Offloading Network Traffic Classification

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Maxime Chevallier

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  - Linux kernel and driver development, system integration, boot time optimization, consulting...
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  - https://bootlin.com

- Contributions:
  - Worked on network (MAC, PHY, switch) engines.
  - Contributed to the Marvell EBU SoCs upstream support.
  - Also worked on SPI and real-time topics.
Discover the classification operations in the kernel.

Discover the hardware technologies used to offload packet classification

Learn about the use cases for classification

Based on PPv2’s behaviour and design, similar on other NICs
Introduction to Ingress Classification

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Packet path from the hardware to userspace

1. A frame arrives to the **PHY**
2. It is transferred to the **MAC**
3. The MAC performs offloaded operations
4. The packet is copied to **RAM** via **DMA**
5. The **MAC** raises an interrupt
MAC

- Upon receiving a frame, the packet goes through a **Packet Processor**
- The **MAC** receives the frames and places them into a buffer using DMA
- Descriptors for that buffer are placed into a **receive queue**
- Once the frame is received, the **MAC** raises an **interrupt**
- Receive queues can have dedicated interrupts, pinned to CPUs
Kernel path

- The interrupt is handled, mostly in softirq context
- napi is used to coalesce interrupts
- Packet processing is done on the CPU that handled the interrupt
- Before going up the network stack, the packet goes through the TC subsystem
- L2 handling, to deal with MAC filtering and VLANs
- L3 handling, to deal with routing
- L4 handling, where we find the socket that will consume the payload
Classification

- Classification consists in **identifying packets of interest**
- We can then perform **actions** on these packets
- We first need to **dissect** the packet
- Determining the various attributes of interest isn’t straightforward
- All fields don’t have a fixed offset in the packet

<table>
<thead>
<tr>
<th>VLAN, IPv4, TCP</th>
<th>IPv4, TCP</th>
<th>VLAN, IPv6, TCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>src</td>
<td>dst</td>
<td>ethtype</td>
</tr>
<tr>
<td>VLAN</td>
<td>EthType</td>
<td>ver TOS len id</td>
</tr>
<tr>
<td>IP SA</td>
<td>IP DA</td>
<td>Proto checksum</td>
</tr>
<tr>
<td>SRC port</td>
<td>DST port</td>
<td>len, chksum, etc.</td>
</tr>
<tr>
<td>len, chksum, etc.</td>
<td>Payload</td>
<td></td>
</tr>
</tbody>
</table>

- Kernel, drivers and embedded Linux - Development, consulting, training and support - [https://bootlin.com](https://bootlin.com)
A **flow** characterises a group of packets that have a common source and destination.

- We group packets based on common attributes, such as:
  - The source and destination IP addresses (2-tuple)
  - The L4 protocol, source and destination ports (5-tuple)

- We manipulate flows to avoid reordering and optimize locality
- We need to extract the required information from the headers.
TC flower

- Traffic Control
- Used for traffic shaping, scheduling, policing and filtering
- In our case, we’ll focus on the tc flower ingress filter
- tc flower is a classifier, which uses either software or hardware
- tc qdisc add dev eth0 ingress
- tc filter add dev eth0 protocol ip parent ffff: flower ip_proto tcp dst_port 80 action drop
ethtool

- **ethtool** is used to interact with network drivers
- **ethtool -N** can be used to configure **n-tuple** filters
- It acts on specific **flow types**: tcp4, udp6, ether, etc.
- Rules are **ordered**, the first one that matches takes precedence
- **ethtool -N eth0 flow-type tcp4 dst-port 80 action -1 loc 0**
- Actions can be:
  - Steer to a Receive Queue
  - Steer to a RSS context
  - Drop
Offloading Classification

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When and why

- Reduce **CPU** load
- Spread traffic across **CPUs** with per-cpu interrupts
- Early drop in case of Denial-of-Service attack
- Early redirection with switches

We must however be careful:

- The kernel might not see important packets
- The kernel might want to have access to the first packet of new flows
- Counters are not up to date anymore
Hardware design

- Need to extract the required fields from the headers at wire speed
- These fields aren't always at a known position
- We need fast ways to lookup these fields, using a parser
- The attributes extracted by the parser are then used for classification
Ternary Content Addressable Memory

- Very fast lookups, but takes place on the die
- Addressed by value, returns the index of the first match
- Match on a ternary value: 0, 1 and X
- The matched pattern is extracted from the header starting from an offset
- The returned index is used to lookup a SRAM containing match actions

```
0100110101001010
0110XXXX0100XXXX
XXXXXXXXXXXX1110
0100XXXXXXXX1010
1100XXXXXXXXXXXX
```

Next offs = 4; VLAN tag present
Next offs = 4; IPv4
Next offs = 12; IPv6
Next offs = 16; TCP
Parser

- Acts as a **dissector**
- Extract useful information from the packet header
- Take into account the various offsets due to DSA, VLAN and L3/L4
- Used as a pre-step for classification
- Often hardcoded in a firmware or a driver
- Multiple iterations per packet, flags are accumulated
 Classifier

- Uses information from the **parser**
- Can use several engines to classify and perform actions:
  - TCAM engines, for exact matches
  - Hash-based engines, for rate limiting and **RSS**
  - Logic engines for complex rules
- A final policing step decides what to do based on results from engines
- Not all these possibilities can be expressed by the generic frameworks
Receive Side Scaling

- Spread traffic across multiple CPUs
- Compute a hash from specific fields from the header
  - $s$: Source IP, $d$: Destination IP
  - $f$: Source port, $n$: Destination port
  - $v$: VLAN tag, $m$: Destination MAC
- Make sure that traffic from the same flows ends up on the same CPU
- Spreading is configured using an **RSS Table**

```
ethtool -N eth2 rx-flow-hash tcp4 sdfn
nethtool -X eth0 weight 2 1 1 0
```
PPv2 example

- PPv2 is found on Marvell SoCs, such as the Armada 70xx and 80xx
- Has a TCAM parser with 256 entries, performing up to 16 matches on 11B
- Classifier has one 512 instruction table, subdivided in subflows
- Has 4 classification engines:
  - C2: TCAM match engine, 8B keys, 256 entries
  - C3: Exact match engine, 12B keys, 4K entries
  - C4: Classification and Marking engine, uses if-then-else constructs
  - C3Hx: Computes hashes, for RSS and C3 lookups.
- Can perform drop (in parser or classifier), steer to queue or RSS, limit traffic, modify and redirect packets.
- Parser and Classifier is shared between multiple ports
PPv2: Current support

- Support for basic RSS
- Support steering on 2-tuple, 5-tuple and VLAN tag
- MAC and VLAN filtering, performed by the parser
- Support steering to RSS tables
- All Parser and Classifier configuration is done by the kernel, no firmware involved
- Only C2 and C3Hx engines are used, others are way too complex
Conclusion

- Offloading classification requires a lot of hardware configuration
- Most of the time, we need to limit ourselves to a subset of what the HW can do
- There are ongoing efforts to solve the issue of stats reporting
- Performance and power consumption improvements make it worth it
- In most cases, a firmware is in charge of configuring most of the tables
Thank you!
Questions? Comments?

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