Linux Kernel Networking

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Disclaimer

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Warning

• This lecture will deal with design functional description side by side with many implementation details; some knowledge of “C” is preferred.
General

- The Linux networking kernel code (including network device drivers) is a large part of the Linux kernel code.

- **Scope:** We will not deal with wireless, IPv6, and multicasting.
  - Also not with user space routing daemons/apps, and with security attacks (like DoS, spoofing, etc.).

- Understanding a packet walkthrough in the kernel is a key to understanding kernel networking. Understanding it is a must if we want to understand Netfilter or IPSec internals, and more.

- There is a 10 pages Linux kernel networking walkthrough document which was written in some university (see 1 in the list of links).
General - Contd.

- Though it deals with 2.4.20 Linux kernel, most of it is relevant.
- This lecture will concentrate on this walkthrough (design and implementation details).
- References to code in this lecture are based on linux-2.6.23-rc2.
- There was some serious cleanup in 2.6.23
Hierarchy of networking layers

- The layers that we will deal with (based on the 7 layers model) are:

  - Transport Layer (L4) (udp,tcp...)
  - Network Layer (L3) (ip)
  - Link Layer (L2) (ethernet)
Networking Data Structures

• The two most important structures of linux kernel network layer are:
  - sk_buff (defined in include/linux/skbuff.h)
  - netdevice (defined in include/linux/netdevice.h)

• It is better to know a bit about them before delving into the walkthrough code.
SK_BUFF

- sk_buff represents data and headers.
- sk_buff API (examples)
  - sk_buff allocation is done with `alloc_skb()` or `dev_alloc_skb()`; drivers use `dev_alloc_skb()`; (free by `kfree_skb()` and `dev_kfree_skb()`).
- `unsigned char* data` : points to the current header.
- `skb_pull(int len)` – removes data from the start of a buffer by advancing data to data+len and by decreasing len.
- Almost always sk_buff instances appear as “skb” in the kernel code.
SK_BUFF - contd

- sk_buff includes 3 unions; each corresponds to a kernel network layer:
  
- **transport_header** (previously called h) – for layer 4, the transport layer (can include tcp header or udp header or icmp header, and more)
  
- **network_header** – (previously called nh) for layer 3, the network layer (can include ip header or ipv6 header or arp header).
  
- **mac_header** – (previously called mac) for layer 2, the link layer.
  
- skb_network_header(skb), skb_transport_header(skb) and skb_mac_header(skb) return pointer to the header.
SK_BUFF - contd.

- **struct dst_entry **\( *dst \)- the route for this sk_buff; this route is determined by the routing subsystem.
  - It has 2 important function pointers:
    - \( int \ (*input)(struct sk_buff*); \)
    - \( int \ (*output)(struct sk_buff*); \)

- **input()** can be assigned to one of the following: ip_local_deliver, ip_forward, ip_mr_input, ip_error or dst_discard_in.

- **output()** can be assigned to one of the following: ip_output, ip_mc_output, ip_rt_bug, or dst_discard_out.
  - we will deal more with dst when talking about routing.
SK_BUFF - contd.

• In the usual case, there is only one dst_entry for every skb.

• When using IPSec, there is a linked list of dst_entries and only the last one is for routing; all other dst_entries are for IPSec transformers; these other dst_entries have the DST_NOHASH flag set.

• **tstamp** (of type ktime_t) : time stamp of receiving the packet.
  
  – *net_enable_timestamp()* must be called in order to get values.
net_device

- net_device represents a network interface card.
- There are cases when we work with virtual devices.
  - For example, bonding (setting the same IP for two or more NICs, for load balancing and for high availability.)
  - Many times this is implemented using the private data of the device (the `void *priv` member of net_device);
  - In OpenSolaris there is a special pseudo driver called “vnic” which enables bandwidth allocation (project CrossBow).
- Important members:
• **unsigned int mtu** – Maximum Transmission Unit: the maximum size of frame the device can handle.

• Each protocol has mtu of its own; the default is **1500** for Ethernet.

• you can change the mtu with ifconfig; for example, like this:
  
  - `ifconfig eth0 mtu 1400`
  
  - You cannot of course, change it to values higher than 1500 on 10Mb/s network:
    
    - `ifconfig eth0 mtu 1501` will give:
      
      - `SIOCSIFMTU: Invalid argument`
net_device - contd

- **unsigned int flags** - (which you see or set using ifconfig utility): for example, RUNNING or NOARP.

- **unsigned char dev_addr[MAX_ADDR_LEN]** : the MAC address of the device (6 bytes).

- **int (*hard_start_xmit)(struct sk_buff *skb,**

  
  ```c
  struct net_device *dev);
  ```

  - a pointer to the device transmit method.

- **int promiscuity**; (a counter of the times a NIC is told to set to work in promiscuous mode; used to enable more than one sniffing client.)
You are likely to encounter macros starting with IN_DEV like:

IN_DEV_FORWARD() or IN_DEV_RX_REDIRECTS(). How are the related to net_device? How are these macros implemented?

**void *ip_ptr**: IPv4 specific data. This pointer is assigned to a pointer to in_device in inetdev_init() (net/ipv4/devinet.c)
• struct in_device have a member named cnf (instance of ipv4_devconf). Setting `/proc/sys/net/ipv4/conf/all/forwarding` eventually sets the forwarding member of in_device to 1. The same is true to accept_redirects and send_redirects; both are also members of cnf (ipv4_devconf).

• In most distros, `/proc/sys/net/ipv4/conf/all/forwarding=0`

• *But probably this is not so on your ADSL router.*
network interface drivers

• Most of the nics are PCI devices; there are also some USB network devices.

• The drivers for network PCI devices use the generic PCI calls, like `pci_register_driver()` and `pci_enable_device()`.

• For more info on nic drives see the article “Writing Network Device Driver for Linux” (link no. 9 in links) and chap17 in ldd3.

• There are two modes in which a NIC can receive a packet.
  - The traditional way is interrupt-driven: each received packet is an asynchronous event which causes an interrupt.
NAPI

- NAPI (new API).
- The NIC works in polling mode.
- In order that the nic will work in polling mode it should be built with a proper flag.
- Most of the new drivers support this feature.
- When working with NAPI and when there is a very high load, packets are lost; but this occurs before they are fed into the network stack. (in the non-NAPI driver they pass into the stack)
- in Solaris, polling is built into the kernel (no need to build drivers in any special way)
User Space Tools

- iputils (including ping, arping, and more)
- net-tools (ifconfig, netstat, route, arp and more)
- IPROUTE2 (ip command with many options)
  - Uses rtnetlink API.
  - Has much wider functionalities; for example, you can create tunnels with “ip” command.
  - Note: no need for “-n” flag when using IPROUTE2 (because it does not work with DNS).
Routing Subsystem

- The routing table and the routing cache enable us to find the net device and the address of the host to which a packet will be sent.

- Reading entries in the routing table is done by calling `fib_lookup(const struct flowi *flp, struct fib_result *res)`

- FIB is the “Forwarding Information Base”.

- There are two routing tables by default: (non Policy Routing case)
  - local FIB table (`ip_fib_local_table` ; ID 255).
  - main FIB table (`ip_fib_main_table` ; ID 254)

- See: `include/net/ip_fib.h`. 
Routes can be added into the main routing table in one of 3 ways:

- By sys admin command (route add/ip route).
- By routing daemons.
- As a result of ICMP (REDIRECT).

A routing table is implemented by struct fib_table.
Routing Tables

- `fib_lookup()` first searches the local FIB table (`ip_fib_local_table`).
- In case it does not find an entry, it looks in the main FIB table (`ip_fib_main_table`).
- Why is it in this order?
- There is one routing cache, regardless of how many routing tables there are.
- You can see the routing cache by running "`route -C`".
- Alternatively, you can see it by: “`cat /proc/net/rt_cache`”.
  - con: this way, the addresses are in hex format
Routing Cache

• The routing cache is built of **rtable** elements:

• `struct rtable` (see: `/include/net/route.h`)

```c
{
    union {
        struct dst_entry dst;
    } u;

    ...
}
```
Routing Cache - contd

- The **dst_entry** is the protocol-independent part.
  - Thus, for example, we have a dst_entry member (also called dst) in rt6_info in ipv6. (`include/net/ip6_fib.h`)

- The key for a lookup operation in the routing cache is an IP address (whereas in the routing table the key is a subnet).

- Inserting elements into the routing cache by: `rt_intern_hash()`

- There is an alternate mechanism for route cache lookup, called **fib_trie**, which is inside the kernel tree (`net/ipv4/fib_trie.c`)
Routing Cache - contd

• It is based on extending the lookup key.

• You should set: CONFIG_IP_FIB_TRIE (=y)
  - (instead of CONFIG_IP_FIB_HASH)

• By Robert Olsson et al (see links).
Creating a Routing Cache Entry

- Allocation of **rtable** instance (rth) is done by: `dst_alloc()`.
  - `dst_alloc()` in fact creates and returns a pointer to `dst_entry` and we cast it to `rtable` (*net/core/dst.c*).

- Setting input and output methods of dst:
  - `(rth->u.dst.input and rth->u.dst.input )`

- Setting the `flowi` member of dst (rth->fl)
  - Next time there is a lookup in the cache, for example, `ip_route_input()`, we will compare against rth->fl.
Routing Cache - Contd.

- A garbage collection call which delete eligible entries from the routing cache.
- Which entries are not eligible?
Policy Routing (multiple tables)

- Generic routing uses destination-address based decisions.
- There are cases when the destination-address is not the sole parameter to decide which route to give; Policy Routing comes to enable this.
Policy Routing (multiple tables)-contd.

• Adding a routing table: by adding a line to: `/etc/iproute2/rt_tables`
  - For example: add the line “252 my_rt_table”.
  - There can be up to 255 routing tables.
• Policy routing should be enabled when building the kernel (CONFIG_IP_MULTIPLE_TABLES should be set.)
• Example of adding a route in this table:
  • `> ip route add default via 192.168.0.1 table my_rt_table`
• Show the table by:
  - `ip route show table my_rt_table`
Policy Routing (multiple tables)-contd.

- You can add a rule to the **routing policy database (RPDB)** by "ip rule add ...
  - The rule can be based on input interface, TOS, fwmark (from netfilter).
- *ip rule list* – show all rules.
Policy Routing: add/delete a rule - example

- `ip rule add tos 0x04 table 252`
  - This will cause packets with tos=0x08 (in the iphdr) to be routed by looking into the table we added (252)
  - So the default gw for these type of packets will be 192.168.0.1
- `ip rule show` will give:
  - 32765: from all tos reliability lookup my_rt_table
  - ...

Policy Routing: add/delete a rule - example

- Delete a rule: `ip rule del tos 0x04 table 252`
Routing Lookup

**Cache lookup**

- Hit

**Miss**

- fib_lookup() in ip_fib_local_table
  - Hit
  - Deliver packet by:
    - `ip_local_deliver()` or `ip_forward()` according to result
  - Miss
  - fib_lookup() in ip_fib_main_table
    - Hit
    - Miss
    - Drop packet

**ip_route_input() in: net/ipv4/route.c**

**ip_route_input_slow() in: net/ipv4/route.c**

Deliver packet by: `ip_local_deliver()` or `ip_forward()` according to result.
Routing Table Diagram

- `tb_lookup()`
- `tb_insert()`
- `tb_delete()`

- `struct fn_zone`
- `struct fn_zone`
- `struct fn_zone`
- `struct fn_zone`
- `struct fn_zone`
- `struct fn_zone`

- `fz_hash`
- `hlist_head`
- `fn_alias`
- `fn_key`
- `fa_info`
- `fib_nh`

- `struct fib_table`
- `struct fn_zone`
- `struct fib_node`
- `struct fib_alias`
- `struct fib_info`
Routing Tables

- Breaking the fib_table into multiple data structures gives flexibility and enables fine grained and high level of sharing.
  - Suppose that we 10 routes to 10 different networks have the same next hop gw.
  - We can have one fib_info which will be shared by 10 fib_aliases.
  - fz_divisor is the number of buckets
Routing Tables - contd

- Each *fib* node element represents a unique subnet.
  - The *fn_key* member of fib_ node is the subnet (32 bit)
Routing Tables - contd

• Suppose that a device goes down or enabled.
• We need to disable/enable all routes which use this device.
• But how can we know which routes use this device?
• In order to know it efficiently, there is the `fib_info_devhash` table.
• This table is indexed by the device identifier.
• See `fib_sync_down()` and `fib_sync_up()` in `net/ipv4/fib_semantics.c`
Routing Table lookup algorithm

- LPM (Longest Prefix Match) is the lookup algorithm.
- The route with the longest netmask is the one chosen.
- Netmask 0, which is the shortest netmask, is for the default gateway.
  - What happens when there are multiple entries with netmask=0?
  - `fib_lookup()` returns the first entry it finds in the fib table where netmask length is 0.
Routing Table lookup - contd.

- It may be that this is not the best choice default gateway.
- So in case that netmask is 0 (prefixlen of the fib_result returned from fib_look is 0) we call `fib_select_default()`.
- `fib_select_default()` will select the route with the lowest priority (metric) (by comparing to `fib_priority` values of all default gateways).
Receiving a packet

• When working in interrupt-driven model, the nic registers an interrupt handler with the IRQ with which the device works by calling request_irq().

• This interrupt handler will be called when a frame is received.

• The same interrupt handler will be called when transmission of a frame is finished and under other conditions. (depends on the NIC; sometimes, the interrupt handler will be called when there is some error).
Receiving a packet - contd

- Typically in the handler, we allocate sk_buff by calling `dev_alloc_skb()`; also `eth_type_trans()` is called; among other things it advances the data pointer of the sk_buff to point to the IP header; this is done by calling `skb_pull(skb, ETH_HLEN)`.

- See: `net/ethernet/eth.c`
  - ETH_HLEN is 14, the size of ethernet header.
Receiving a packet - contd

- The handler for receiving a packet is \texttt{ip\_rcv()}. (\texttt{net/ipv4/ip\_input.c})
- Handler for the protocols are registered at init phase.
  - Likewise, \texttt{arp\_rcv()} is the handler for ARP packets.
- First, \texttt{ip\_rcv()} performs some sanity checks. For example:

  \begin{verbatim}
  if (iph->ihl < 5 || iph->version != 4)
    goto inhdr\_error;
  \end{verbatim}
  
  - \texttt{iph} is the ip header ; \texttt{iph->ihl} is the ip header length (4 bits).
  - The ip header must be at least 20 bytes.
  - It can be up to 60 bytes (when we use ip options)
Then it calls `ip_rcv_finish()`, by:

```c
NF_HOOK(PF_INET, NF_IP_PRE_ROUTING, skb, dev, NULL, ip_rcv_finish);
```

This division of methods into two stages (where the second has the same name with the suffix `finish` or `slow`, is typical for networking kernel code.)

In many cases the second method has a “slow” suffix instead of “finish”; this usually happens when the first method looks in some cache and the second method performs a lookup in a table, which is slower.
Receiving a packet - contd

- *ip_rcv_finish()* implementation:

```c
if (skb->dst == NULL) {
    int err = ip_route_input(skb, iph->daddr, iph->saddr, iph->tos,
                             skb->dev);
...
}
...
return dst_input(skb);
```
Receiving a packet - contd

- **ip_route_input()**:  
  First performs a lookup in the routing cache to see if there is a match. If there is **no match (cache miss)**, calls **ip_route_input_slow()** to perform a lookup in the routing table. (This lookup is done by calling **fib_lookup()**).

- **fib_lookup(const struct flowi *flp, struct fib_result *res)**
  The results are kept in fib_result.

- **ip_route_input()** returns 0 upon successful lookup. (also when there is a cache miss but a successful lookup in the routing table.)
Receiving a packet - contd

According to the results of `fib_lookup()`, we know if the frame is for local delivery or for forwarding or to be dropped.

- If the frame is for local delivery, we will set the input() function pointer of the route to `ip_local_deliver()`:

  ```c
  rth->u.dst.input = ip_local_deliver;
  ```

- If the frame is to be forwarded, we will set the input() function pointer to `ip_forward()`:

  ```c
  rth->u.dst.input = ip_forward;
  ```
Local Delivery

• Prototype:

```
ip_local_deliver(struct sk_buff *skb) (net/ipv4/ip_input.c).
- calls NF_HOOK(PF_INET, NF_IP_LOCAL_IN, skb, skb->dev, NULL, ip_local_deliver_finish);
```

• Delivers the packet to the higher protocol layers according to its type.
Forwarding

• Prototype:
  - `int ip_forward(struct sk_buff *skb)`
    • `(net/ipv4/ip_forward.c)`
  - decreases the ttl in the ip header
  - If the ttl is <=1, the methods send ICMP message (`ICMP_TIME_EXCEEDED`) and drops the packet.
  - Calls `NF_HOOK(PF_INET,NF_IP_FORWARD, skb, skb->dev, rt->u.dst.dev, ip_forward_finish);`
Forwarding- Contd

- `ip_forward_finish()`: sends the packet out by calling `dst_output(skb)`.

- `dst_output(skb)` is just a wrapper, which calls `skb->dst->output(skb)`. (see `include/net/dst.h`)
Sending a Packet

- Handling of sending a packet is done by `ip_route_output_key()`.
- We need to perform routing lookup also in the case of transmission.
- In case of a cache miss, we calls `ip_route_output_slow()`, which looks in the routing table (by calling `fib_lookup()`, as also is done in `ip_route_input_slow()`.
- If the packet is for a remote host, we set `dst->output` to `ip_output()`
Sending a Packet-contd

- *ip_output()* will call *ip_finish_output()*
  - This is the NF_IP_POST_ROUTING point.

- *ip_finish_output()* will eventually send the packet from a neighbor by:
  - *dst-*neighbour-*output(skb)*
  - *arp_bind_neighbour()* sees to it that the L2 address of the next hop will be known. (*net/ipv4/arp.c*)
Sending a Packet - Contd.

- If the packet is for the local machine:
  - \( \text{dst}\rightarrow\text{output} = \text{ip\_output} \)
  - \( \text{dst}\rightarrow\text{input} = \text{ip\_local\_deliver} \)
  - \text{ip\_output()} \) will send the packet on the loopback device,
  - Then we will go into \text{ip\_rcv()} and \text{ip\_rcv\_finish()}, but this time \text{dst} is NOT null; so we will end in \text{ip\_local\_deliver()}.  

- See: \text{net/ipv4/route.c}
Multipath routing

- This feature enables the administrator to set multiple next hops for a destination.
- To enable multipath routing, `CONFIG_IP_ROUTE_MULTIPATH` should be set when building the kernel.
- There was also an option for multipath caching: (by setting `CONFIG_IP_ROUTE_MULTIPATH_CACHED`).
- It was experimental and removed in 2.6.23 - See links (6).
Linux Kernel v2.6.21-rc7 Configuration

Networking options

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

[ ] Network packet debugging
[*] Packet socket
[*] Packet socket: mmapped IO
[*] Unix domain sockets
[*] Transformation user configuration interface
[*] Transformation sub policy support (EXPERIMENTAL)
[*] Transformation migrate database (EXPERIMENTAL)
<M> PF_KEY sockets
[*] PF_KEY MIGRATE (EXPERIMENTAL)
[*] TCP/IP networking
[*] IP: multicasting
[*] IP: advanced router
Choose IP: FIB lookup algorithm (choose FIB_HASH if unsure) (FIB_HASH)
[*] IP: policy routing
[*] IP: equal cost multipath
[*] IP: equal cost multipath with caching support (EXPERIMENTAL)

<MULTIPATH: round robin algorithm
<MULTIPATH: random algorithm (NEW)
<MULTIPATH: weighted random algorithm (NEW)
<MULTIPATH: interface round robin algorithm (NEW)

<Select>  < Exit >  < Help >
Netfilter

- Netfilter is the kernel layer to support applying iptables rules.
  - It enables:
    - Filtering
    - Changing packets (masquerading)
    - Connection Tracking
Netfilter rule - example

- Short example:
- Applying the following iptables rule:
  - `iptables -A INPUT -p udp --dport 9999 -j DROP`
- This is NF_IP_LOCAL_IN rule;
- The packet will go to:
  - `ip_rcv()`
  - and then: `ip_rcv_finish()`
  - And then `ip_local_deliver()`
Netfilter rule - example (contd)

• but it will **NOT** proceed to *ip_local_deliver_finish()* as in the usual case, without this rule.

• As a result of applying this rule it reaches *nf_hook_slow()* with verdict == NF_DROP (calls *skb_free()* to free the packet)

• See */net/netfilter/core.c.*
ICMP redirect message

- ICMP protocol is used to notify about problems.
- A REDIRECT message is sent in case the route is suboptimal (inefficient).
- There are in fact 4 types of REDIRECT
- Only one is used:
  - Redirect Host (ICMP_REDIR_HOST)
- See RFC 1812 (Requirements for IP Version 4 Routers).
ICMP redirect message - contd.

• To support sending ICMP redirects, the machine should be configured to send redirect messages.
  
  – `/proc/sys/net/ipv4/conf/all/send_redirects` should be 1.

• In order that the other side will receive redirects, we should set

  `/proc/sys/net/ipv4/conf/all/accept_redirects` to 1.
ICMP redirect message - contd.

• Example:

• Add a suboptimal route on 192.168.0.31:

  route add -net 192.168.0.10 netmask 255.255.255.255 gw 192.168.0.121

• Running now “route” on 192.168.0.31 will show a new entry:

  Destination  Gateway  Genmask  Flags Metric Ref Use Iface
  192.168.0.10  192.168.0.121  255.255.255.255 UGH 0 0 0 eth0
ICMP redirect message - contd.

- Send packets from 192.168.0.31 to 192.168.0.10:

- ping 192.168.0.10 (from 192.168.0.31)

- We will see (on 192.168.0.31):
  - From 192.168.0.121: icmp_seq=2 Redirect Host(New nexthop: 192.168.0.10)

- now, running on 192.168.0.121:
  - route -Cn | grep .10

- shows that there is a new entry in the routing cache:
ICMP redirect message - contd.

- 192.168.0.31 192.168.0.10 192.168.0.10 ri 0 0 34 eth0
- The “r” in the flags column means: RTCF_DOREDIRECT.
- The 192.168.0.121 machine had sent a redirect by calling `ip_rt_send_redirect()` from `ip_forward()`.

(net/ipv4/ip_forward.c)
ICMP redirect message - contd.

- And on 192.168.0.31, running “route -C | grep .10” shows now a new entry in the routing cache: (in case accept_redirects=1)
  - 192.168.0.31 192.168.0.10 192.168.0.10 0 0 0 1 eth0
- In case accept_redirects=0 (on 192.168.0.31), we will see:
  - 192.168.0.31 192.168.0.10 192.168.0.121 0 0 0 0 eth0
- which means that the gw is still 192.168.0.121 (which is the route that we added in the beginning).
ICMP redirect message - contd.

- Adding an entry to the routing cache as a result of getting ICMP REDIRECT is done in `ip_rt_redirect()`, `net/ipv4/route.c`.
- The entry in the routing table is not deleted.
Neighboring Subsystem

- Most known protocol: ARP (in IPV6: ND, neighbour discovery)
- ARP table.
- Ethernet header is 14 bytes long:
  - Source mac address (6 bytes).
  - Destination mac address (6 bytes).
  - Type (2 bytes).
    - 0x0800 is the type for IP packet (ETH_P_IP)
    - 0x0806 is the type for ARP packet (ETH_P_ARP)

see: include/linux/if_ether.h
Neighboring Subsystem - contd

• When there is no entry in the ARP cache for the destination IP address of a packet, a broadcast is sent (ARP request, `ARPOP_REQUEST` : who has IP address x.y.z...). This is done by a method called `arp_solicit()`. (net/ipv4/arp.c)

• You can see the contents of the arp table by running:

  
  "cat /proc/net/arp" or by running the "arp" from a command line .

• You can delete and add entries to the arp table; see man arp.
Bridging Subsystem

- You can define a bridge and add NICs to it (“enslaving ports”) using `brctl` (from bridge-utils).
- You can have up to 1024 ports for every bridge device (BR_MAX_PORTS).
- Example:
  - `brctl addbr mybr`
  - `brctl addif mybr eth0`
  - `brctl show`
Bridging Subsystem - contd.

• When a NIC is configured as a bridge port, the `br_port` member of `net_device` is initialized.
  
  - (`br_port` is an instance of `struct net_bridge_port`).

• When we receive a frame, `netif_receive_skb()` calls `handle_bridge()`.
Bridging Subsystem - contd.

- The bridging forwarding database is searched for the destination MAC address.
- In case of a hit, the frame is sent to the bridge port with `br_forward()` (net/bridge/br_forward.c).
- If there is a miss, the frame is flooded on all bridge ports using `br_flood()` (net/bridge/br_forward.c).
- Note: this is not a broadcast!
- The ebtables mechanism is the L2 parallel of L3 Netfilter.
Bridging Subsystem- contd

- Ebtables enable us to filter and mangle packets at the link layer (L2).
IPSec

- Works at network IP layer (L3)
- Used in many forms of secured networks like VPNs.
- Mandatory in IPv6. (not in IPv4)
- Implemented in many operating systems: Linux, Solaris, Windows, and more.
- RFC2401
- In 2.6 kernel: implemented by Dave Miller and Alexey Kuznetsov.
- Transformation bundles.
- Chain of dst entries; only the last one is for routing.
IPSec-cont.

- User space tools: http://ipsec-tools.sf.net
- Building VPN: http://www.openswan.org/ (Open Source).
- There are also non IPSec solutions for VPN
  - example: pptp
- struct xfrm_policy has the following member:
  - struct dst_entry *bundles.
  - __xfrm4_bundle_create() creates dst_entries (with the DST_NOHASH flag) see: net/ipv4/xfrm4_policy.c
- Transport Mode and Tunnel Mode.
IPSec-contd.

- Show the security policies:
  - `ip xfrm policy show`

- Create RSA keys:
  - `ipsec rsasigkey --verbose 2048 > keys.txt`
  - `ipsec showhostkey --left > left.publickey`
  - `ipsec showhostkey --right > right.publickey`
Example: Host to Host VPN (using openswan)
in /etc/ipsec.conf:

conn linux-to-linux
left=192.168.0.189
leftnexthop=%direct
leftrtsasigkey=0sAQPPQ...
right=192.168.0.45
rightnexthop=%direct
rightrtsasigkey=0sAQNwb...
type=tunnel
auto=start
IPSec-contd.

- `service ipsec start` (to start the service)
- `ipsec verify` – Check your system to see if IPsec got installed and started correctly.
- `ipsec auto -status`
  - If you see “IPsec SA established”, this implies success.
- Look for errors in `/var/log/secure` (fedora core) or in kernel syslog
Tips for hacking

- Documentation/networking/ip-sysctl.txt: networking kernel tunables
- Example of reading a hex address:
  - `iph->daddr == 0x0A00A8C0` or means checking if the address is 192.168.0.10 (C0=192, A8=168, 00=0, 0A=10).
Tips for hacking - Contd.

- Disable ping reply:
  
- `echo 1 > /proc/sys/net/ipv4/icmp_echo_ignore_all`

- Disable arp: `ip link set eth0 arp off` (the NOARP flag will be set)
  
- Also `ifconfig eth0 -arp` has the same effect.

- How can you get the Path MTU to a destination (PMTU)?
  - Use tracepath (see man tracepath).
  - Tracepath is from iputils.
• Keep iphdr struct handy (printout): (from linux/ip.h)

struct iphdr {
    __u8   ihl:4,
    version:4;
    __u8   tos;
    __be16  tot_len;
    __be16  id;
    __be16  frag_off;
    __u8   ttl;
    __u8   protocol;
    __sum16  check;
    __be32  saddr;
    __be32  daddr;
    /*The options start here. */
};
Tips for hacking - Contd.

- NIPQUAD() : macro for printing hex addresses
- CONFIG_NET_DMA is for TCP/IP offload.
- When you encounter: xfrm / CONFIG_XFRM this has to do with IPSEC. (transformers).
New and future trends

- IO/AT.
- NetChannels (Van Jacobson and Evgeniy Polyakov).
- TCP Offloading.
- RDMA.
- Mulitqueues: some new nics, like e1000 and IPW2200, allow two or more hardware Tx queues. There are already patches to enable this.
New and future trends - contd.

- Some more info in: Documentation/networking/multiqueue.txt in recent Linux kernels.
- Devices with multiple TX/RX queues will have the NETIF_F_MULTI_QUEUE feature (include/linux/netdevice.h)
- MQ nic drivers will call `alloc_etherdev_mq()` or `alloc_netdev_mq()` instead of `alloc_etherdev()` or `alloc_netdev()`.
Links and more info

1) Linux Network Stack Walkthrough (2.4.20):
   http://gicl.cs.drexel.edu/people/sevy/network/Linux_network_stack_walkthrough.html

2) Understanding the Linux Kernel, Second Edition
   By Daniel P. Bovet, Marco Cesati
   Second Edition December 2002
   chapter 18: networking.
   - Understanding Linux Network Internals, Christian benvenuti
Links and more info

3) Linux Device Driver, by Jonathan Corbet, Alessandro Rubini, Greg Kroah-Hartman

   - Chapter 17, Network Drivers

4) Linux networking: (a lot of docs about specific networking topics)
   - http://linux-net.osdl.org/index.php/Main_Page

5) netdev mailing list: http://www.spinics.net/lists/netdev/
Links and more info

6) Removal of multipath routing cache from kernel code:

   http://lists.openwall.net/netdev/2007/03/12/76
   http://lwn.net/Articles/241465/

7) Linux Advanced Routing & Traffic Control :

   http://lartc.org/

8) ebtables – a filtering tool for a bridging:

   http://ebtables.sourceforge.net/
9) Writing Network Device Driver for Linux: (article)

10) Netconf – a yearly networking conference; first was in 2004.

- Next one: Linux Conf Australia, January 2008, Melbourne
- David S. Miller, James Morris, Rusty Russell, Jamal Hadi Salim, Stephen Hemminger, Harald Welte, Hideaki YOSHIFUJI, Herbert Xu, Thomas Graf, Robert Olsson, Arnaldo Carvalho de Melo and others
11) **Policy Routing With Linux** - Online Book Edition
   - by Matthew G. Marsh (Sams).

12) THRASH - A dynamic LC-trie and hash data structure:
    Robert Olsson Stefan Nilsson, August 2006

13) IPSec howto:
    [http://www.ipsec-howto.org/t1.html](http://www.ipsec-howto.org/t1.html)
14) Openswan: Building and Integrating Virtual Private Networks, by Paul Wouters, Ken Bantoft


publisher: Packt Publishing.