PF_RING ZC you can use the zero-copy framework even with non-PF_RING aware drivers. This means that you can dispatch, process, originate, and inject packets into the zero-copy framework even though they have not been originated from ZC devices. Once the packet has been copied (one-copy) to the ZC world, from then onwards the packet will always be processed in zero-copy during all his lifetime. For instance the zbalance_ipc demo application can read packet in 1-copy mode from a non-PF_RING aware device (e.g. a WiFI-device or a Broadcom NIC) and send them inside ZC for performing zero-copy operations with them.

7. 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/

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

7.1. 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.

8. 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 memcpy() to PF_RING and also to the standard Linux path.
- transparent_mode=2 (PF_RING -aware drivers only)
  Packets are ONLY memcpy() 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.

8.1. 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]
```

8.2. Libpfring and Libpcap Installation

Both libpfring (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.

8.3. 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]
```

8.4. 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 the card.
  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).

- ZC module.
  This module can be used to open a device in ZC mode, if you own a supported card and a PF_RING-aware driver with ZC support. As with DNA, ZC dramatically increases the packet capture and transmission speed as the kernel layer is bypassed and applications can communicate directly with the card.
  Currently these ZC drivers are available:
  - e1000e
  - igb
  - ixgbe

  The drivers are part of the PF_RING distribution and can be found in drivers/PF_RING_aware/ identified by the suffix '-zc'. With all the drivers you can achieve wire rate at any packet size, both for RX and TX. In order to open a device in ZC mode you should use the "zc:" prefix: "zc:ethX".

- 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_recv() has to be used.

9. 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 overview.
- Extensions to the libpcap library for supporting legacy applications.

Please refer to the doxygen documentation (pfring.h header file) for functions descriptions.

9.1. 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.

9.2. 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.

9.3. 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).

9.4. 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.

9.5. 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.

9.6. 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.

10. libzero for DNA API Overview

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.

10.1.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.

10.1.1.The Master API

Please refer to the doxygen documentation for the pfring_zero.h file (look for dna_cluster_*).

10.1.2.The Slave API

A DNA Cluster slave thread/application uses a superset of the PF_RING API, granting backward compatibility with all existing applications.

In addition to the standard PF_RING API the functions below are defined. Please refer to the doxygen documentation for pfring.h.

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

int pfring_set_pkt_buff_len(pfring *ring, pfring_pkt_buff *pkt_handle, u_int32_t len);

int pfring_set_pkt_buff_ifindex(pfring *ring, pfring_pkt_buff *pkt_handle, int if_index);

int pfring_add_pkt_buff_ifindex(pfring *ring, pfring_pkt_buff *pkt_handle, int if_index);

pfring_pkt_buff* pfring_alloc_pkt_buff(pfring *ring);

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

int pfring_recv_pkt_buff(pfring *ring, pfring_pkt_buff *pkt_handle, struct pfring_pkthdr *hdr, u_int8_t wait_for_incoming_packet);

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

10.2.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 modo-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.

10.2.1.The DNA Bouncer API

Please refer to the doxygen documentation for the pfring_zero.h file (look for pfring_dna_bouncer_*).

10.3.Code Snippets for Common Use Cases

10.3.1.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);
```

10.3.2.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_recv_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);
 }
}
```

10.3.3.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);
```

10.3.4.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);
```

10.3.5.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);
```

11. 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.

11.1. 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).

11.2. 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 0 on success, a negative value otherwise.

11.3. 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 0 if the packet has not matched the rule filter, a positive value otherwise.

11.4. 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 the length of the rule stats, or 0 in case of error.

11.5. 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.

12. 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 higest 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;
```

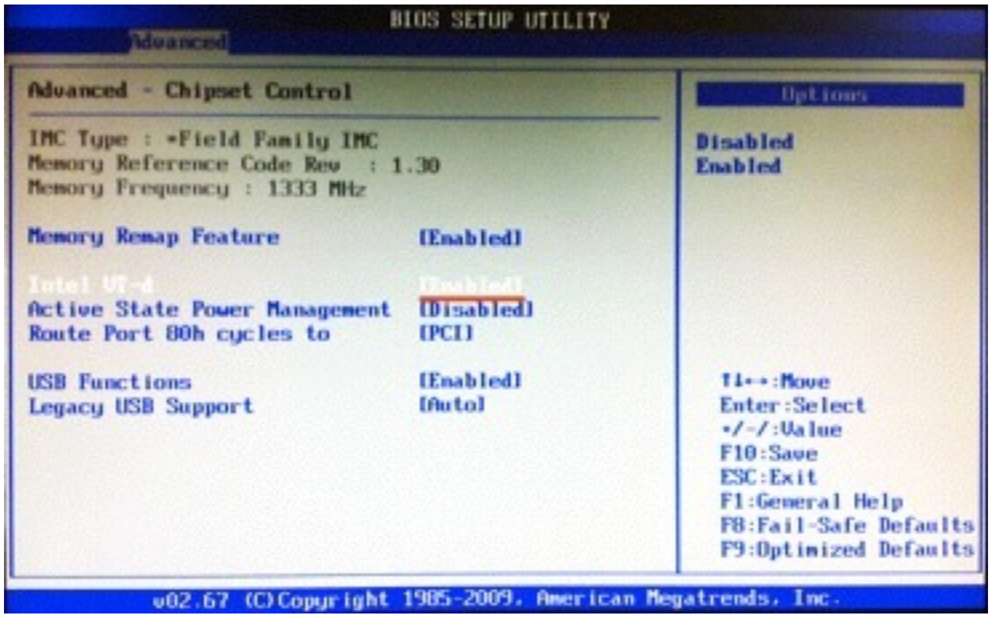
```
typedef enum {
  forward_packet_and_stop_rule_evaluation = 0,
  dont_forward_packet_and_stop_rule_evaluation,
  execute_action_and_continue_rule_evaluation,
  execute_action_and_stop_rule_evaluation,
  forward_packet_add_rule_and_stop_rule_evaluation,/* auto-filled hash rule or
                                                      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;
```

13. 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.

13.1. BIOS Configuration

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

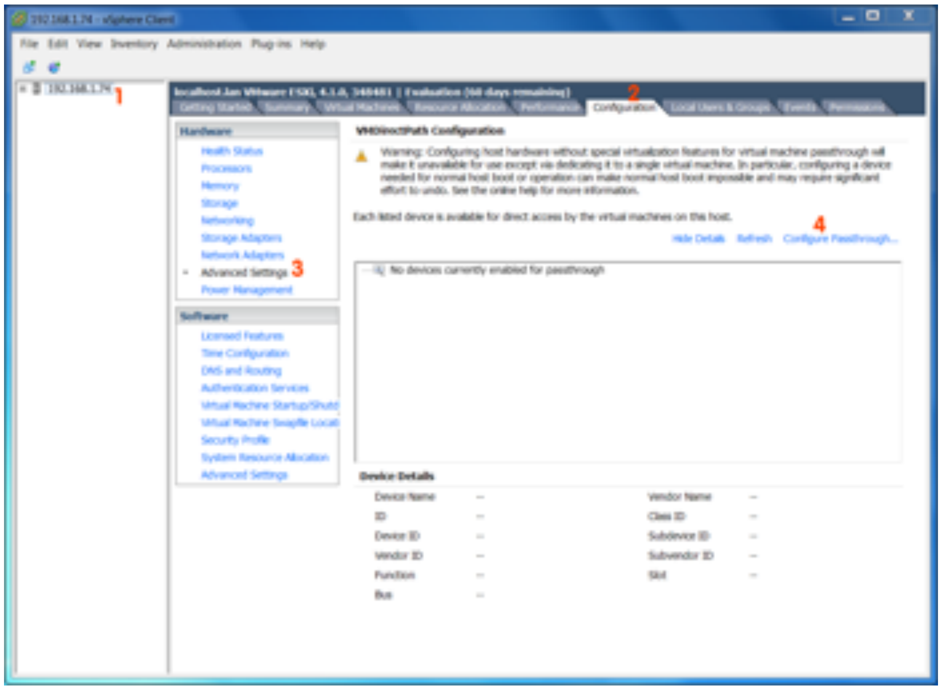


```
                         BIOS SETUP UTILITY
   Advanced
 Advanced - Chipset Control                          Options

 IMC Type : *Field Family IMC                        Disabled
 Memory Reference Code Rev   : 1.30                  Enabled
 Memory Frequency : 1333 MHz

 Memory Remap Feature           [Enabled]

 Intel VT-d                     [Enabled]
 Active State Power Management  [Disabled]
 Route Port 80h cycles to       [PCI]

 USB Functions                  [Enabled]              ↑↓←→:Move
 Legacy USB Support             [Auto]                 Enter:Select
                                                       +/-/:Value
                                                       F10:Save
                                                       ESC:Exit
                                                       F1:General Help
                                                       F8:Fail-Safe Defaults
                                                       F9:Optimized Defaults

        v02.67 (C)Copyright 1985-2009, American Megatrends, Inc.
```

13.2.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".



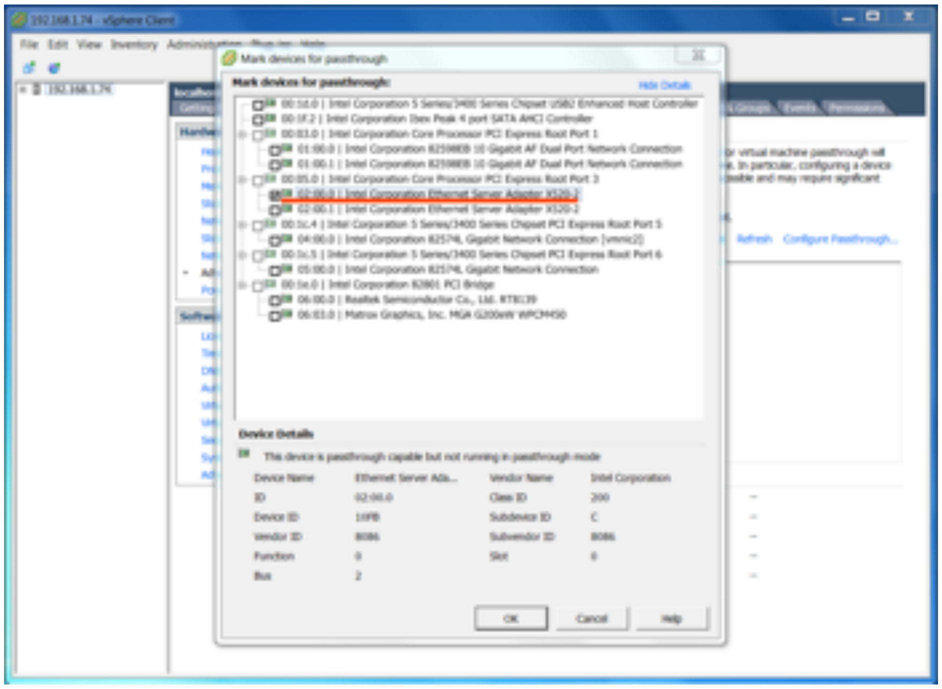
Warning: Configuring host hardware without special virtualization features for virtual machine passthrough will make it unavailable for use except via dedicating it to a single virtual machine. In particular, configuring a device needed for normal host boot or operation can make normal host boot impossible and may require significant effort to undo. See the online help for more information.

Each listed device is available for direct access by the virtual machines on this host.

No devices currently enabled for passthrough

Device Name	--	Vendor Name	--
ID	--	Class ID	--
Device ID	--	Subdevice ID	--
Vendor ID	--	Subvendor ID	--
Function	--	Slot	--
Bus	--		

Select the devices you want to assign to the VMs.


192.168.1.74 - vSphere Client
Mark devices for passthrough
Mark devices for passthrough:
Hide Details
Device Details
OK
Cancel
Help

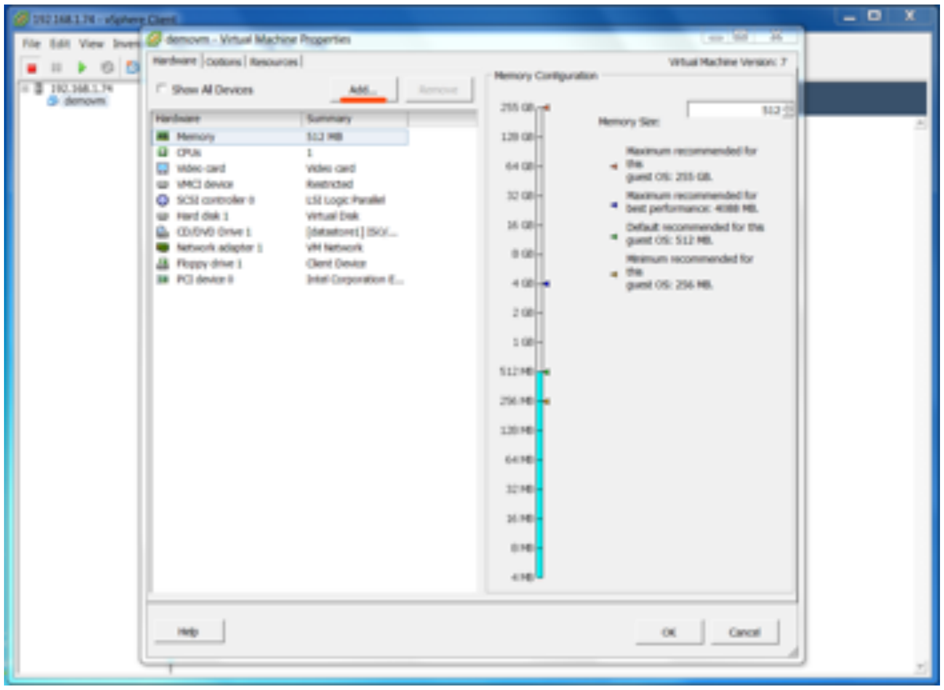
```
00:1d.0 | Intel Corporation 5 Series/3400 Series Chipset USB2 Enhanced Host Controller
00:1f.2 | Intel Corporation Ibex Peak 4 port SATA AHCI Controller
00:03.0 | Intel Corporation Core Processor PCI Express Root Port 1
    01:00.0 | Intel Corporation 82598EB 10 Gigabit AF Dual Port Network Connection
    01:00.1 | Intel Corporation 82598EB 10 Gigabit AF Dual Port Network Connection
00:05.0 | Intel Corporation Core Processor PCI Express Root Port 3
    02:00.0 | Intel Corporation Ethernet Server Adapter X520-2
    02:00.1 | Intel Corporation Ethernet Server Adapter X520-2
00:1c.4 | Intel Corporation 5 Series/3400 Series Chipset PCI Express Root Port 5
    04:00.0 | Intel Corporation 82574L Gigabit Network Connection [vmnic2]
00:1c.5 | Intel Corporation 5 Series/3400 Series Chipset PCI Express Root Port 6
    05:00.0 | Intel Corporation 82574L Gigabit Network Connection
00:1e.0 | Intel Corporation 82801 PCI Bridge
    06:00.0 | Realtek Semiconductor Co., Ltd. RT8139
    06:03.0 | Matrox Graphics, Inc. MGA G200eW WPCM450
```

This device is passthrough capable but not running in passthrough mode

Device Name	Ethernet Server Ada...	Vendor Name	Intel Corporation
ID	02:00.0	Class ID	200
Device ID	10FB	Subdevice ID	C
Vendor ID	8086	Subvendor ID	8086
Function	0	Slot	0
Bus	2		

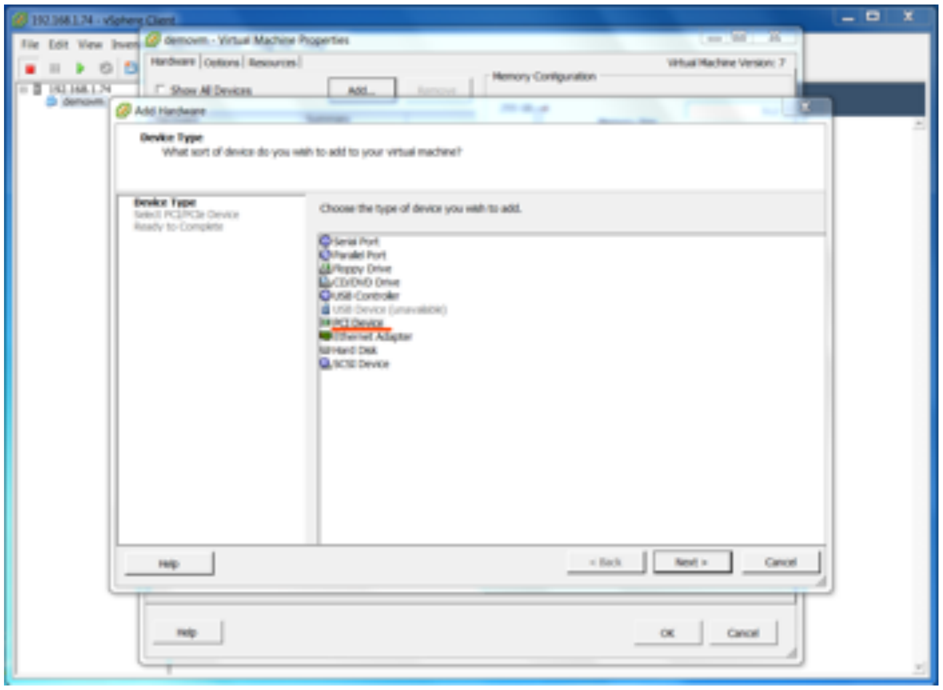
Reboot the server.

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.

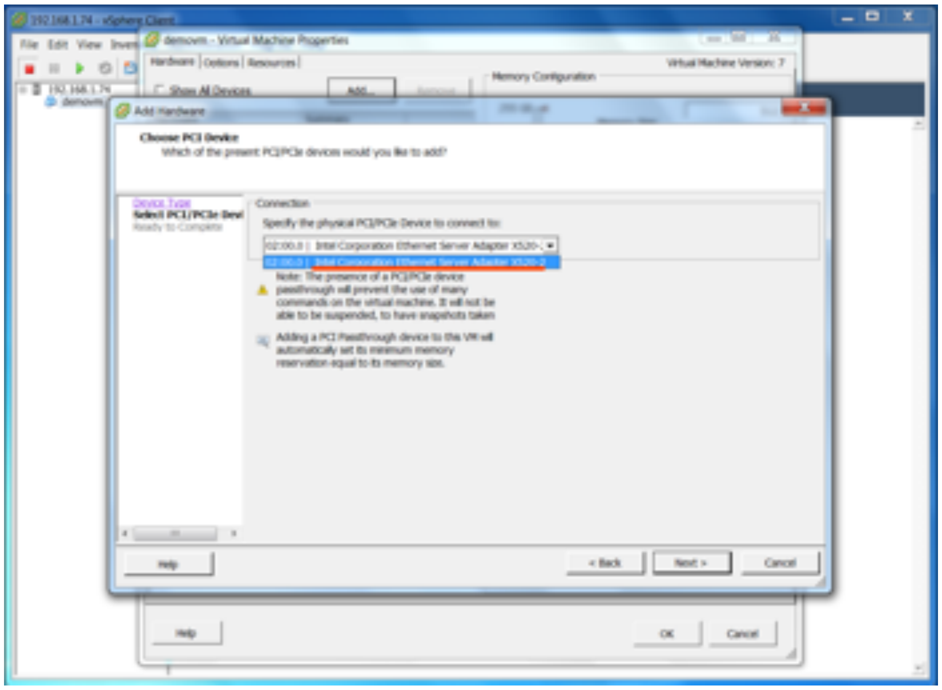


Hardware	Summary
Memory	512 MB
CPUs	1
Video card	Video card
VMCI device	Restricted
SCSI controller 0	LSI Logic Parallel
Hard disk 1	Virtual Disk
CD/DVD Drive 1	[datastore1] ISO/...
Network adapter 1	VM Network
Floppy drive 1	Client Device
PCI device 0	Intel Corporation E...

Select "PCI Device".



Select the device to assign to the VM.


192.168.1.74 - vSphere Client
demovm - Virtual Machine Properties
Add Hardware
Choose PCI Device
Which of the present PCI/PCIe devices would you like to add?
Device Type
Select PCI/PCIe Device
Ready to Complete
Connection
Specify the physical PCI/PCIe Device to connect to:
02:00.0 | Intel Corporation Ethernet Server Adapter X520-2
Note: The presence of a PCI/PCIe device passthrough will prevent the use of many commands on the virtual machine. It will not be able to be suspended, to have snapshots taken
Adding a PCI Passthrough device to this VM will automatically set its minimum memory reservation equal to its memory size.
Help
< Back
Next >
Cancel
OK

Boot the VM and install PF_RING with the DNA driver as in the native case.

13.3. 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.)

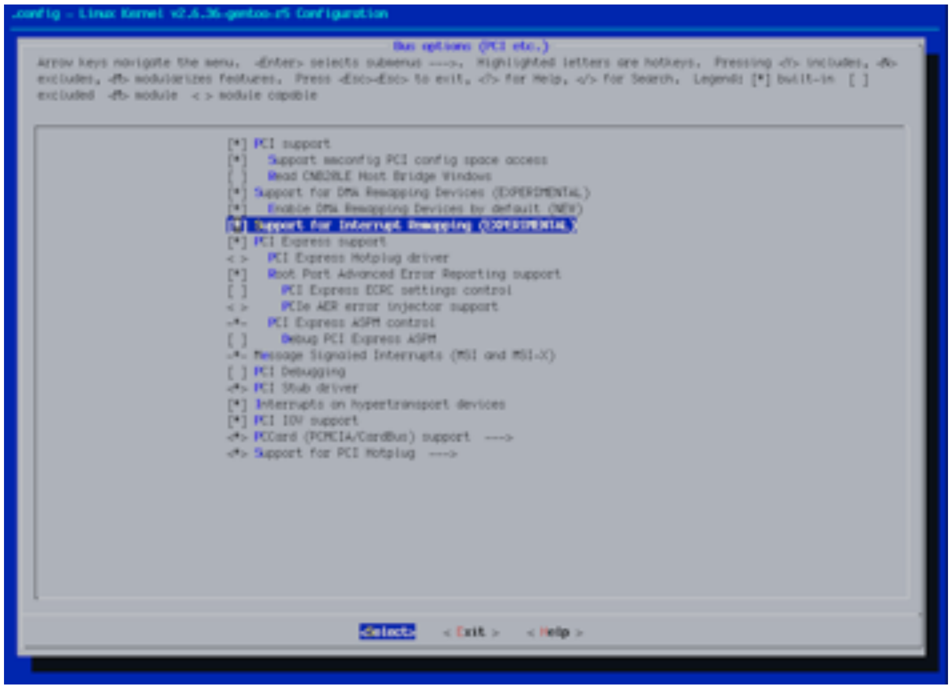
[*] Support for DMA Remapping Devices

[*] Enable DMA Remapping Devices

[*] Support for Interrupt Remapping

<*> PCI Stub driver

```
$ cd /usr/src/linux
$ make menuconfig
```



```
.config - Linux Kernel v2.6.36-gentoo-r5 Configuration
                              Bus options (PCI etc.)
  Arrow keys navigate the menu.  <Enter> selects submenus --->.  Highlighted letters are hotkeys.  Pressing <Y> includes, <N>
  excludes, <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ]
  excluded  <M> module  < > module capable

                    [*] PCI support
                    [*]   Support mmconfig PCI config space access
                    [ ]   Read CNB20LE Host Bridge Windows
                    [*] Support for DMA Remapping Devices (EXPERIMENTAL)
                    [*]   Enable DMA Remapping Devices by default (NEW)
                    [*] Support for Interrupt Remapping (EXPERIMENTAL)
                    [*] PCI Express support
                    < >   PCI Express Hotplug driver
                    [*]   Root Port Advanced Error Reporting support
                    [ ]     PCI Express ECRC settings control
                    < >     PCIe AER error injector support
                    -*-   PCI Express ASPM control
                    [ ]     Debug PCI Express ASPM
                    -*- Message Signaled Interrupts (MSI and MSI-X)
                    [ ] PCI Debugging
                    <*> PCI Stub driver
                    [*] Interrupts on hypertransport devices
                    [*] PCI IOV support
                    <*> PCCard (PCMCIA/CardBus) support  --->
                    <*> Support for PCI Hotplug  --->

                        <Select>    < Exit >    < Help >
```

```
$ 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.