The adventures of a Suricate in eBPF land

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Stamus Networks

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What is Suricata

- IDS and IPS engine
- Get it here: `http://www.suricata-ids.org`
- Open Source (GPLv2)
- Initially publicly funded now funded by consortium members
- Run by Open Information Security Foundation (OISF)
- More information about OISF at `http://www.openinfosecfoundation.org/`

Suricata Features

- High performance, scalable through multi threading
- Advanced Protocol handling
  - Protocol recognition
  - Protocol analysis: field extraction, filtering keywords
  - Transaction logging in extensible JSON format
- File identification, extraction, on the fly MD5 calculation
  - HTTP
  - SMTP
- TLS handshake analysis, detect/prevent things like Diginotar
- Lua scripting for detection
- Hardware acceleration support:
  - Endace
  - Napatech,
  - CUDA
  - PF_RING

A typical signature example

Signature example: Chat facebook

```
alert http $HOME_NET any -> $EXTERNAL_NET any \
(
 msg:"ET CHAT Facebook Chat about netdev"; \
 flow:established,to_server; content:"POST"; http_method; \
 content:"/ajax/chat/send.php"; http_uri; content:"facebook.com"; http_host; \
 content:"netdev"; http_client_body;
 reference:url,www.emergingthreats.net/cgi-bin/cvsweb.cgi/sigs/POLICY/POLICY_Facebook_Chat; \
 sid:2010784; rev:4; \
)
```

This signature tests:

- The HTTP method: *POST*
- The page: */ajax/chat/send.php*
- The domain: *facebook.com*
- The body content: *netdev*

No passthrough

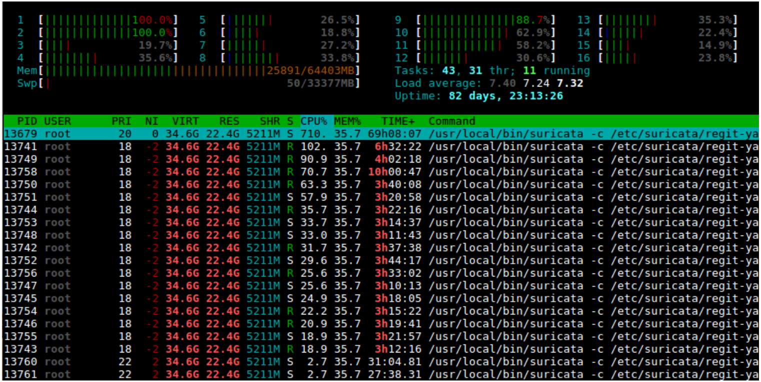
All signatures are inspected

- Different from a firewall
- More than 15000 signatures in standard rulesets

Optimization on detection engine

- Tree pre filtering approach to limit the set of signatures to test
- Multi pattern matching on some buffers

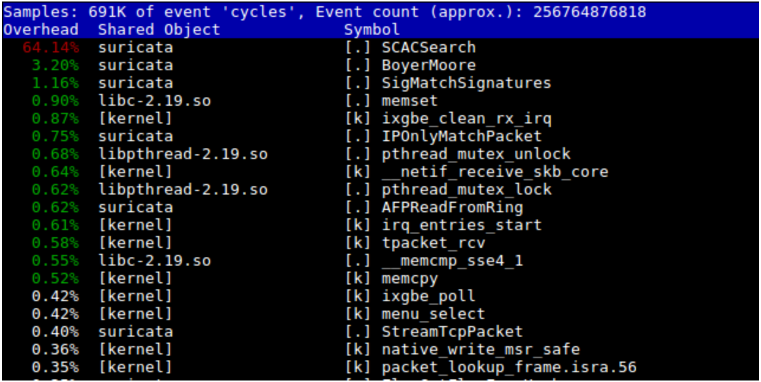
CPU intensive



```
  1  [|||||||||||||100.0%]   5  [|||||||         26.5%]     9  [||||||||||||||88.7%]   13 [||||||||         35.3%]
  2  [|||||||||||||100.0%]   6  [|||||           18.8%]     10 [|||||||||||| 62.9%]    14 [||||||           22.4%]
  3  [||||          19.7%]   7  [||||||          27.2%]     11 [|||||||||||  58.2%]    15 [||||             14.9%]
  4  [||||||||      35.6%]   8  [||||||||        33.8%]     12 [|||||||      30.6%]    16 [|||||            23.8%]
  Mem[||||||||||||||||||||||||||||||||25891/64403MB]        Tasks: 43, 31 thr; 11 running
  Swp[|                                  50/33377MB]        Load average: 7.40 7.24 7.32
                                                            Uptime: 82 days, 23:13:26

  PID USER      PRI  NI  VIRT   RES   SHR S CPU% MEM%   TIME+  Command
13679 root       20   0 34.6G 22.4G 5211M S 710. 35.7 69h08:07 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13741 root       18  -2 34.6G 22.4G 5211M R 102. 35.7  6h32:22 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13749 root       18  -2 34.6G 22.4G 5211M R 90.9 35.7  4h02:18 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13758 root       18  -2 34.6G 22.4G 5211M R 70.7 35.7 10h00:47 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13750 root       18  -2 34.6G 22.4G 5211M R 63.3 35.7  3h40:08 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13751 root       18  -2 34.6G 22.4G 5211M S 57.9 35.7  3h20:58 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13744 root       18  -2 34.6G 22.4G 5211M R 35.7 35.7  3h22:16 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13753 root       18  -2 34.6G 22.4G 5211M S 33.7 35.7  3h14:37 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13748 root       18  -2 34.6G 22.4G 5211M S 33.0 35.7  3h11:43 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13742 root       18  -2 34.6G 22.4G 5211M R 31.7 35.7  3h37:38 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13752 root       18  -2 34.6G 22.4G 5211M S 29.6 35.7  3h44:17 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13756 root       18  -2 34.6G 22.4G 5211M R 25.6 35.7  3h33:02 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13747 root       18  -2 34.6G 22.4G 5211M S 25.6 35.7  3h10:13 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13745 root       18  -2 34.6G 22.4G 5211M S 24.9 35.7  3h18:05 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13754 root       18  -2 34.6G 22.4G 5211M R 22.2 35.7  3h15:22 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13746 root       18  -2 34.6G 22.4G 5211M R 20.9 35.7  3h19:41 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13755 root       18  -2 34.6G 22.4G 5211M S 18.9 35.7  3h21:57 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13743 root       18  -2 34.6G 22.4G 5211M R 18.9 35.7  3h12:16 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13760 root       22   2 34.6G 22.4G 5211M S  2.7 35.7 31:04.81 /usr/local/bin/suricata -c /etc/suricata/regit-ya
13761 root       22   2 34.6G 22.4G 5211M S  2.7 35.7 27:38.31 /usr/local/bin/suricata -c /etc/suricata/regit-ya
```

Perf top



```
Samples: 691K of event 'cycles', Event count (approx.): 256764876818
Overhead  Shared Object             Symbol
  64.14%  suricata                  [.] SCACSearch
   3.20%  suricata                  [.] BoyerMoore
   1.16%  suricata                  [.] SigMatchSignatures
   0.90%  libc-2.19.so              [.] memset
   0.87%  [kernel]                  [k] ixgbe_clean_rx_irq
   0.75%  suricata                  [.] IPOnlyMatchPacket
   0.68%  libpthread-2.19.so        [.] pthread_mutex_unlock
   0.64%  [kernel]                  [k] __netif_receive_skb_core
   0.62%  libpthread-2.19.so        [.] pthread_mutex_lock
   0.62%  suricata                  [.] AFPReadFromRing
   0.61%  [kernel]                  [k] irq_entries_start
   0.58%  [kernel]                  [k] tpacket_rcv
   0.55%  libc-2.19.so              [.] __memcmp_sse4_1
   0.52%  [kernel]                  [k] memcpy
   0.42%  [kernel]                  [k] ixgbe_poll
   0.42%  [kernel]                  [k] menu_select
   0.40%  suricata                  [.] StreamTcpPacket
   0.36%  [kernel]                  [k] native_write_msr_safe
   0.35%  [kernel]                  [k] packet_lookup_frame.isra.56
```

Scalability

- Bandwith per core is limited
  - From 150Mb/s
  - To 500Mb/s
- Scaling
  - Using RSS
  - Splitting load on workers

AF_PACKET

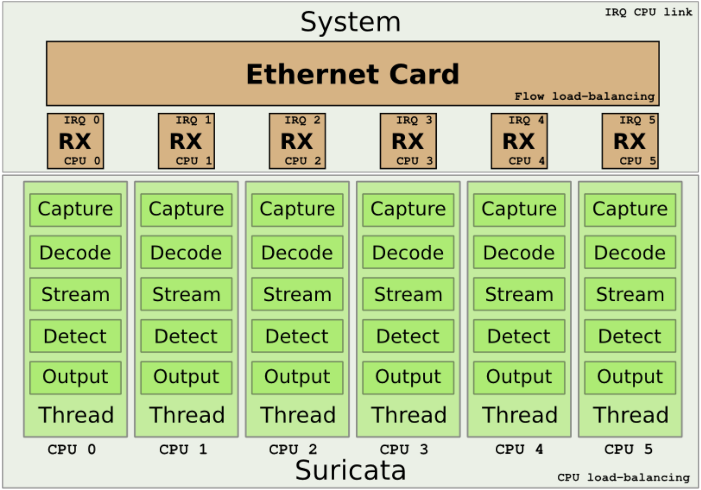
Linux raw socket

- Raw packet capture method
- Socket based or mmap based

Fanout mode

- Load balancing over multiple sockets
- Multiple load balancing functions
  - Flow based
  - CPU based
  - RSS based
  - eBPF based

Suricata workers mode



Load balancing and hash symmetry

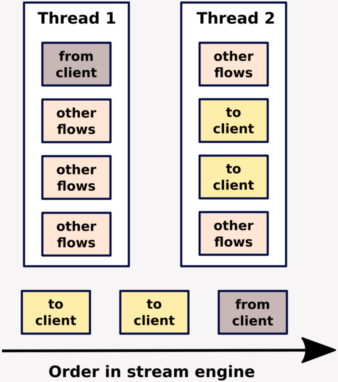
Stream reconstruction

- Using packets sniffed from network
- to reconstruct TCP stream as seen by remote application

Non symmetrical hash break

- Out of order packets

Effect of non symmetrical hash



Broken symmetry

History

- T. Herbert introduce asymmetrical hash function in flow
  - Kernel 4.2
- Users did start to complain
- And our quest did begin
- Fixed in 4.6 and pushed to stable by David S. Miller

Intel NIC RSS hash

- XL510 hash is not symmetrical
- XL710 could be symmetrical
  - Hardware is capable
  - Driver does not allow it
  - Patch proposed by Victor Julien

NETWORKS

eBPF cluster

Userspace to the rescue

- Program your own hash function in userspace
- Available since Linux 4.3
- Developed by Willem de Bruijn
- Using eBPF infrastructure by Alexei Storovoitov

eBPF cinematic

- Syscall to load the BPF code in kernel
- Setsockopt to set returned fd as cluster BPF

The big flow problem

Ring buffer overrun

- Limited sized ring buffer
- Overrun cause packets loss
- that cause streaming malfunction

Bypassing big flow

- Limiting treatment time at maximum
- Stopping it earlier as possible
  - local bypass: Suricata limit handling
  - capture bypass: interaction with lower layer

Stream depth

Attacks characteristic

- In most cases attack is done at start of TCP session
- Generation of requests prior to attack is not common
- Multiple requests are often not even possible on same TCP session

Stream reassembly depth

- Suricata reassemble TCP sessions till `stream.reassembly.depth` bytes.
- Stream is not analyzed once limit is reached

Introducing bypass

Principle

- No need to get packet from kernel after stream depth is reached
- If there is
  - no file store
  - or other operation

Usage

Set `stream.bypass` option to `yes` in Suricata config file to bypass

Selective bypass

Ignore some traffic

- Ignore intensive traffic like Netflix
- Can be done independently of stream depth
- Can be done using generic or custom signatures

The bypass keyword

- A new `bypass` signature keyword
- Trigger bypass when signature match
- Example of signature

```
alert http any any -> any any (content:"netdevconf.org"; \\
          http_host; bypass; sid:6666; rev:1;)
```

Implementation

Suricata update

- Add callback function
- Capture method register itself and provide a callback
- Suricata calls callback when it wants to offload

Coded for NFQ

- Update capture register function
- Written callback function
  - Set a mark with respect to a mask on packet
  - Mark is set on packet when issuing the verdict

And now AF_PACKET

What's needed

- Suricata to tell kernel to ignore flows
- Kernel system able to
  - Maintain a list of flow entries
  - Discard packets belonging to flows in the list
  - Update from userspace
- nftables is too late even in ingress

eBPF filter using maps

- eBPF introduce maps
- Different data structures
  - Hash, array, . . .
  - Update and fetch from userspace
- Looks good!

eBPF usage

Handling code

- Need to generate code
- Load code
- Address code from Suricata

Interact with code

- Add elements in hash table
- Query elements
- Delete elements

LLVM backend

From C file to eBPF code

- Write C code
- Use eBPF LLVM backend (since LLVM 3.7)
- Get ELF file
- Extract and load section in kernel

BCC: BPF Compiler Collection

A complete framework

- Instrument eBPF filter
- Multi language
    - Python
    - Lua
    - C++
- Transparent handling of kernel interaction

Cinematic

- eBPF C code is a side file or integrated into code
- C code is dynamically built when script is started
- It is injected to kernel
- Post processing is done

Importing mechanism

- Syscall to load the object inside kernel
- A file descriptor is returned
- It can be used by setsockopt to define the cluster using provided fd

Suricata eBPF cluster

Initial version

- LLVM backend
- Using libelf to load object

Time saver

- Debug message from kernel eBPF code
- bpt_trace_printk() function
- `cat /sys/kernel/tracing/trace`

AF_PACKET bypass

Logic is the same

- Using eBPF filter this time
- Syscall to load eBPF
- Linking via setsockopt
- Need to use a eBPF map of type hash

Here comes the map

- Map is used by kernel and userspace
- eBPF file can't contain absolute reference
- Maps must be created by userspace
- Relocation must be done in ELF file

Game Over

Switch to libbpf

Library from tools/lib/bpf

- Provide high level function to load eBPF elf file
- Create maps for user
- Do the relocation

Sample usage

```
struct bpf_object *bpfobj = bpf_object__open(path);
bpf_object__load(bpfobj);
pfd = bpf_program__fd(bpfprog);
/* store the map in our array */
bpf_map__for_each(map, bpfobj) {
    map_array[last].fd = bpf_map__fd(map);
    map_array[last].name = strdup(bpf_map__name(map));
    last++;
}
```

Libbpf implementation

libbpf is work in progress

- Not network ready
- Missing a few filter types
- Missing functions to interact

Patchset in progress

- Cleaning of initially proposed code
- Adding missing features

Kernel code and exchange structure

```c
struct pair {
    uint64_t time;
    uint64_t packets;
    uint64_t bytes;
};

struct bpf_map_def SEC("maps") flow_table_v4 = {
    .type = BPF_MAP_TYPE_HASH,
    .key_size = sizeof(struct flowv4_keys),
    .value_size = sizeof(struct pair),
    .max_entries = 32768,
};

value = bpf_map_lookup_elem(&flow_table_v4, &tuple);
if (value) {
    __sync_fetch_and_add(&value->packets, 1);
    __sync_fetch_and_add(&value->bytes, skb->len);
    value->time = bpf_ktime_get_ns();
    return 0;
}
return -1;
```

Sharing data

- Data is updated with stats
- Getting last flow activity time allow Suricata to handle timeout

Userspace code

```c
struct flowv4_keys {
    __be32 src;
    __be32 dst;
    union {
        __be32 ports;
        __be16 port16[2];
    };
    __u32 ip_proto;
};

while (bpf_get_next_key(mapfd, &key, &next_key) == 0) {
    bpf_lookup_elem(mapfd, &key, &value);
    clock_gettime(CLOCK_MONOTONIC, &curtime);
    if (curtime->tv_sec * 1000000000 - value.time > BYPASSED_FLOW_TIMEOUT)
        flowstats->count++;
        flowstats->packets += value.packets;
        flowstats->bytes += value.bytes;
        bpf_delete_elem(fd, key);
    }
    key = next_key;
}
```

Japan and IPv6

Got to be ready

- This is KAME land: `http://www.kame.net/`

IPv6 bypass

IPv6 is the same as IPv4

- Same algorithm
- Second hash table using IPv6 tuple

Really ?

- Parsing is a bit different due to next header
- IPv6 hash table is failing to load in kernel

Let’s call a friend

> The exercise of adding the egress counterpart and IPv6 support is left to the reader
>
> Daniel Borkmann in tc_bpf.8

IPv6 bypass

Two hash tables

- A bug in libbpf
- Invalid offset computation of map definition
- Fixed by mimic tc_bpf.c code (thanks Daniel Borkmann)

IPv6 parsing

- For now, sending weird packets to userspace

Test methodology

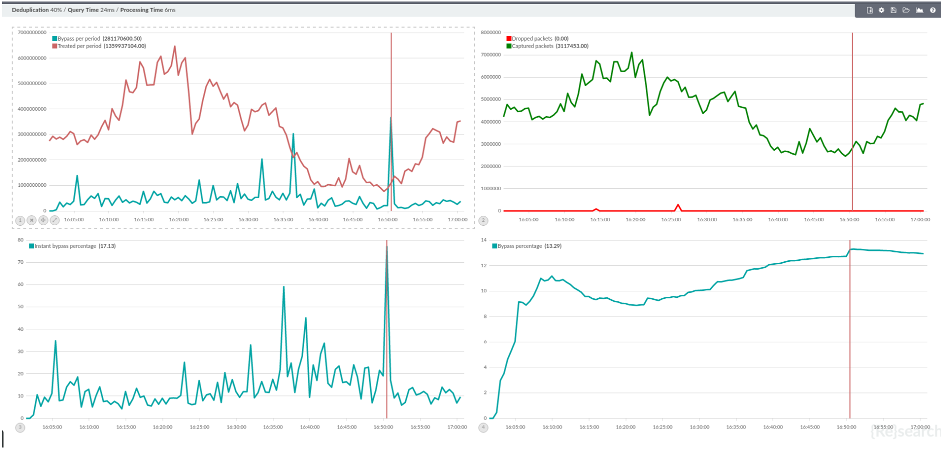
Test setup

- Intel(R) Xeon(R) CPU E5-2680 0 @ 2.70GHz
- Intel Corporation 82599ES 10-Gigabit SFI/SFP+
- Live traffic:
  - Around 1Gbps to 2Gbps
  - Real users so not reproducible

Tests

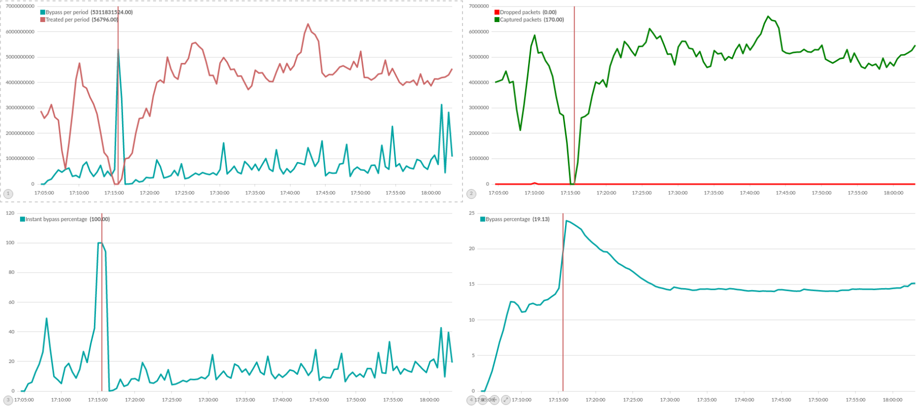
- One hour long run
- Different stream depth values
- Collected Suricata statistics counters (JSON export)
- Graphs done via Timelion (`https://www.elastic.co/blog/timelion-timeline`)

Results: bypass at 1mb



Deduplication 40% / Query Time 24ms / Processing Time 6ms

Results: bypass at 512kb



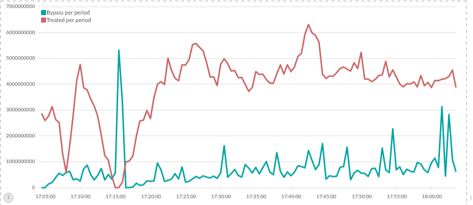
A few words on graphics

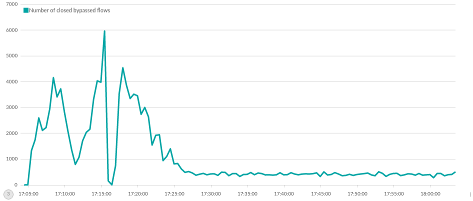
Tests at 1mb

- Mark show some really high rate bypass
- Potentialy a big high speed flow

Tests at 512kb

- We have on big flow that kill the bandwidth
- Capture get almost null
- Even number of closed bypassed flows is low





AF_PACKET bypass and your CPU is peaceful

Conclusion

Suricata and eBPF

- A fresh but interesting method
- Bypass looks promising
- More tests to come

More information

- Suricata: `http://www.suricata-ids.org/`
- Stamus Networks: `https://www.stamus-networks.com/`
- Suricata eBPF code: `https://github.com/regit/suricata/tree/ebpf-3.7`

Questions ?

Thanks to

- Alexei Storovoitov
- Daniel Borkmann
- David S. Miller

Contact me

- Mail: eleblond@stamus-networks.com
- Twitter: @regiteric

More information

- Suricata eBPF code: `https://github.com/regit/suricata/tree/ebpf-3.7`