Testing the reassembly consistency of IDS and OS in the presence of overlapping data

SuperviZ workshop

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Plan

Plan

Context

Chunking mechanism in some Internet protocols

Generic networking problem

Application wants to send a lot of data and medium/underlying protocol is limited.

Solution

Chunk it

- Ethernet/IPv4||IPv6: fragmentation
- Ethernet/IP/TCP: segmentation

Context

Chunking mechanism in some Internet protocols: examples

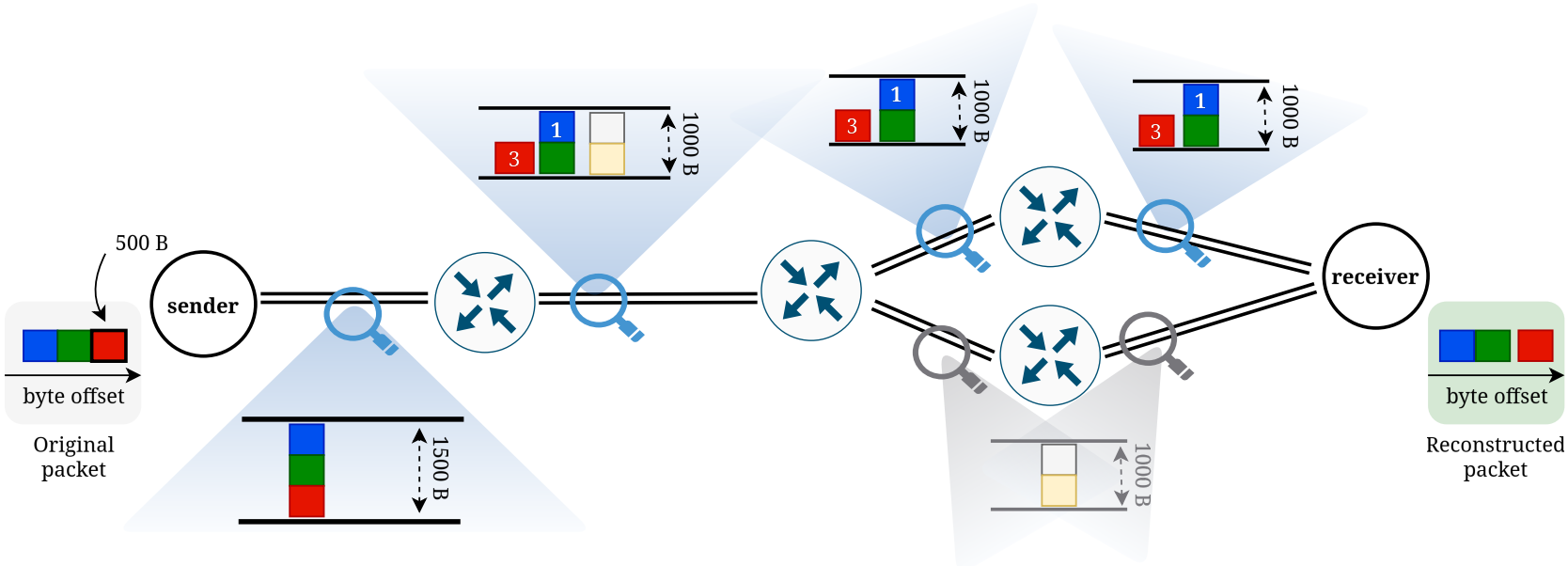


Figure 1: Normal chunk transmission

Context

Chunking mechanism in some Internet protocols: examples

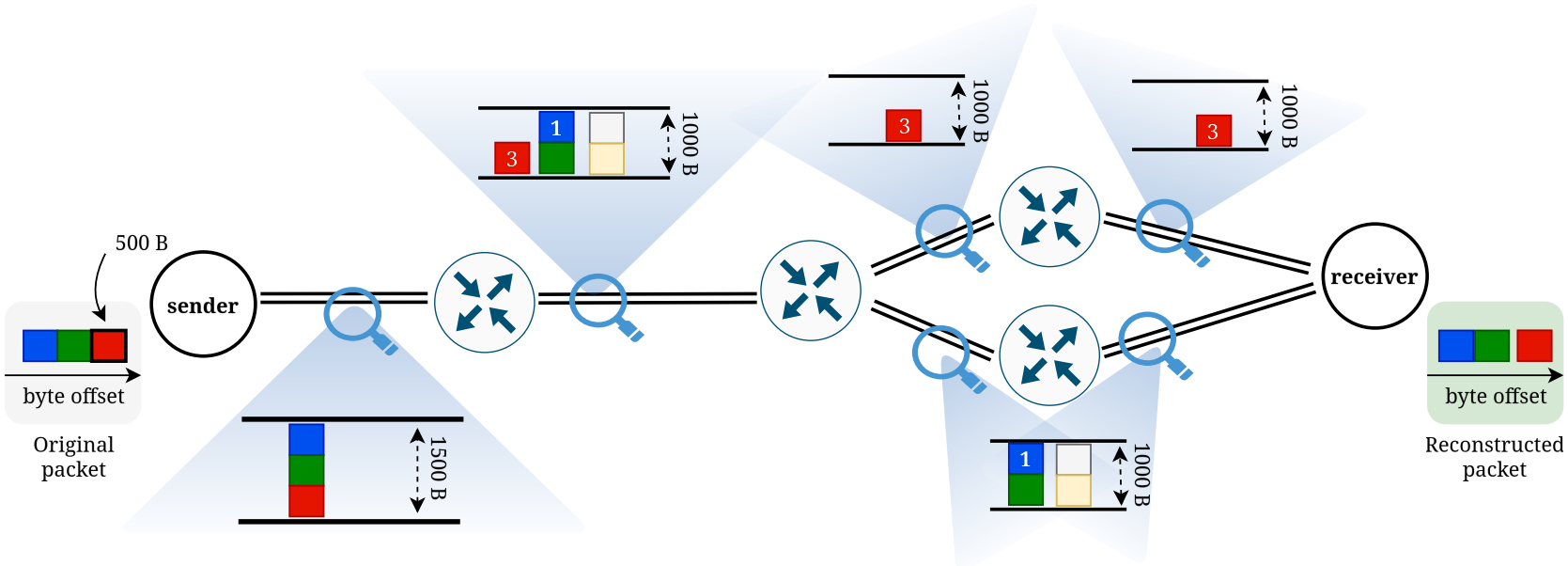


Figure 2: Chunk reordering

Context

Chunking mechanism in some Internet protocols: examples

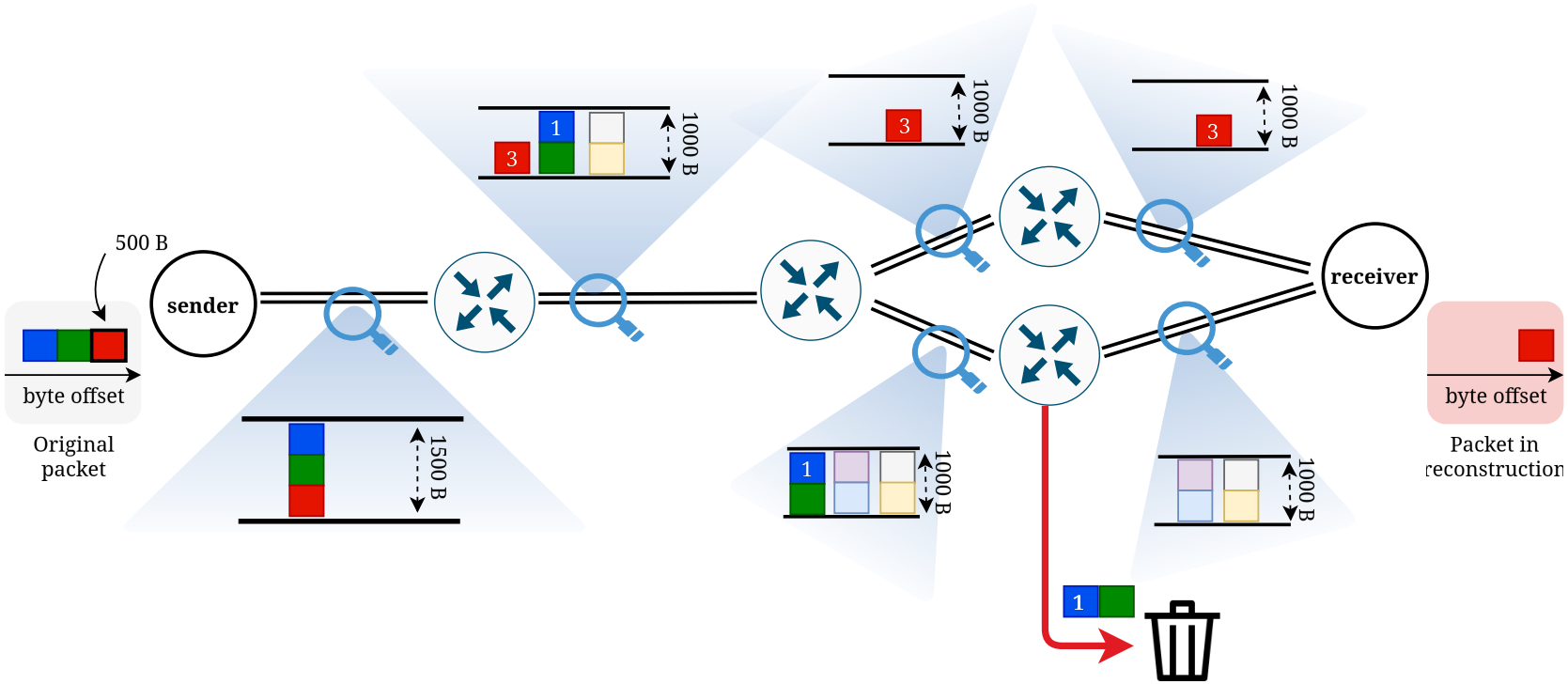


Figure 3: Chunk loss

Context

Chunking mechanism in some Internet protocols: examples

Reassembly policies may change depending on OSes for IPv4[1], IPv6[2], TCP[3] protocols and depending on QUIC implementations[4]

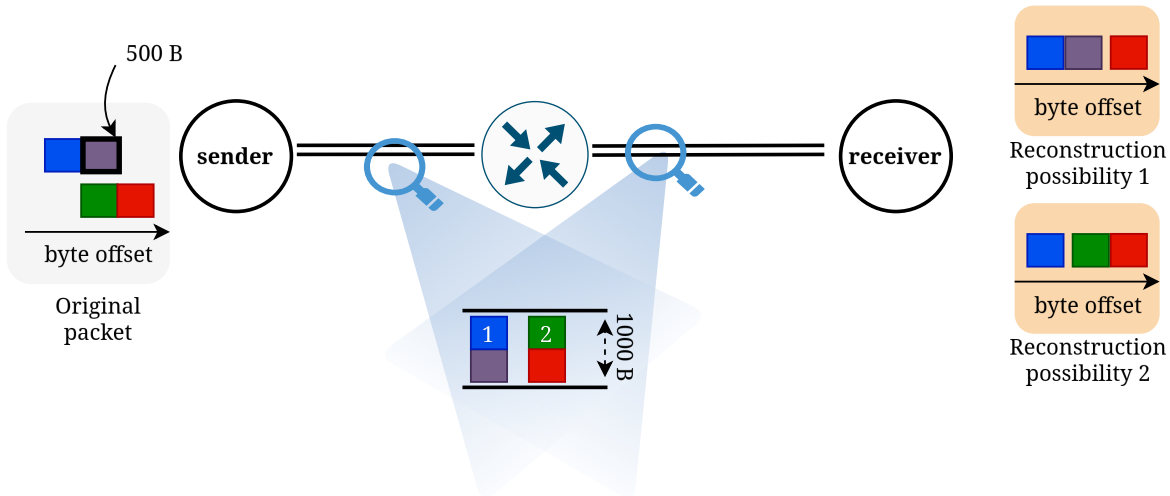


Figure 4: Chunk overlap

[1] J. Novak. *Target-based fragmentation reassembly*. 2005, U. Shankar **and** V. Paxson. *Active mapping: Resisting NIDS evasion withouts altering traffic*. 2003.

[2] A. Atlasis. *Attacking ipv6 implementation using fragmentation*. 2012.

[3] J. Novak **and** S. Sturges. *Target-based tcp stream reassembly*. 2007, U. Shankar **and** V. Paxson. *Active mapping: Resisting NIDS evasion withouts altering traffic*. 2003.

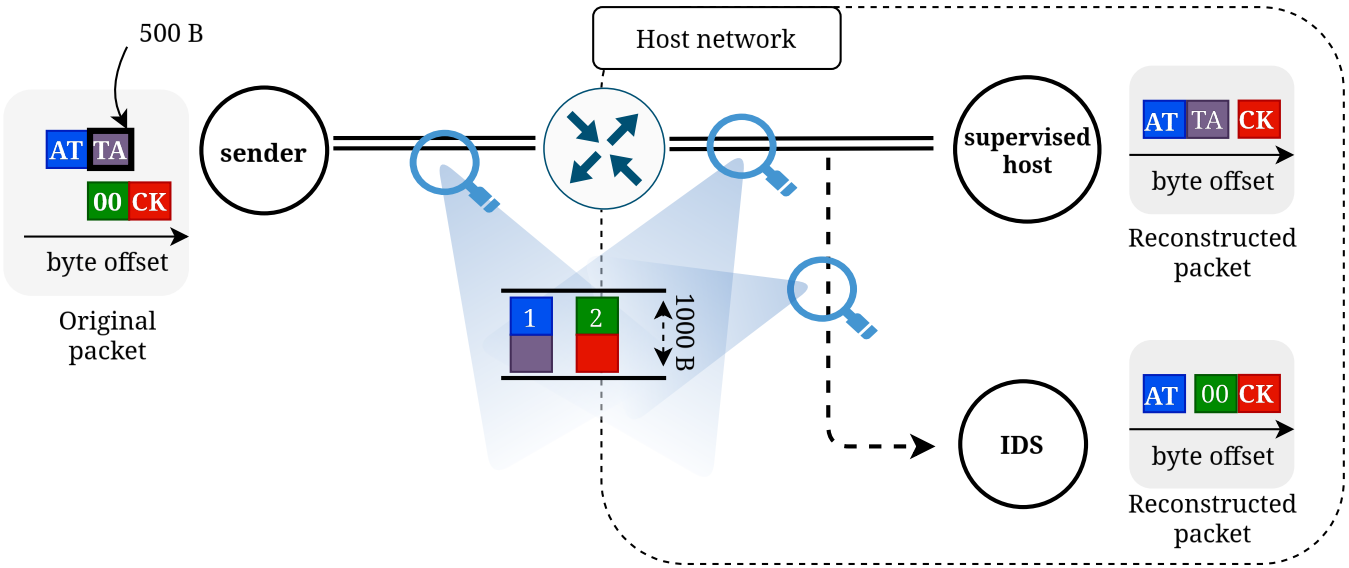
[4] G-S. Reen **and** C. Rossow. *DPIFuzz: a differential fuzzing framework to detect DPI elusion strategies for QUIC*. 2020.

Context

Attacks targetting IDSes using chunking mechanism

Problem

- Attacks targeting IDSes and exploiting data overlap exist[5]



Existing countermeasure

- manually configure an IDS to associate an IP address with a reassembly policy

[5] T. Ptacek **and** T. Newsham. *Insertion, evasion, and denial of service: Eluding network intrusion detection*. 1998.

Context

Considered attack types

Attack type	Host	Target	Reassembled data	Attack scenario
Evasion	IDS		-	E1
	Supervised host	✗	"ATTACK"	
	IDS		"AT00CK"	E2
	Supervised host	✗	"ATTACK"	
Insertion	IDS	✗	"ATTACK"	I1
	Supervised host		-	
	IDS	✗	"ATTACK"	I2
	Supervised host		"AT00CK"	

Table 1: Attack type illustration. - means the implementation *ignores* the flow chunk data.

Related work limits

- Manual or semi-automatic (fuzzing, symbolic execution) methods are used to generate overlap test cases

  RQ1. *Are these methods exhaustive? If not, can we do better?*

- It's been 10 years no work have specifically addressed OSes' IPv4 and TCP policy reassemblies

  RQ2. *Have the reassembly policies of recent OSes changed?*

- Some IDSes allow one to configure the host reassembly policy

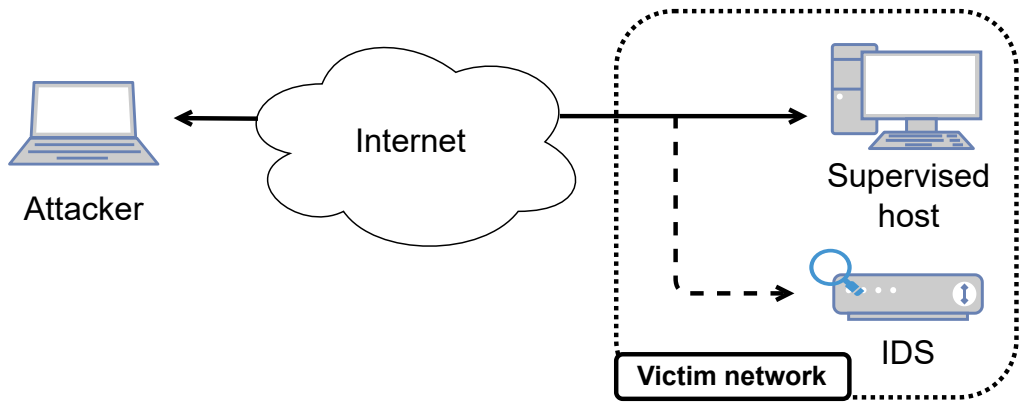
  RQ3. *Do such IDSes reassemble consistently with OSes?*

Plan

Threat model

Attacker needs to:

- identify victim host OS and IDS reassembly policies.
- craft IP header fields and payload (IP fragment-based attack).
- craft TCP header fields and payload (TCP segment-based attack).



Plan

Test case modeling

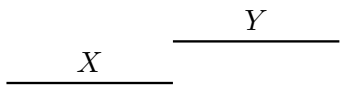
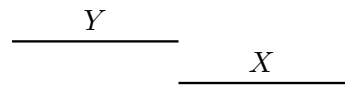
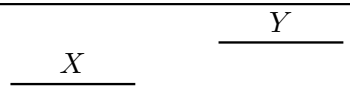
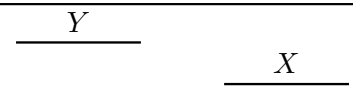
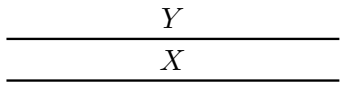
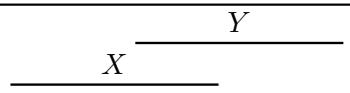
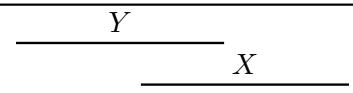
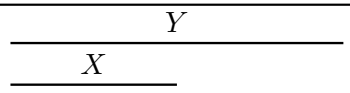
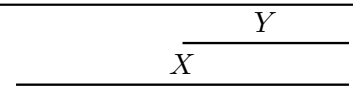
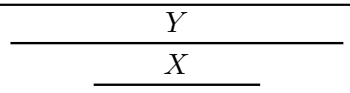
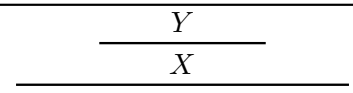
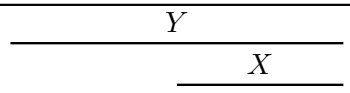
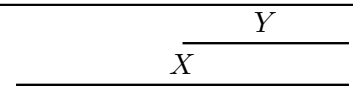
Relation *R*	Interpretation	Relation *R* inverse	
X ***M*** Y 	meets	 X ***Mi*** Y	non-overlapping relations
X ***B*** Y 	before	 X ***Bi*** Y	
X ***Eq*** Y 	equal	-	overlapping relations
X ***O*** Y 	overlap	 X ***Oi*** Y	
X ***S*** Y 	start	 X ***Si*** Y	
X ***D*** Y 	during	 X ***Di*** Y	
X ***F*** Y 	finish	 X ***Fi*** Y	

Table 2: Allen's interval algebra relations.

Test case modeling and related works

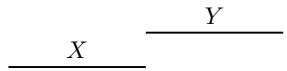
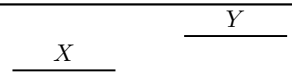
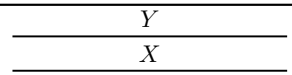
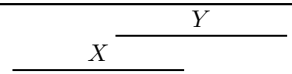
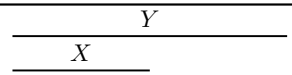
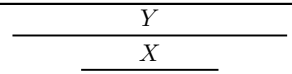
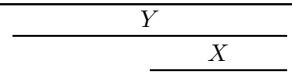
Relation *R*	Illustration
X ***M***eets Y	
X ***B***efore Y	
X ***Eq***ual Y	
X ***O***verlaps Y	
X ***S***tarts Y	
X ***D***uring Y	
X ***F***inishes Y	

Table 3: Allen's interval algebra relations.

→

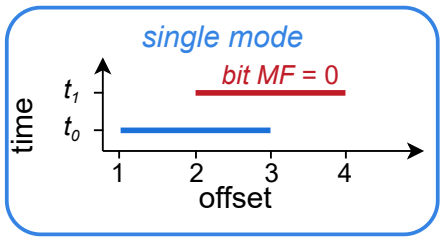
Work	Year	Protocol	Tested Allen relations	Exhaustivity
Ptaceck et al. [5]	1998	IPv4 /TCP	*Fi*, *D*	
Shankar et al. [7]	2003	IPv4	*O*, *Oi*, *Eq*	
		TCP	*O*, *D*	
Novak [3]	2005	IPv4	*O*, *Oi*, *S*, *Si*, *F*, *Fi*, *D*, *Di*, *Eq*	✓
Novak et al. [4]	2007	TCP	*O*, *Oi*, *S*, *Si*, *F*, *Fi*, *D*, *Di*, *Eq*	✓
Atlasis [1]	2012	IPv6	*O*, *Oi*, *S*, *Si*, *F*, *Fi*, *D*, *Di*, *Eq*	✓
Di Paolo et al. [2]	2023	IPv6	*O*, *Oi*, *Eq*	
Us	-	IPv4/IPv6/ TCP	*O*, *Oi*, *S*, *Si*, *F*, *Fi*, *D*, *Di*, *Eq*	✓

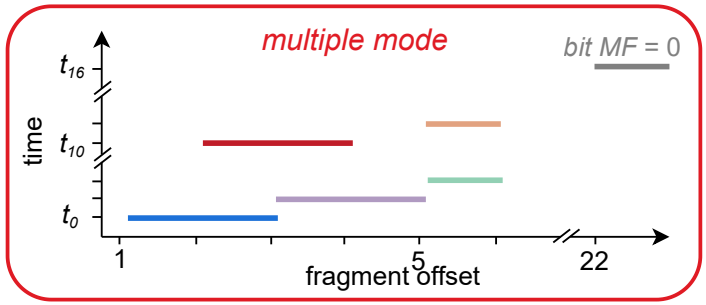
Table 4: Summary regarding overlap-based works.

Test modes

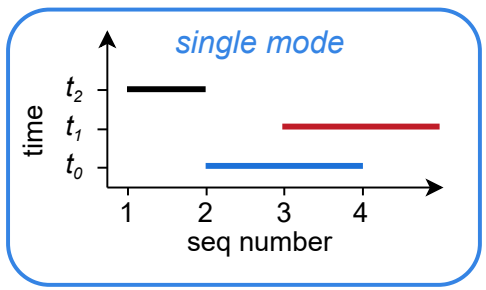
(O) test case

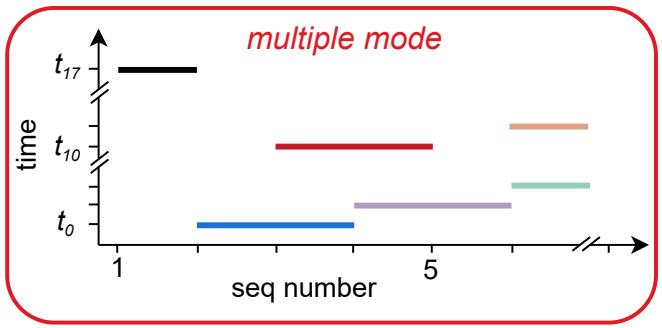
IP testing





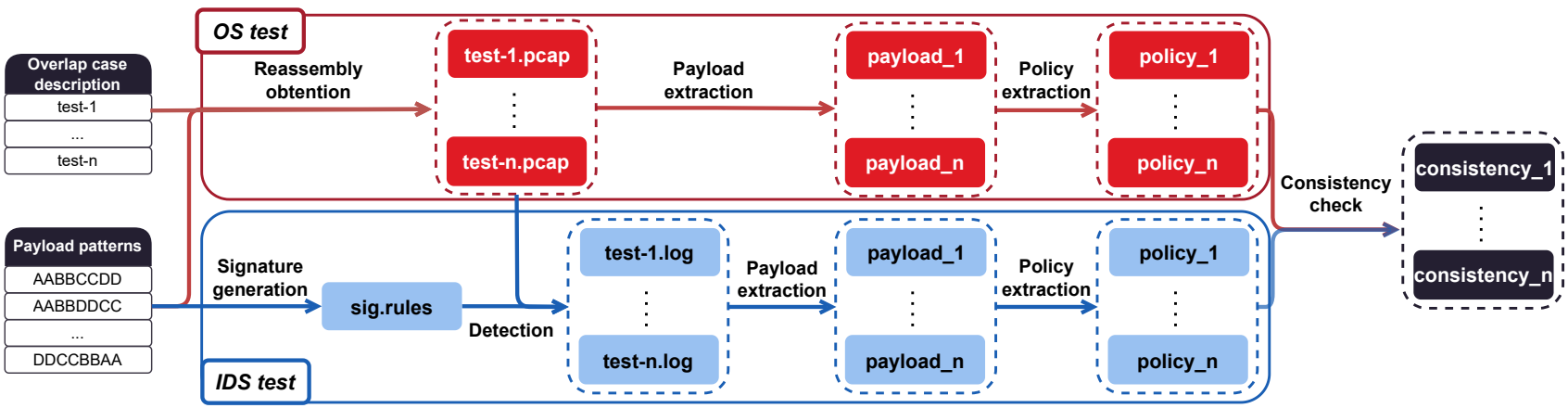
TCP testing





Pyrolyse test pipeline

Easy to extend tool written in Rust that implements the following generic steps:



Plan

Results

OS reassembly policy evolution

OS	Protocol version	Test case: Testing mode	Overlapping relation: *F*	*Fi*	*S*	*Si*	*O*	*Oi*	*D*	*Di*	*Eq*
Windows 10	IPv4	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
		single	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
	IPv6	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
		single	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
	TCP	*multiple*	o	o	o	o	o	o	o	o	o
		single	o	o	o	o	o	o	o	o	o
Debian 12	IPv4	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
		single	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
	IPv6	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
		single	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
	TCP	*multiple*	n	o	**o**	o	o	n	n	o	o
		single	n	o	**n**	o	o	n	n	o	o
SunOS 5.11	IPv4	*multiple*	n	**o**	**o**	o	o	o	n	o	**o**
		single	n	∅	**n**	o	o	o	n	o	**n**
	IPv6	*multiple*	n	**o**	**o**	o	o	o	n	o	**o**
		single	n	∅	**n**	o	o	o	n	o	**n**
	TCP	*multiple*	n	o	n	o	n	o	n	o	**n**
		single	n	o	n	o	n	o	n	o	**o**
FreeBSD 13.1/ OpenBSD 7.4	IPv4	*multiple*	n	**o**	**o**	o	o	n	n	o	**o**
		single	n	∅	**n**	o	o	n	n	o	**n**
	IPv6	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
		single	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
	TCP	*multiple*	n	o	o	o	o	n	n	o	o
		single	n	o	o	o	o	n	n	o	o

Results

Debian 12 reassembly policy evolution

Protocol	Testing mode	Test case: Overlapping relation								
		F	***Fi***	***S***	***Si***	***O***	***Oi***	***D***	***Di***	***Eq***
IPv4	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
	single	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
IPv6	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
	single	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
TCP	*multiple*	n	o	**o**	o	o	n	n	o	o
	single	n	o	**n**	o	o	n	n	o	o

Table 5: IP and TCP reassembly policies of Debian 12. o means that oldest fragment data is prefered, n means that newest fragment data is prefered and ∅ means that the OS ignores the overlap. Bold blue means that *multiple* and *single* strategies are reassembled differently. Green (resp. red) means the observed reassembly is consistent (resp. inconsistent) with latest related works[6].

[6] J. Novak. *Target-based fragmentation reassembly*. 2005, J. Novak **and** S. Sturges. *Target-based tcp stream reassembly*. 2007, Edoardo Di Paolo, Enrico Bassetti **and** Angelo Spognardi. "A New Model for Testing IPv6 Fragment Handling". **in***European Symposium on Research in Computer Security*: Springer. 2023, **pages** 277–294.

Results

IDS/OS consistency

Implementation	Rule file	Testing mode	Test case: Overlapping relation								
			F	*Fi*	*S*	*Si*	*O*	*Oi*	*D*	*Di*	*Eq*
Windows 10	-	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
Suricata-*windows*	any		o	o	o	o	o	o	n	o	o
Snort-*windows*	any		o	o	o	o	o	o	n	o	o
Zeek	-		o	o	o	o	o	o	o	o	o
Windows 10	-	*single*	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
Suricata-*windows*	default		n	∅	n	o	o	o	n	o	n
Suricata-*windows*	flow		∅	∅	∅	∅	o	o	∅	∅	∅
Snort-*windows*	default		n	∅	n	o	o	o	n	o	n
Snort-*windows*	flow		∅	∅	∅	∅	o	o	∅	∅	∅
Zeek	-		n	o	n	o	o	o	n	o	n
Debian 12	-	*multiple*	∅	∅	∅	∅	∅	∅	∅	∅	∅
Suricata-*linux*	any		n	o	n	n	o	n	n	o	n
Snort-*linux*	any		n	o	n	n	o	n	n	o	n
Zeek	-		o	o	o	o	o	o	o	o	o
Debian 12	-	*single*	**n**	∅	**n**	**o**	∅	∅	**n**	**o**	**n**
Suricata-*linux*	default		n	o	n	o	o	n	n	o	n
Suricata-*linux*	flow		∅	o	∅	∅	o	n	∅	∅	∅
Snort-*linux*	default		n	∅	n	o	o	n	n	o	n
Snort-*linux*	flow		∅	∅	∅	∅	o	n	∅	∅	∅
Zeek	-		n	o	n	o	o	o	n	o	n
SunOS 5.11	-	*multiple*	**n**	**o**	**o**	**o**	**o**	**o**	**n**	**o**	**o**
Suricata-*solaris*	any		n	o	o	o	o	o	n	o	o
Snort-*solaris*	any		n	o	o	o	o	o	n	o	o
Zeek	-		o	o	o	o	o	o	o	o	o
SunOS 5.11	-	*single*	**n**	∅	**n**	**o**	**o**	**o**	**n**	**o**	**n**
Suricata-*solaris*	default		n	o	n	o	o	o	n	o	n
Suricata-*solaris*	flow		∅	o	∅	∅	o	o	∅	∅	∅
Snort-*solaris*	default		n	∅	n	o	o	o	n	o	n
Snort-*solaris*	flow		∅	∅	∅	∅	o	o	∅	∅	∅
Zeek	-		n	o	n	o	o	o	n	o	n
FreeBSD 13.1	-	*multiple*	**n**	**o**	**o**	**o**	**o**	**n**	**n**	**o**	**o**
Suricata-*bsd*	any		n	o	o	o	o	n	n	o	o
Snort-*bsd*	any		n	o	o	o	o	n	n	o	o
Zeek	-		o	o	o	o	o	o	o	o	o
FreeBSD 13.1	-	*single*	**n**	∅	**n**	**o**	**o**	**n**	**n**	**o**	**n**
Suricata-*bsd*	default		n	o	n	o	o	o	n	o	n
Suricata-*bsd*	flow		∅	o	∅	∅	o	o	∅	∅	∅
Snort-*bsd*	default		n	∅	n	o	o	n	n	o	n
Snort-*bsd*	flow		∅	∅	∅	∅	o	n	∅	∅	∅
Zeek	-		n	o	n	o	o	o	n	o	n

Table 6: IDS IPv4 reassembly policy consistency with OSes.

Results

IDS evasion and insertion attack opportunities

Protocol	IDS	Reassembly inconsistencies	Number of OSes w/ possible attack type	
			Evasion	Insertion
IPv4	Suricata	8 (22%)	1/4	4/4
	Snort	4 (11%)	0/4	2/4
	Zeek	9 (25%)	4/4	1/4
IPv6	Suricata	9 (25%)	0/4	4/4
	Snort	6 (17%)	0/4	3/4
	Zeek	28 (78%)	4/4	4/4
TCP	Suricata	1 (3%)	1/4	1/4
	Snort	1 (3%)	1/4	1/4
	Zeek	11 (31%)	3/4	3/4

Table 7: IDS inconsistencies with OS reassemblies and corresponding attack opportunities for the *single* test mode.

Responsible disclosure

Every reassembly inconsistency is a possible security issue

- communication with IDS developers
- Suricata already fixed some misassemblies

Conclusion and future works

Conclusion

- OS reassembly policies evolve
- overlap-based attacks can still target IDSes $\rightarrow$ they must take into account OS reassembly evolutions

Future works

- Investigate $n > 2$ overlapping chunks
- Target more protocol implementations (e.g., offloaded stacks on NIC, embedded stacks)

Testing the reassembly consistency of IDS and OS in the presence of overlapping data

SuperviZ workshop

Thanks!