OVS

Open vSwitch

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The Discrepancy of the MegaFlow Cache in OVS Part II.

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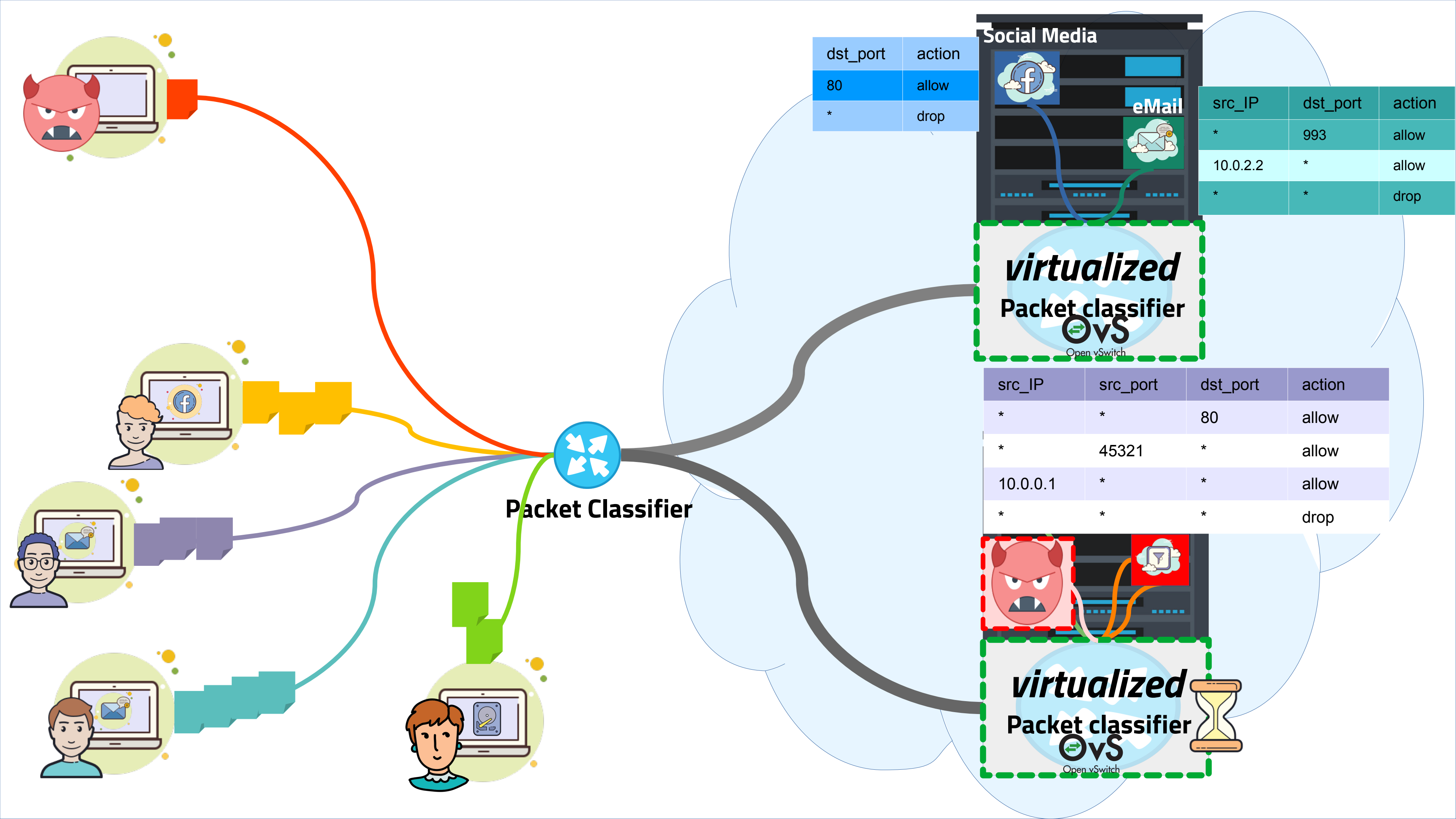
Quick Recap from Part I.

- **Algorithmic deficiency in Tuple Space Search** scheme
  - used in the MegaFlow Cache (MFC)
- Easy to achieve
  - **according to the flow table**
    - as simple as "allow some but drop others"
  - **less than 1 Mbps specially crafted packet sequence**
  - **Full Denial-of-Service** (OVS performance drops close to 0%)
- Works in (public) cloud deployments
  - **against co-located victims**
  - **No mitigation is available**
    - low rate, no specific attack signature, completely legitimate packets
  - Kubernetes/OVN, OpenStack/Neutron/OVN, Docker/OVN, etc.

src_IP	dst_port	action
*	80	allow
10.0.2.2	*	allow
*	*	drop

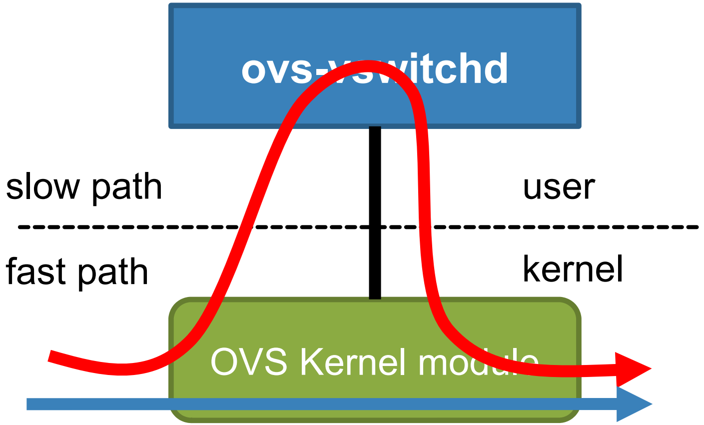

Social Media
eMail
dst_port action
80 allow
* drop
src_IP dst_port action
* 993 allow
10.0.2.2 * allow
* * drop
virtualized
Packet classifier
OvS
Open vSwitch
src_IP src_port dst_port action
* * 80 allow
* 45321 * allow
10.0.0.1 * * allow
* * * drop
Packet Classifier
virtualized
Packet classifier
OvS
Open vSwitch

Recap: Packet Processing in OVS

- Flow table
  - ordered set of **wildcard rules**
  - operating on a **set of header fields**
  - **set of packet processing primitives**
  - *flow rules can overlap! (priorities)*

Flow Table

ip_src	action
10.0.0.0/8	output:1
*	drop



- Fastening packet classification
  - *First packet*
    - *full-blown flow table processing*
  - *Subsequent packets*
    - *flow-specific rules and actions are **cached***
    - ***MegaFlow Cache – Tuple Space Search sheme***

Tuple Space Search

Flow Table

DST_PORT	action
80	output:1
*	drop

- Entries matching on the same headers are collected into a hash
  - masked packet headers can be found fast
- However, masks and associated hashes are searched sequentially
  - PKT_IN → APPLY_MASK → LookUp → Repeat until found

Can be a costly linear search in case of lots of masks!

0/ffc0

1	drop
2	drop
3	drop
4	drop
5	drop
6	drop
...	...
63	drop

64/fff0

64	drop
65	drop
66	drop
67	drop
68	drop
69	drop
...	...
79	drop

80/ffff

80	allow

81/ffff

81	drop

...

256/ff00

256	drop
257	drop
258	drop
259	drop
260	drop
261	drop
...	...
511	drop

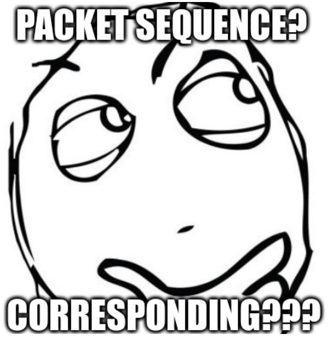
...

32768/8000

32768	drop
32769	drop
32770	drop
32771	drop
32772	drop
32773	drop
...	
65535	drop

Recap: Blow up the MegaFlow Cache

- **KEY FINDIND**: More masks -> slower packet processing
- For every `allow rule`
  - corresponding packet sequence to reach this end
- Strategy:
  - one packet for the `allow rule`
  - add a packet with each of the relevant bits inverted
    - 1 packet -> 1 MFC mask



Flow Table	
DST_PORT	action
80	output:1
*	drop

Binary representation	DST_PORT
0000 0000 0101 0000	80 (allow rule)
0000 0000 0101 000**1**	81
0000 0000 0101 00**1**0	82
0000 0000 0101 0**1**00	84
…	…
1000 0000 0101 0000	32848

Tuple Space Explosion (TSE) attack animated ;)

Flow Table	
DST_PORT	action
80	output:1
*	drop

16384/
32768/8000

Tuple Space Explosion

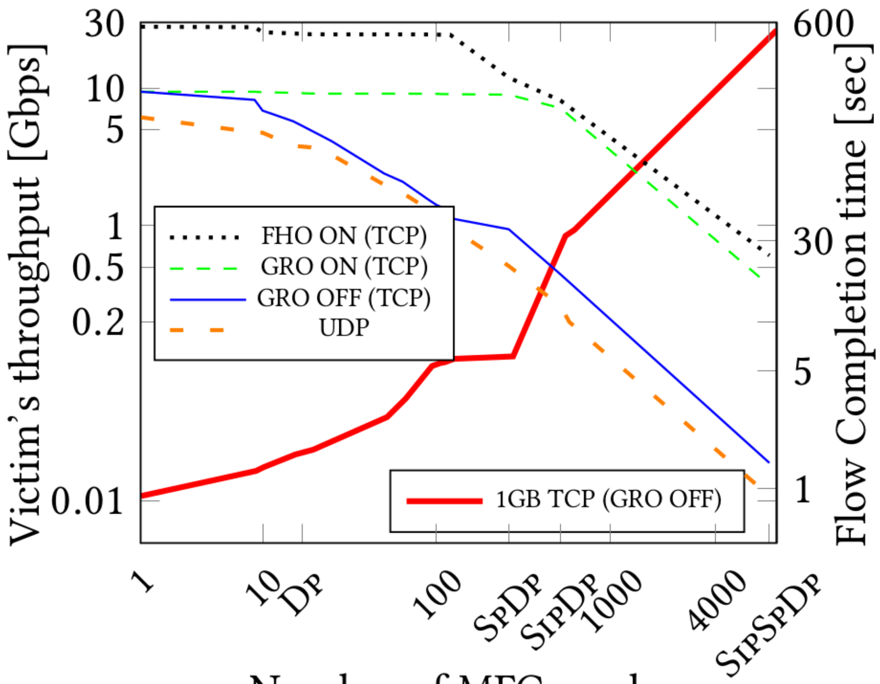
- Cache growth
  1) **16-bit** DST_PORT -> **16 masks**
  2) **32-bit** SRC_IP -> **32 masks**
- ONLY ONE allow rule on ONE HEADER FIELD

Flow Table	
DST_PORT	action
80	output:1
*	drop

- Multiple allow rules on multiple header fields -> Exponential growth
- Matching on either **1)** and **2)** -> **512 masks**

Tuple Space Explosion (TSE) - IMPACT

- FHO – Full HW Offload
  - Mellanox ConnectX-4
- GRO – Generic Recv. Offload
  - *should be* enabled by default
- UDP: no offloading :(
  - Dp (16 masks)
    - allow rule on DST_PORT only
  - SpDp (256 masks)
    - allow rules on SRC_PORT and DST_PORT
  - SipDp (512 masks)
    - allow rules in SRC_IP and DST_PORT
  - SipSpDp (8192 masks)
    - allow rules on SRC_IP, SRC_PORT and DST_PORT



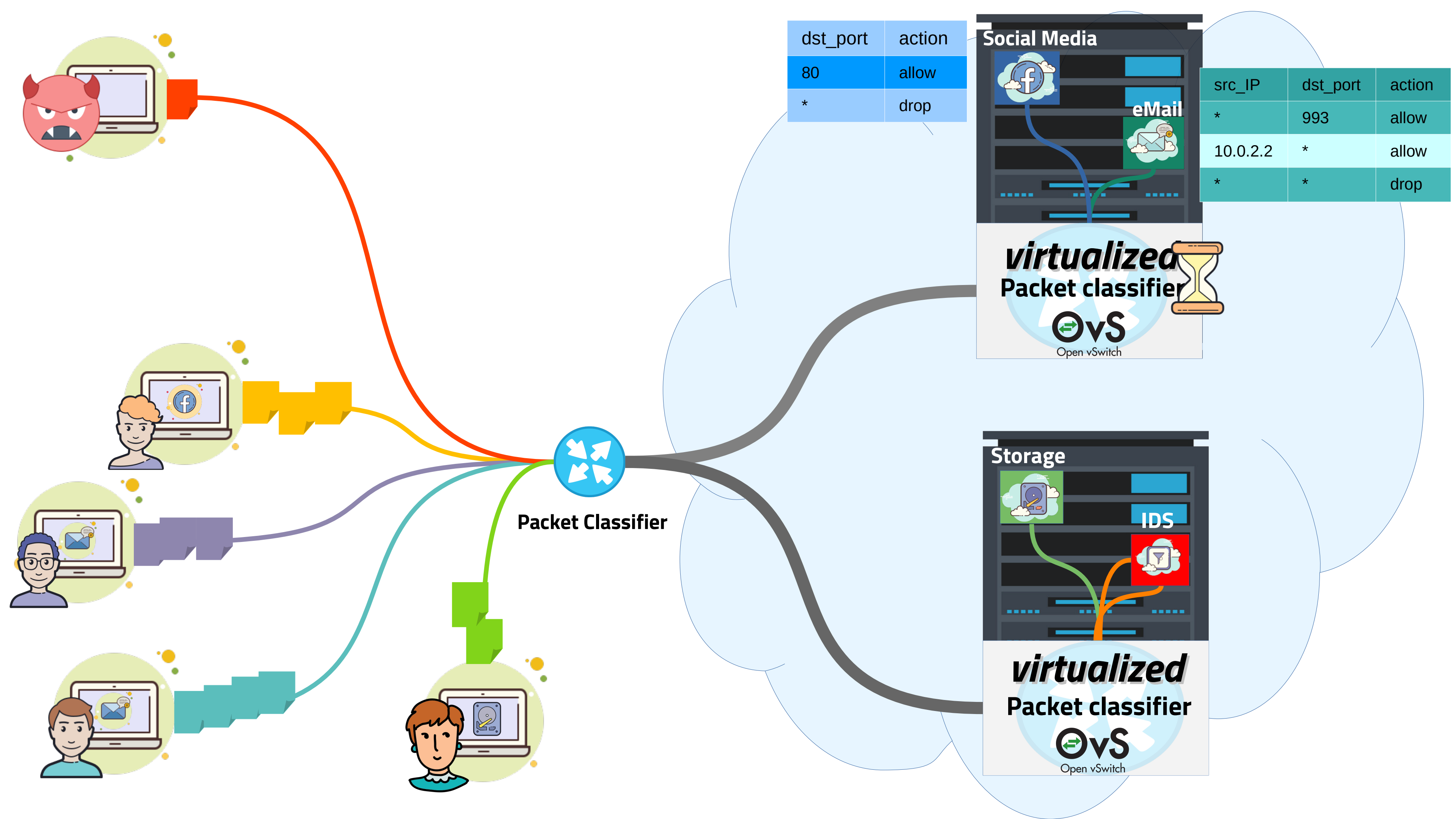
OVS 2.9.2 (stable) Ubuntu 18.04

Tuple Space Explosion – Main takeaways

- Being aware/in control of the flow table
  - **few thousand** `pps` -> **complete denial-of-service**
- 10 sec timeout in the MFC
  - makes an adversary's job easier
- Microflow cache might alleviate this, **BUT**
  - easily saturated in normal operation
  - or with high entropy in non-important headers in the attack sequence
    - e.g., TTL
  - disabled by default (OVS kernel module coming from the dist. repo)

Part II: In this talk

- We **DO NOT** present:
  - New deficiency of OVS/TSS
  - Implementation of another packet classifier
  - Improvement to the packet classifier itself
- We **DO** discuss:
  - Can the *attack* be *more generic without* the need of
    - *co-location*
    - and *flow table-awareness*
  - *Countermeasures*


dst_port
action
80
allow
*
drop
Social Media
eMail
src_IP
dst_port
action
*
993
allow
10.0.2.2
*
allow
*
*
drop
virtualized
Packet classifier
OvS
Open vSwitch
Packet Classifier
Storage
IDS
virtualized
Packet classifier
OvS
Open vSwitch

Generic Tuple Space Explosion (TSE) Attack

- Challenge:
  - Blow up the MFC w/o knowing/in control of the flow table
- Possible?
  - How much effort does it need?
  - How successful can it be?
- Countermeasure?

How to generate the packets?

- *Being unaware of the flow table* -> **Difficult!**
  - All possible packets *could* work
    - 2^k packets for a header of *k* bits
    - too much effort!
    - easily detectable e.g., portscan, volumetric (2.9 pbps in case of SipDp)

?? / ????

- Can't we just use **random packets** instead?

Generic TSE Attack: Expectations

- What are the chances that a random packet spawns an MFC mask [1] ?

dport=32769

32768/8000

32768	drop
32769	drop
32770	drop
32771	drop
32772	drop
32773	drop
...	
65535	drop

Flow Table

DST_PORT	action
80	output:1
*	drop

- Key: number of wildcarded bits (*k*) for header length *h*

$$p_k(MFC) = \frac{2^k}{2^h}$$

- `1*** **** **** **** (32768) ~ 50%`
- `0000 0000 01** **** (64)    ~ 0.1%`

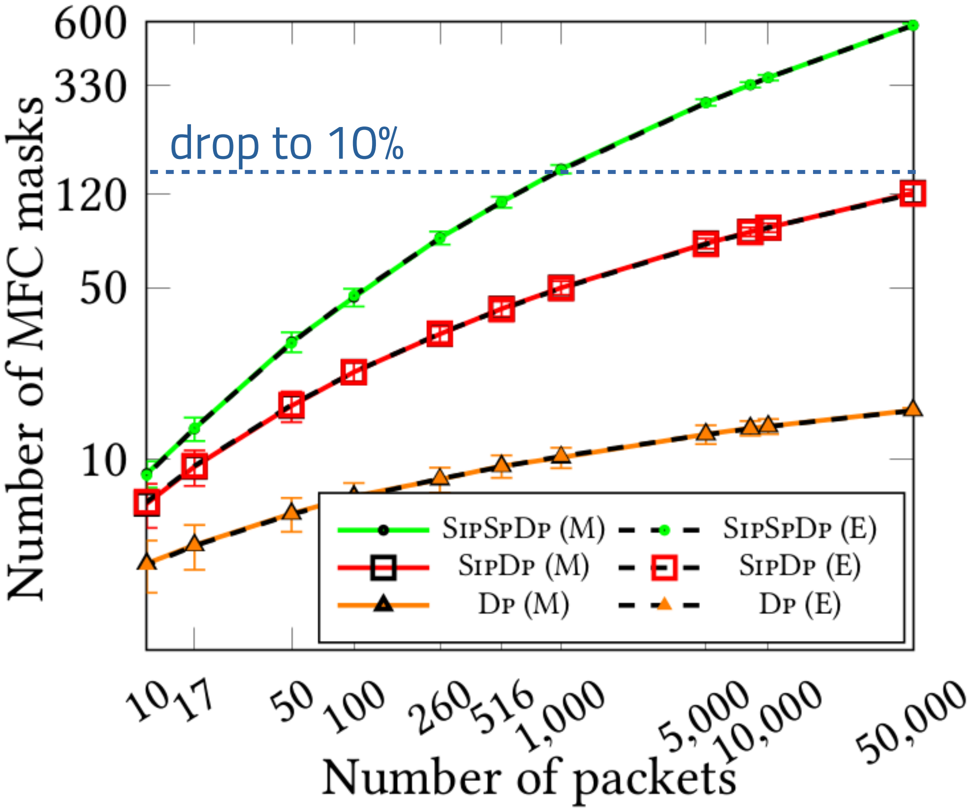
64/fff0

64	drop
65	drop
66	drop
67	drop
68	drop
69	drop
...	...
79	drop

[1] L. Csikor *et al.*, "*Tuple Space Explosion: A Denial-of-Service Attack Against a Software Packet Classifier*", ACM CoNEXT'19, Dec, 2019.

Generic TSE Attack: Results

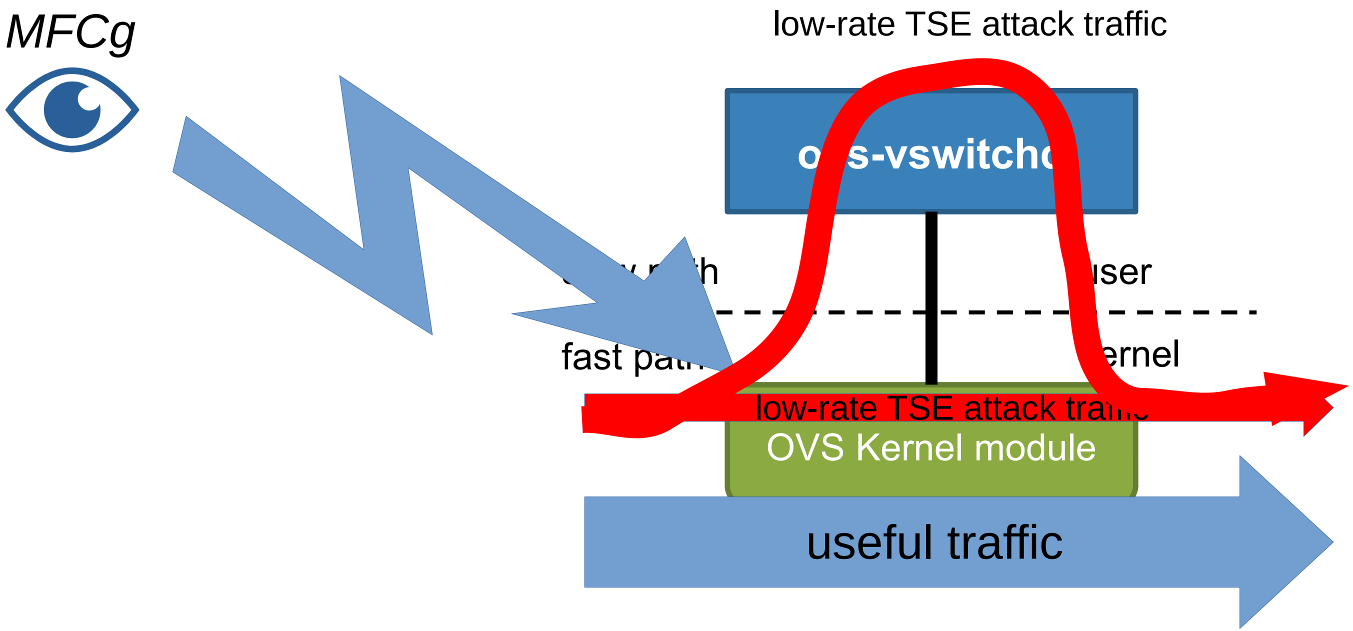
- **(M)**easured and **(E)**xpected numbers for the different ACLs installed by a victim
  - Dp: `DST_PORT` only
  - SpDp: `SRC_PORT + DST_PORT`
  - SipDpSp: `SRC_IP + DST_PORT + SRC_PORT`
- **672 kbps (!)** attack traffic
  - **90% performance drop**
  - 1000 pps: 10Gbps -> 1 Gbps



Countermeasures

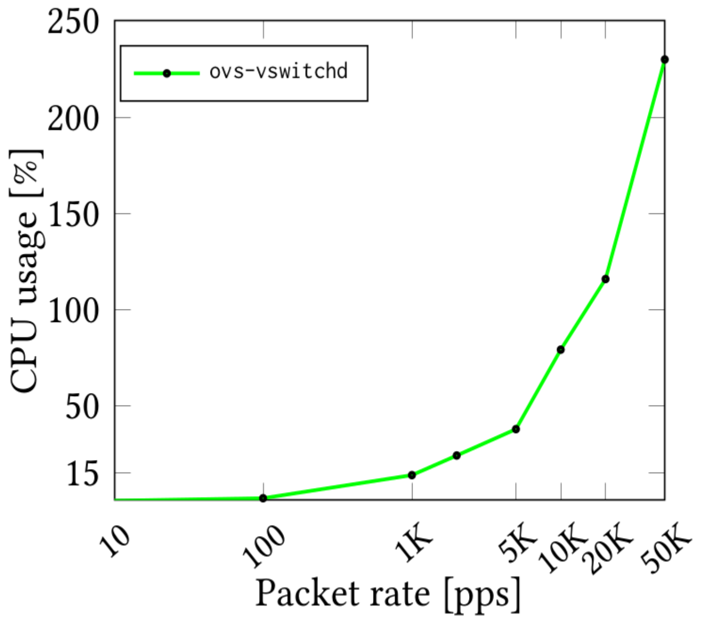
- **Detections hard**
  - legitimate traffic
  - no attack signature (full random packets)
  - low attack rate
- `MFCGuard (MFCg)`
  - Monitors the MFC
    - #masks > threshold
      - looks for TSE pattern
    - wipe out corresponding entries from the cache
  - **Attack traffic** goes to the **slow path** again
    - **benign traffic** remains (fast) **in the fast path**

MFCg


MFCg
low-rate TSE attack traffic
user
fast path
low-rate TSE attack traffic
OVS Kernel module
useful traffic

MFCg

- Cleaned MFC -> normal throughput
- Neither documented nor expected behaviour
  - Attack traffic should be cached again
    - but they never will be
- Constant overhead on the slow path
  - ***1 kpps* attack traffic = 15% overhead**
  - ***10 kpps* attack traffic = 80% overhead**



MFCg

- GRO OFF
- Attack:
  - SipDp
  - 100 pps

MFCg (Future Work)

- **More sophisticated algorithm is needed**
  - *Wipe out only some select flows*
  - Maintain good balance between the fast path and slow path
- **Dynamically set a per-flow timeout in the MFC**
  - avoid uniform 10 sec timout
  - more hits for a mask -> longer timeout
- **Prioritize**
  - Hashes with no masked bits (derived from flow table)
    - e.g., 80/ffff, 10.0.0.1/ffffffff

Conclusion

- **Tuple Space Search** algorithm has an **algorithmic-complexity vulnerability**
- Can be exploited by an adversary (easily)
- **Tuple Space Explosion attack**
  - against the infrastructure **via co-location**
    - **full-blown denial-of-service**
  - against an **arbitrary target**
    - **substantial degradation-of-service**
- *MFCguard*
  - *keep the fast path clean for the benign traffic*

Contact

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