SmartCookie: Blocking Large-Scale SYN Floods with a Split-Proxy Defense on Programmable Data Planes

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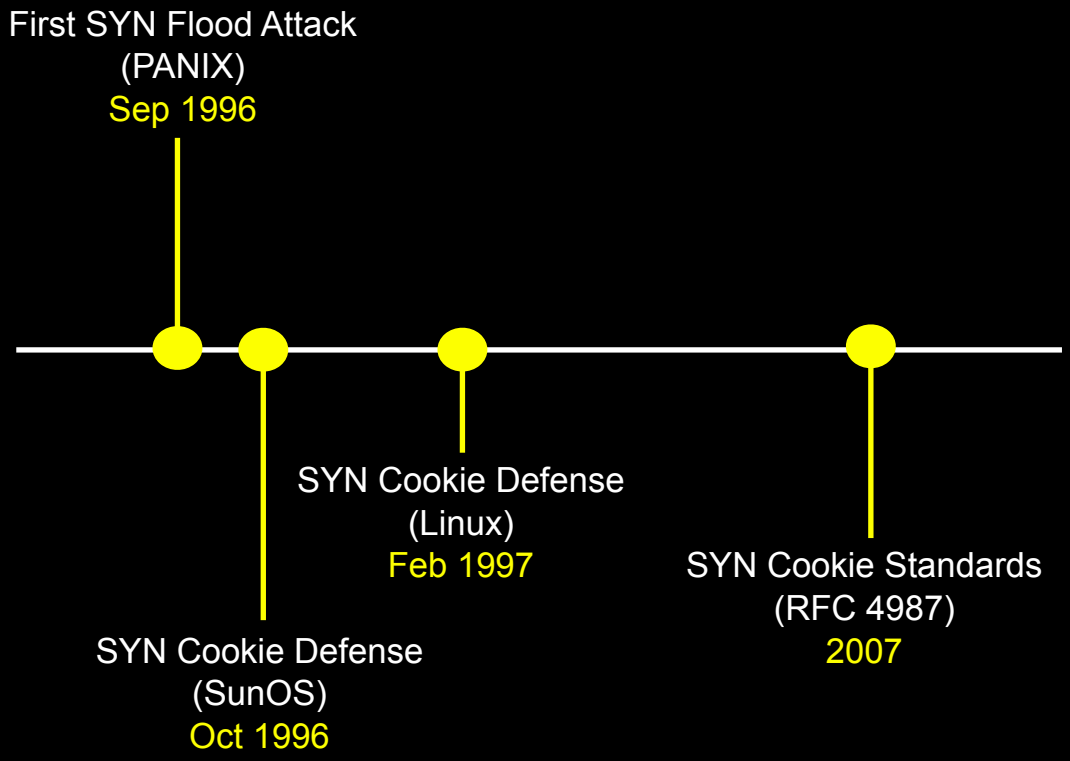
PRINCETON
UNIVERSITY

A brief timeline of SYN flooding attacks



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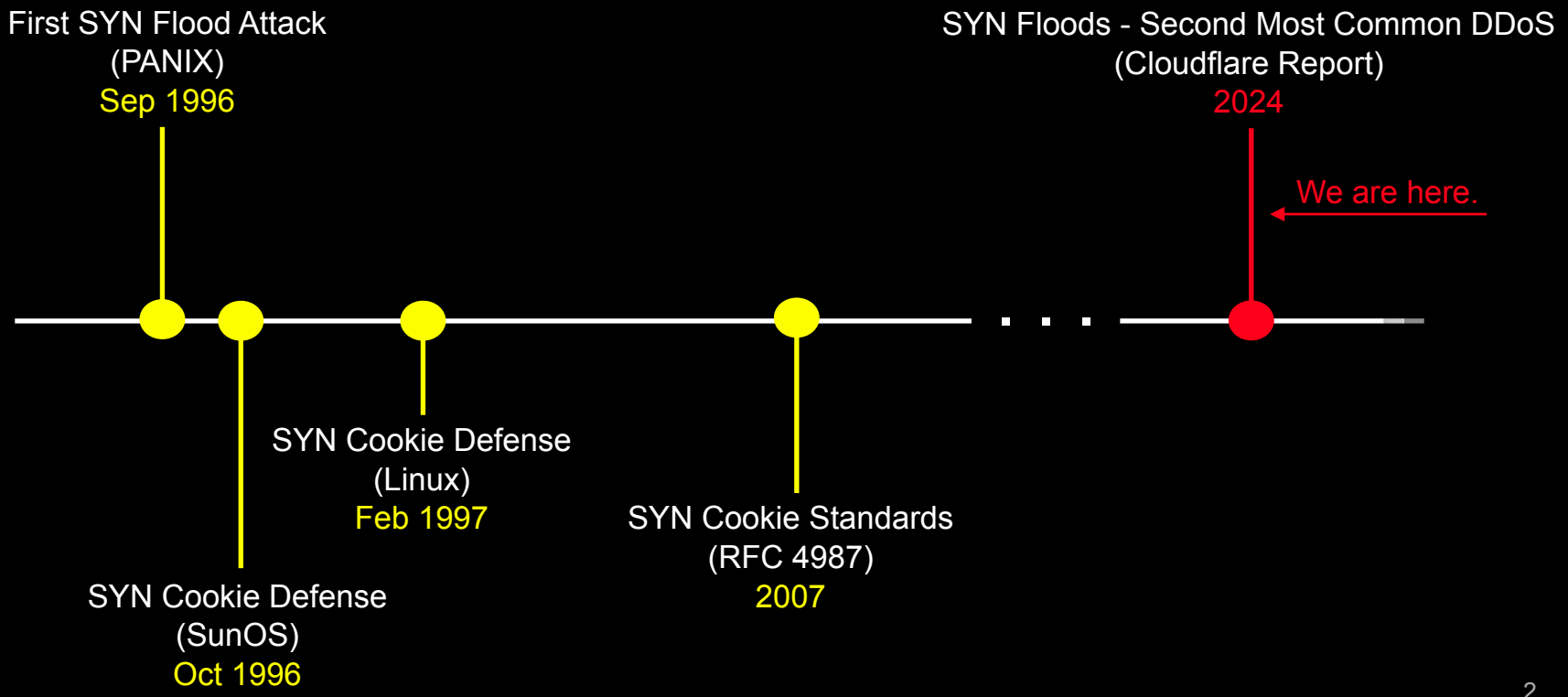

What modern SYN flood defenses really need…

- ⁉ Security
- ⁉ Scalability
- ⁉ Performance

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- ⁉ Security …blocking attacks from adaptive adversaries
- ⁉ Scalability …handling large amounts of benign and attack traffic
- ⁉ Performance …maintaining low latency for benign clients

Network providers must performantly serve client traffic

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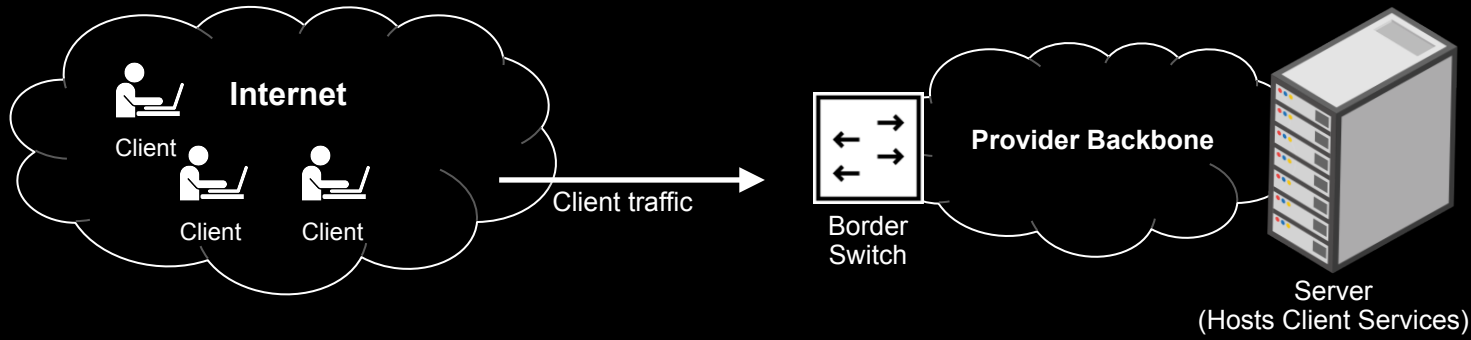

Network providers must performantly serve client traffic

while blocking attack traffic as early as possible in the provider network

- ⁉ Security …blocking attacks from adaptive adversaries
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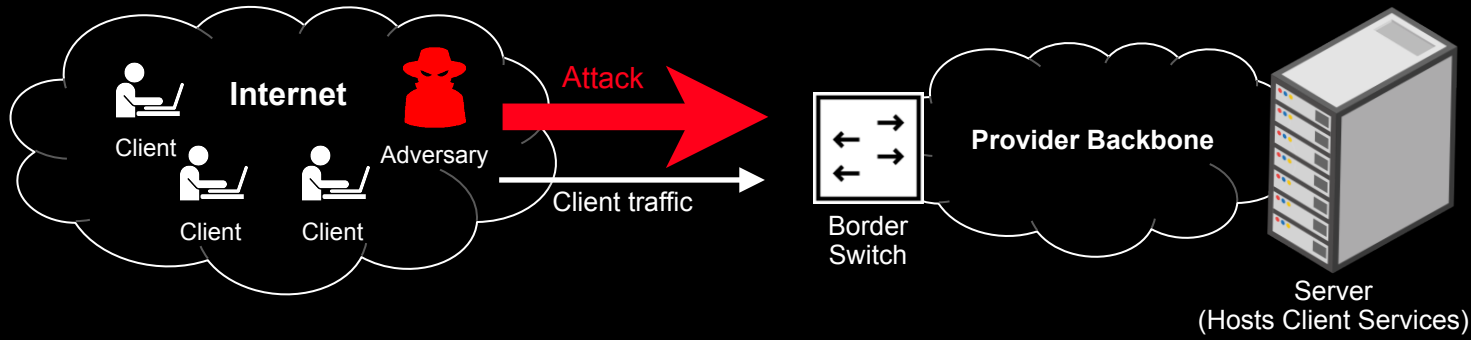
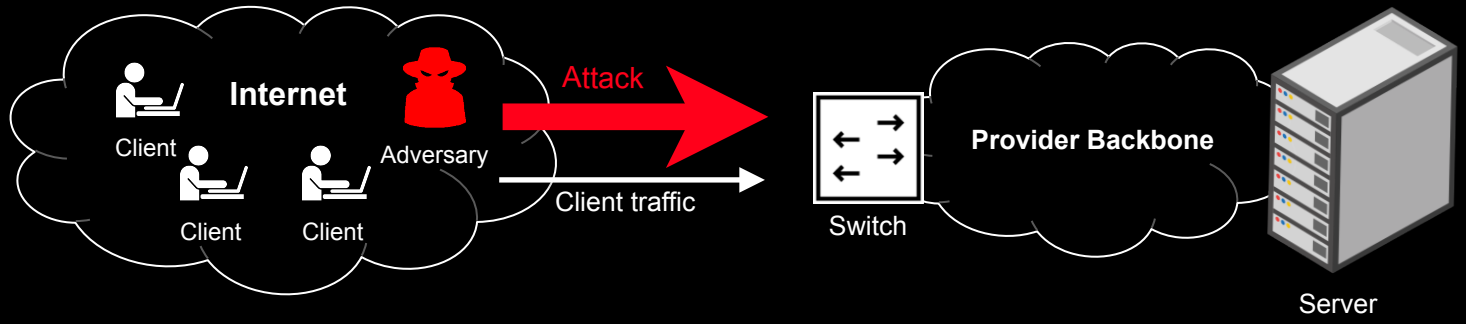
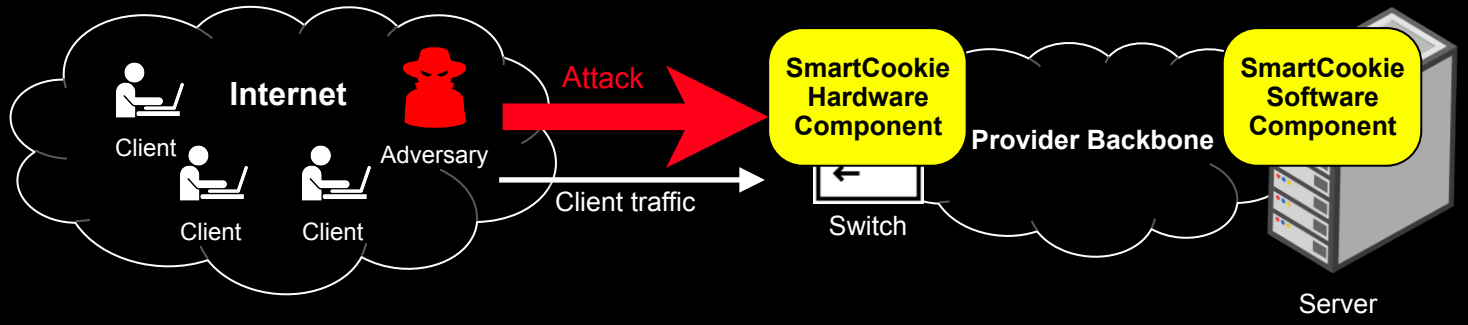


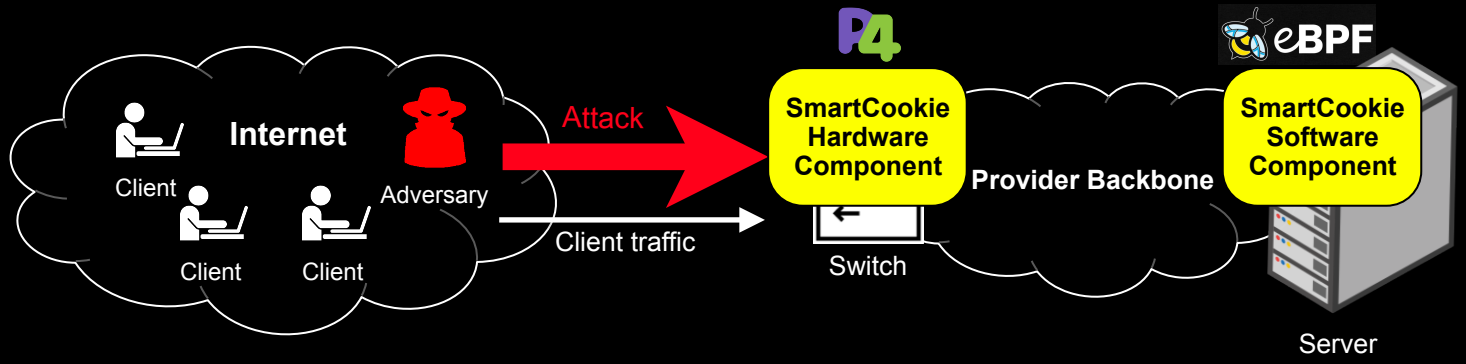

Internet
Client
Client
Client
Adversary
Attack
Client traffic
Switch
Provider Backbone
Server

SmartCookie: a *collaborative*, *split-layer design*



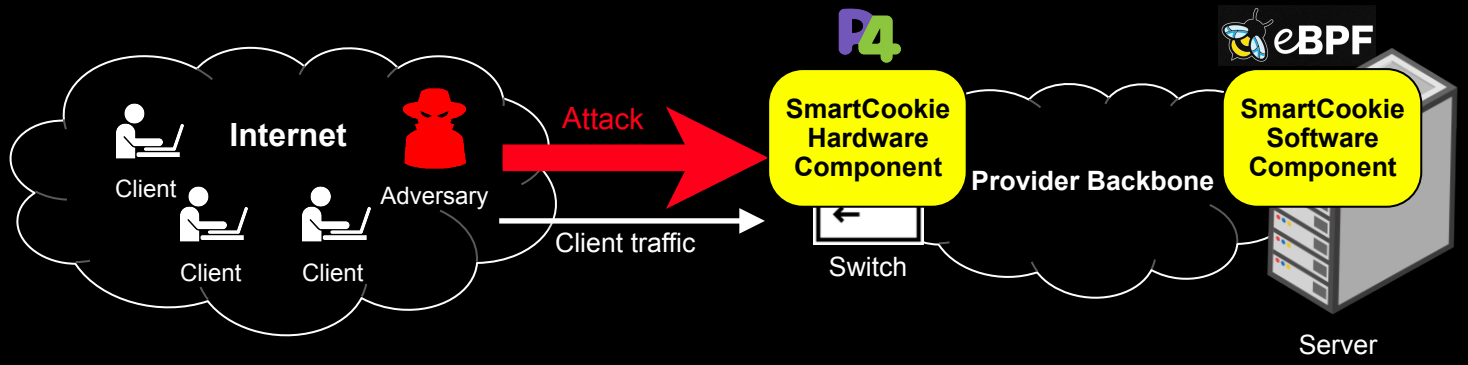
SmartCookie: a *collaborative*, *split-layer design*

…enabled by the power of programmable targets



SmartCookie: a *collaborative*, *split-layer design*

where each component handles functionality based on its unique resources



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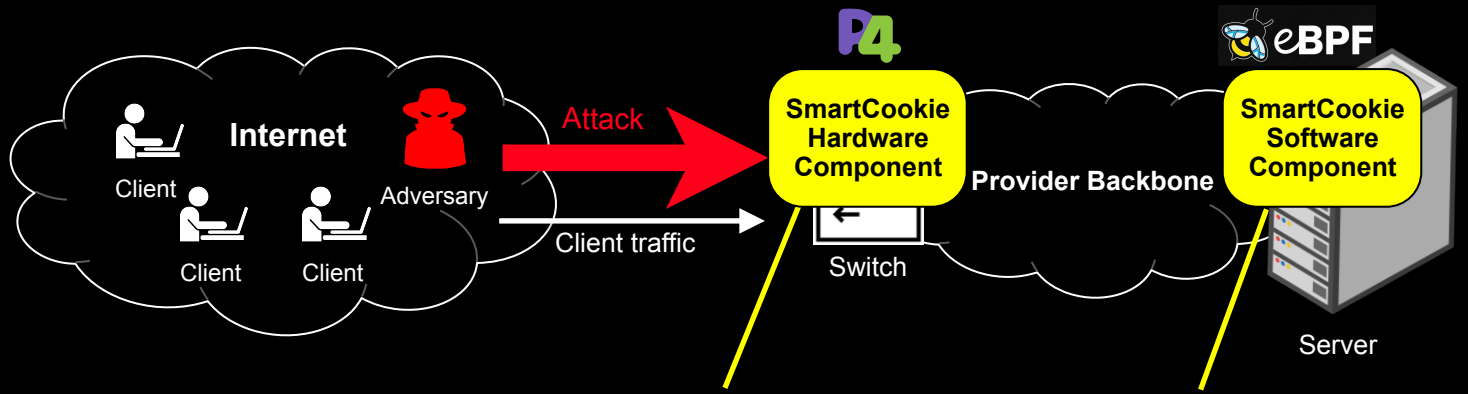


(i) Hardware blocks large bulk of attack traffic
+ passes through all client traffic

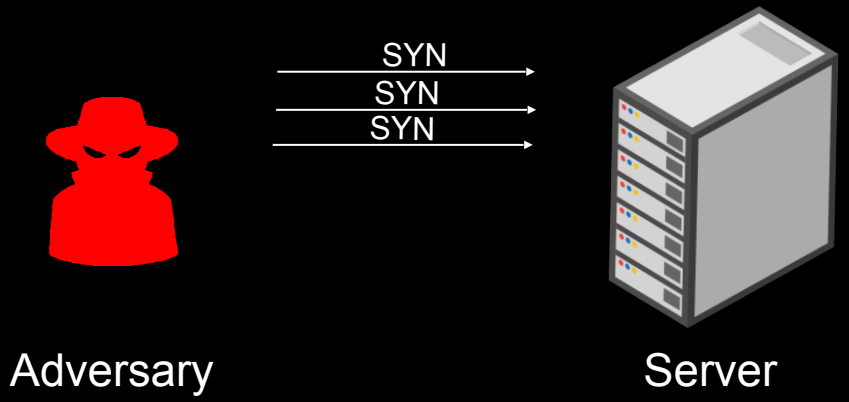
(ii) Software blocks any leftover attack traffic
+ serves all client traffic as normal

SYN Flooding: an asymmetric attack on resources

Adversary

Server

SYN Flooding: an asymmetric attack on resources



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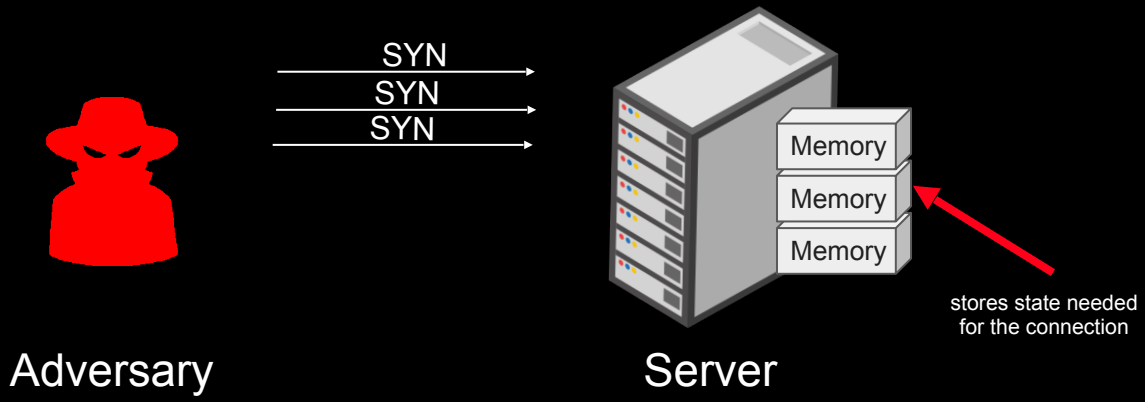

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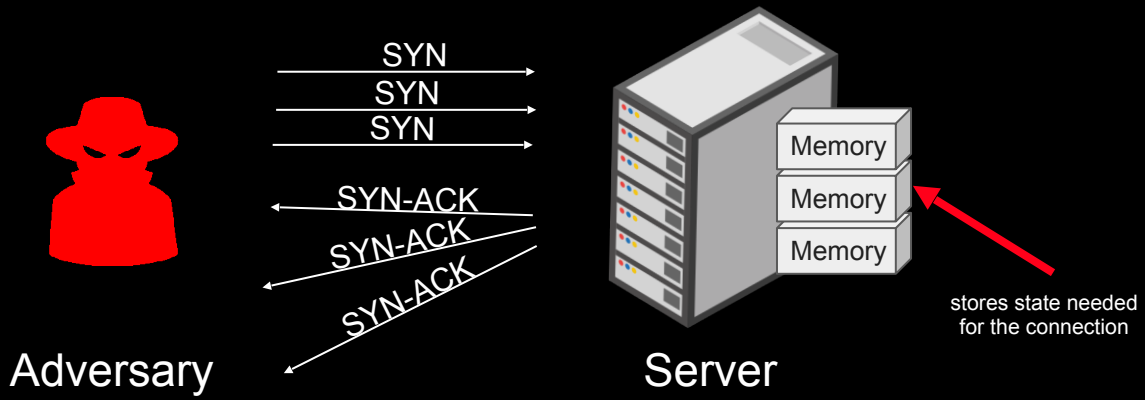

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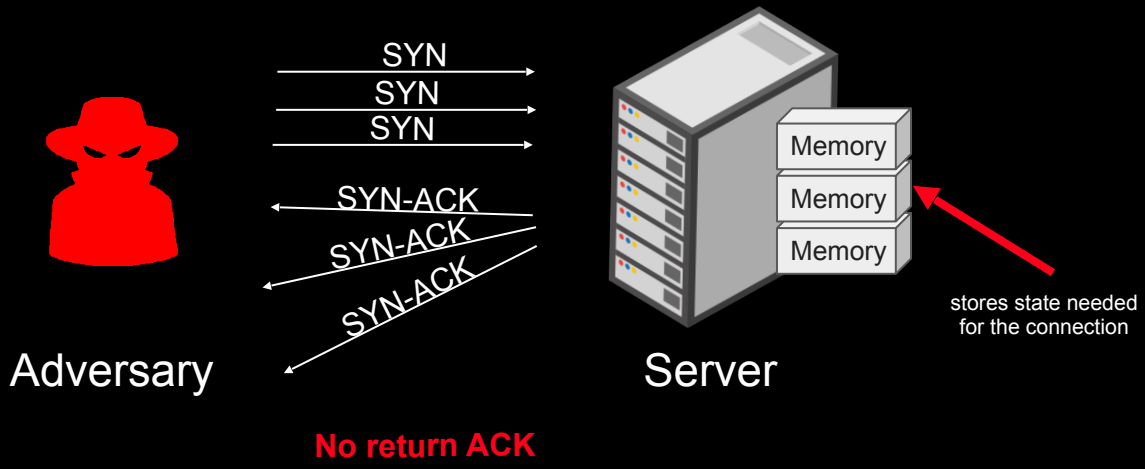
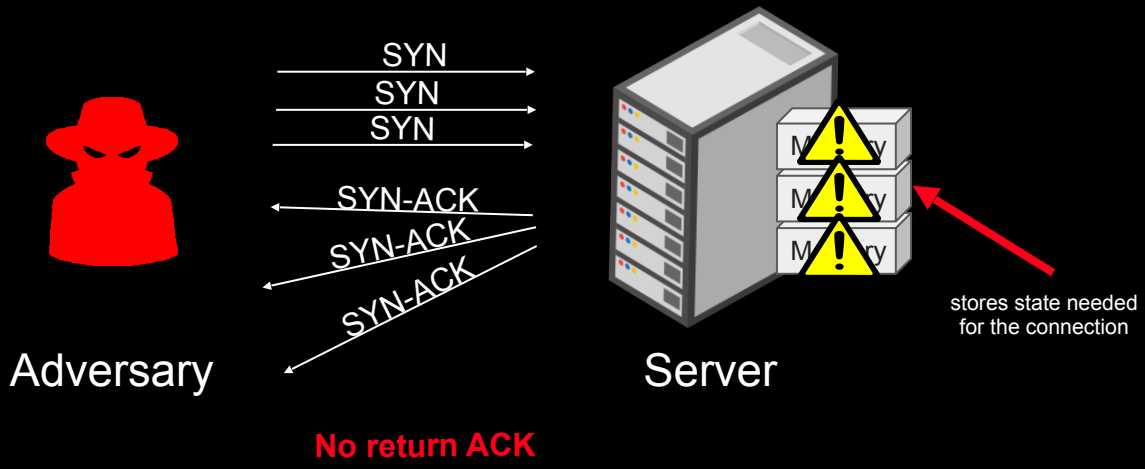


SYN Flooding: an asymmetric attack on resources

Server memory is depleted, leading to DoS for new requests



SYN Cookies: a stateless solution

Adversary

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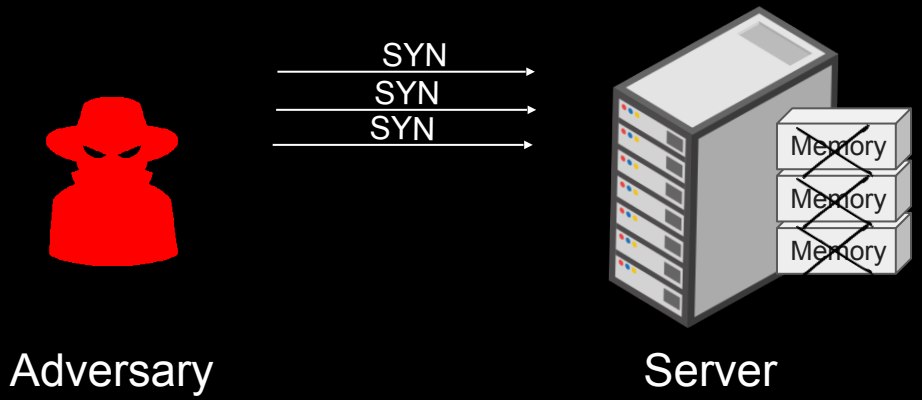
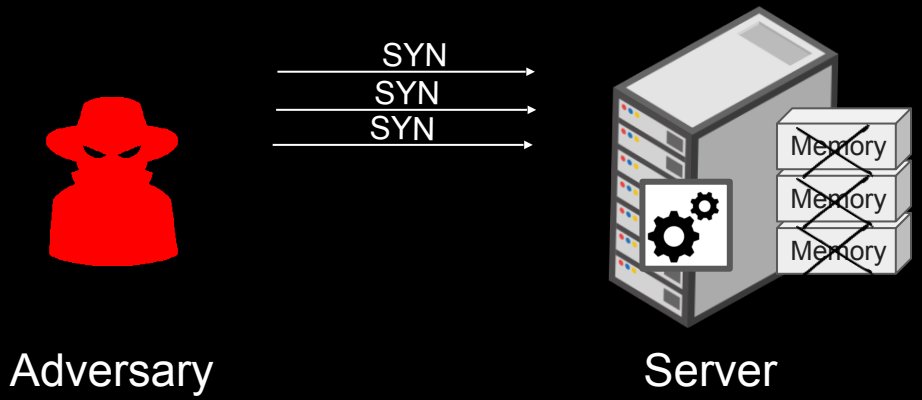
SYN Cookies: a stateless solution

Trading memory…



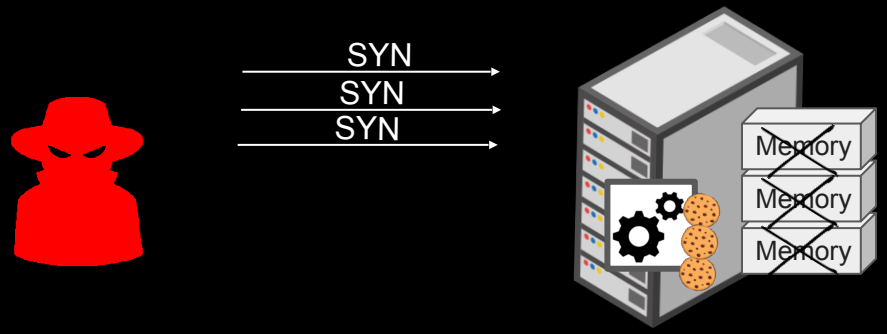
SYN Cookies: a stateless solution

…for compute



SYN Cookies: a stateless solution

Cryptographically secure “cookie” computed to store the relevant state



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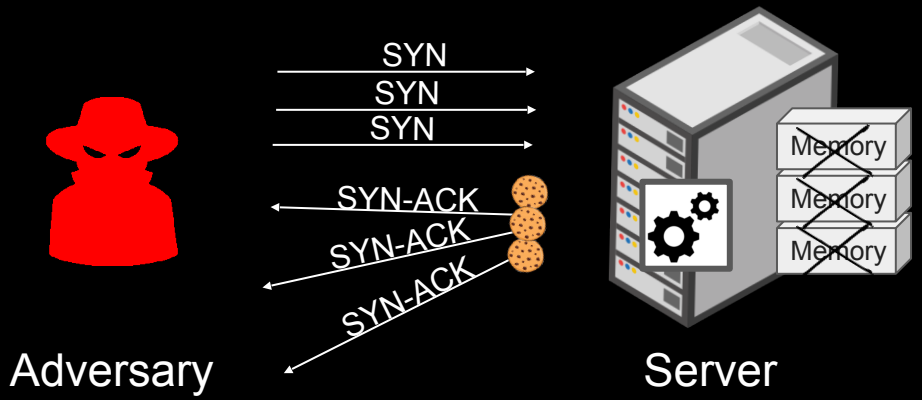

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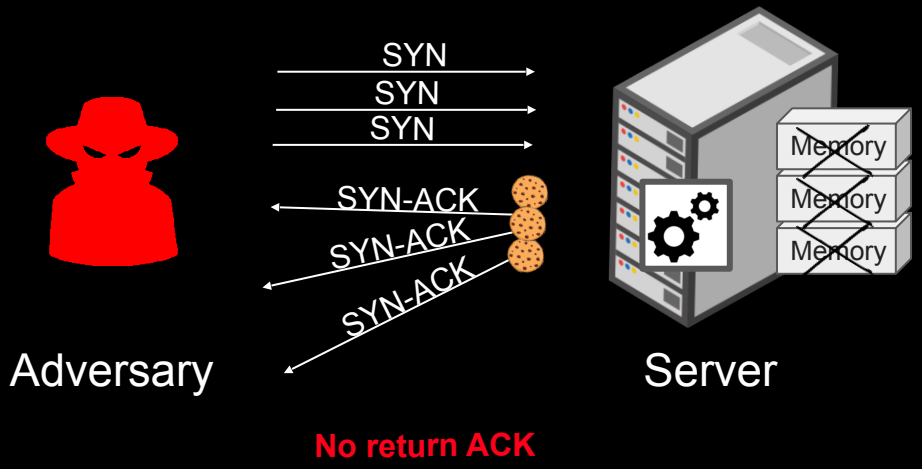
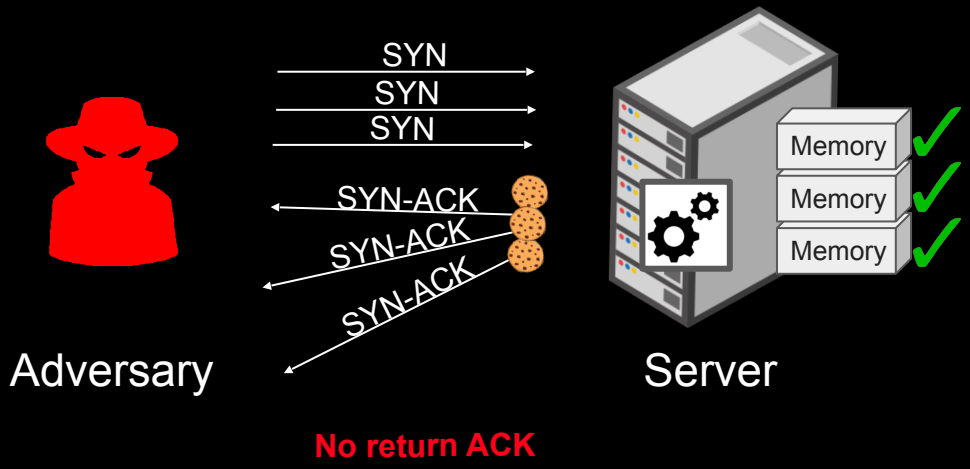


SYN Cookies: a stateless solution

Memory protected for legitimate connection requests

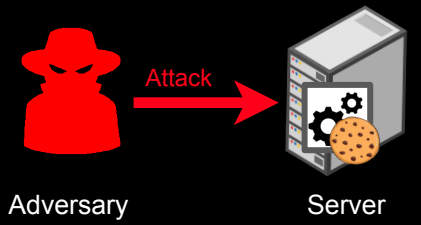


Why is a secure, scalable, and performant defense so hard?

Software-Only Solutions Can’t Scale Compute

Computational cost to identify attacks leads to early CPU exhaustion.

Cryptographically computing cookies in software is costly



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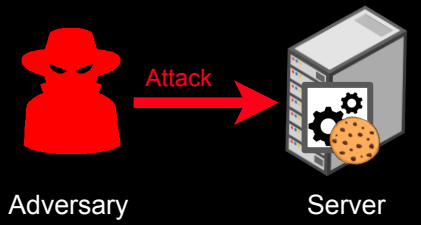
Cryptographic cookie computation and packet processing for every potential connection



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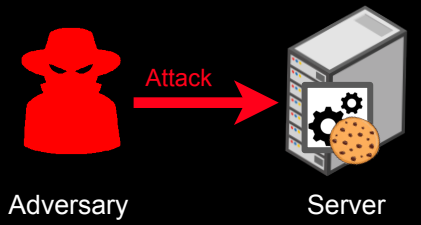

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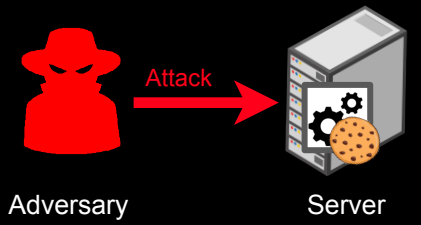

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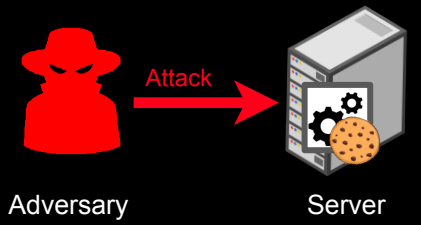
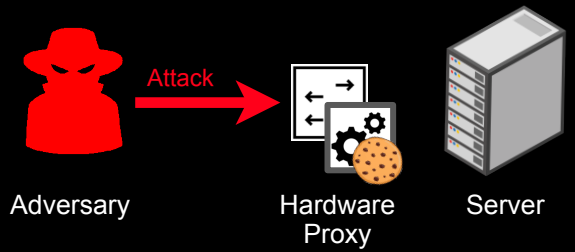
Application performance degraded, clients experience DoS (again)

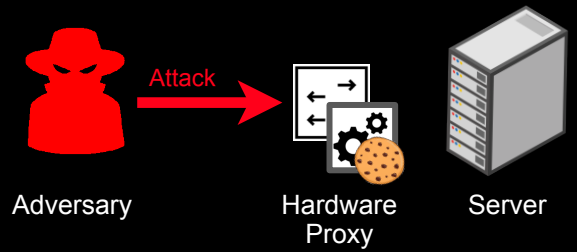


Why not move the cookie defense to a hardware proxy?



Why not move the cookie defense to a hardware proxy?

…like a high-speed programmable switch!



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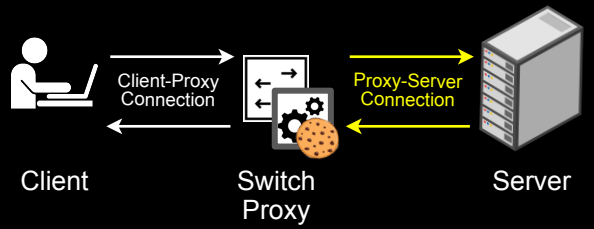

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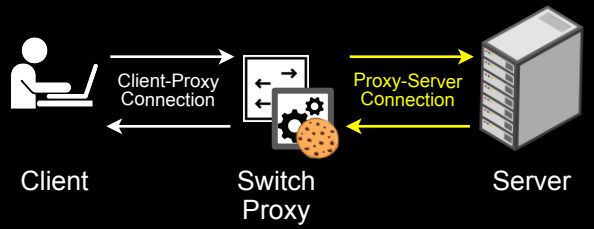

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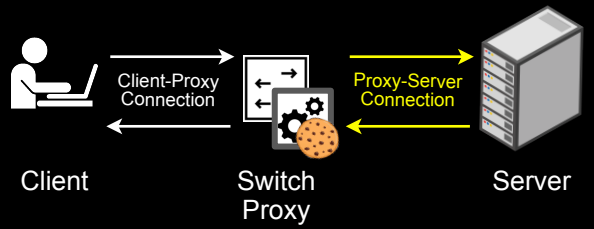

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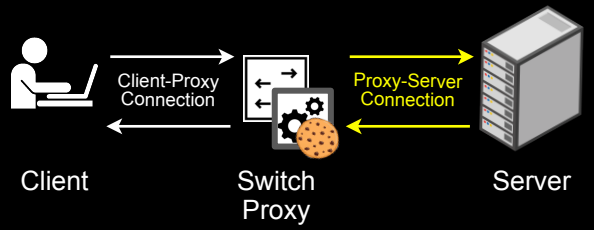

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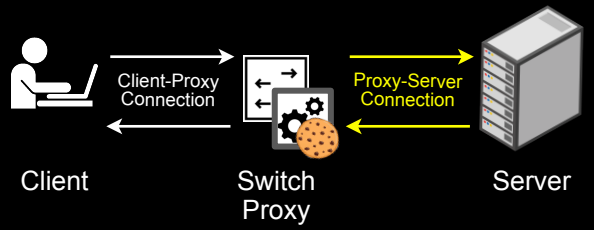

Jaqen[1] avoids memory usage, at a performance cost (extra RTT and added latency for all benign flows)

[1] Liu, et al. *Jaqen: A High-Performance Switch-Native Approach for Detecting and Mitigating Volumetric DDoS Attacks with Programmable Switches.* USENIX Security Symposium, 2021.

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Weak hashing for cookie generation breaks security.

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Cookie = hash(4-tuple, secret)

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Hardware solutions (Jaqen[1], Poseidon[2]) rely on CRC Checksum for hashing - insecure!

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Security abandoned, compute AND memory consumed

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Outline

Motivation

SmartCookie

Results

Conclusion

SmartCookie solves these challenges! 

Key Insight:

modern SYN flood defenses must be layered,

a *collaborative split-layer design* of hardware + software

SmartCookie solves these challenges! 

Intelligent division of labor

SmartCookie solves these challenges! 

Intelligent division of labor

- What functionality should be partitioned?
- How should it be partitioned?

What functionality should be partitioned?

What functionality should be partitioned?

We observe three key elements of SYN cookie proxy defenses

(F1) Cookie checks

(F2) Header translations

(F3) Keeping state for verified connections

How should this functionality be partitioned?

(F1) Cookie checks

(F2) Header translations

(F3) Keeping state for verified connections

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Insight 1: Switches are highly performant, but severely memory-limited

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…switches are an excellent first line of defense, but should not keep per-flow state!

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Insight 1: Switches are highly performant, but severely memory-limited
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(F1) Cookie checks

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Insight 1: Switches are highly performant, but severely memory-limited
…switches are an excellent first line of defense, but should not keep per-flow state!

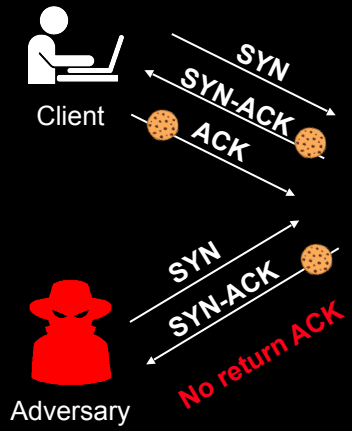
Insight 2: Servers are provisioned with memory for benign flows, but they are slow
…servers are ideal for exactly tracking benign flows, but should not block attacks!

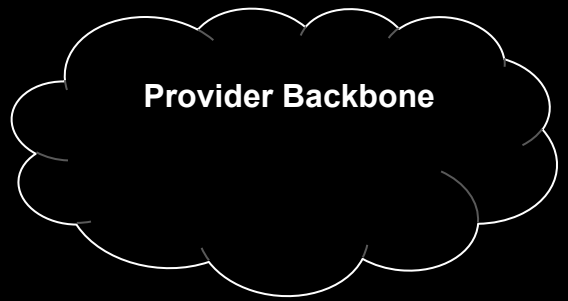
SmartCookie's Split-Proxy Architecture

(F1) Cookie checks

(F2) Header translations

(F3) Keeping state for verified connections

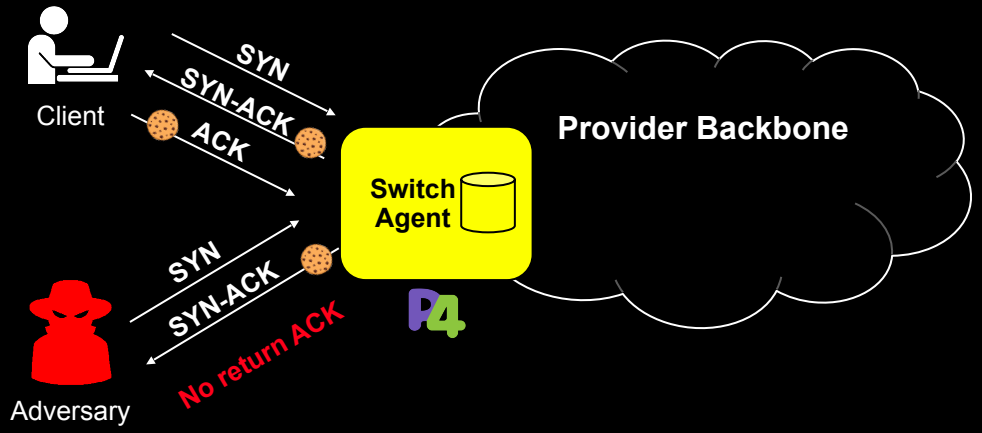




SmartCookie's Split-Proxy Architecture

Switch agent performs *secure* cookie checks with a robust hash, not CRC (F1)

(F1) Cookie checks	(F2) Header translations	(F3) Keeping state for verified connections



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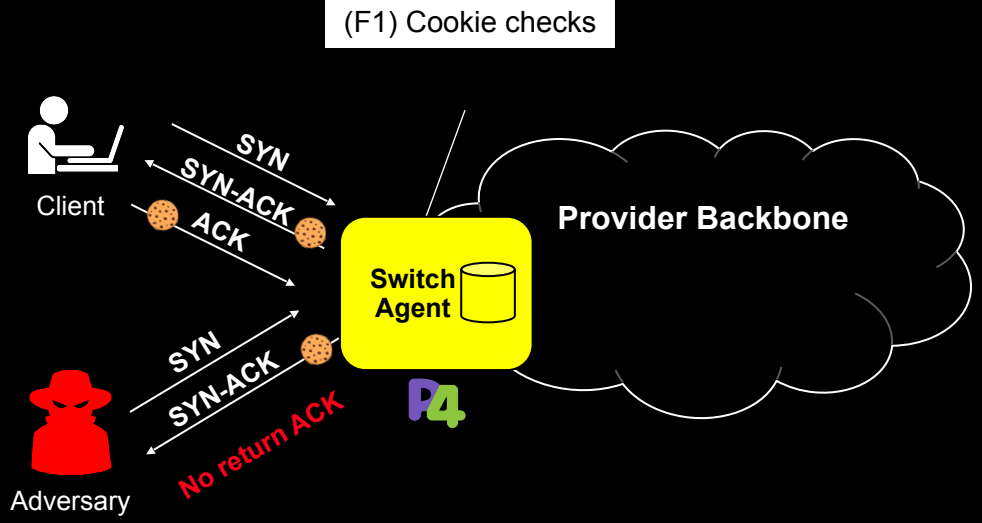


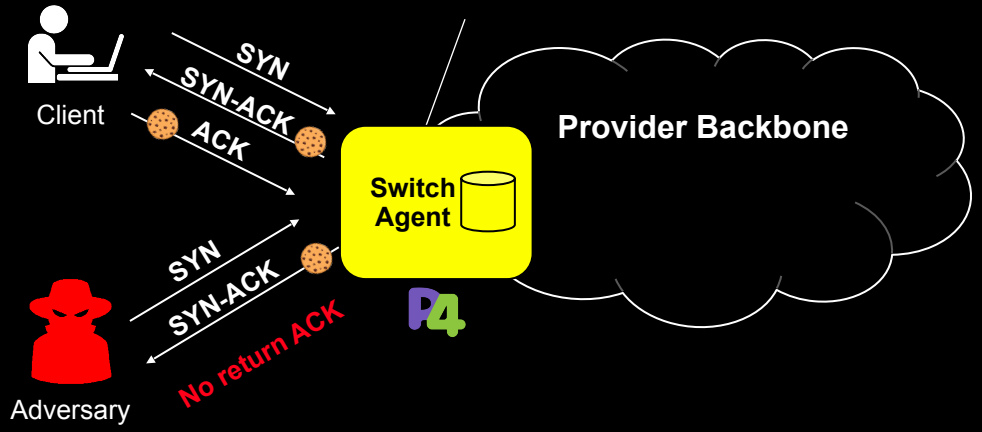
SmartCookie's Split-Proxy Architecture

Switch agent *approximately* tracks verified connections (F3.A)

(F2) Header translations

(F3) Keeping state for verified connections

(F1) Cookie checks



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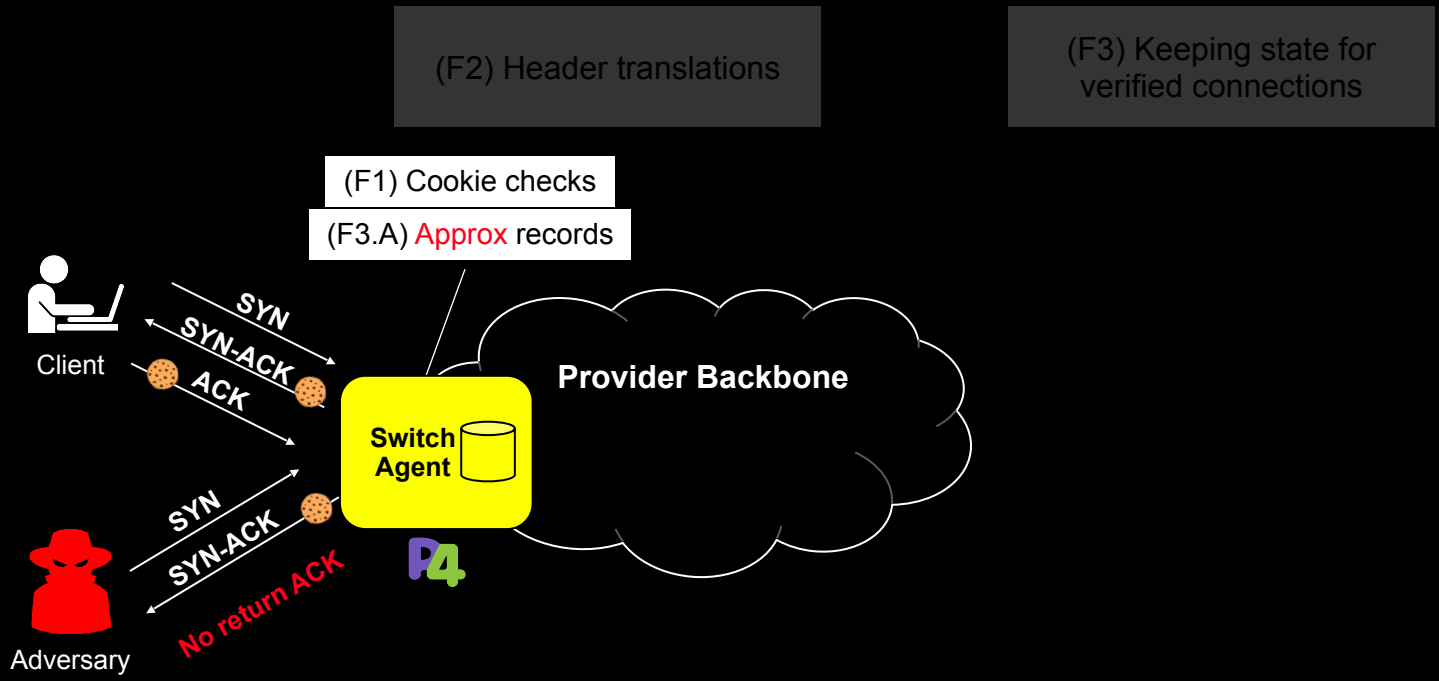
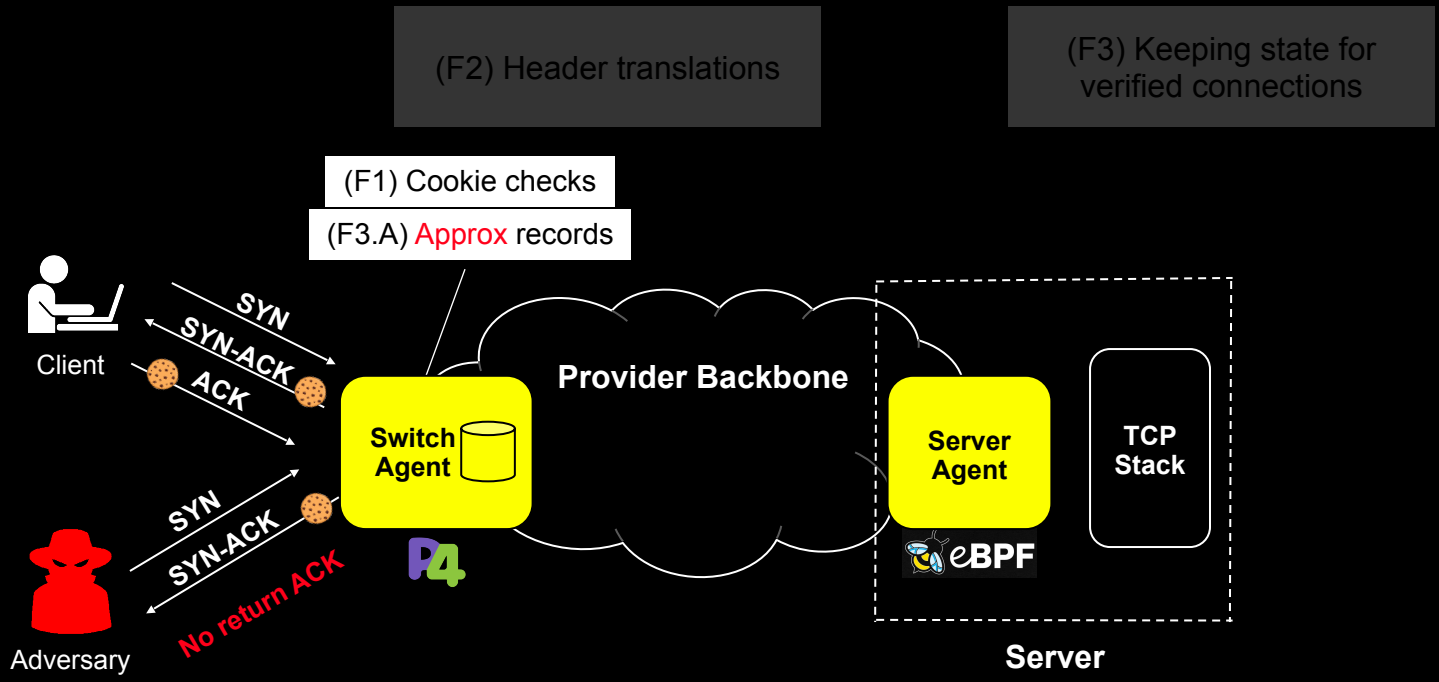


SmartCookie's Split-Proxy Architecture

Server agent handles header translations on behalf of switch agent (F2)



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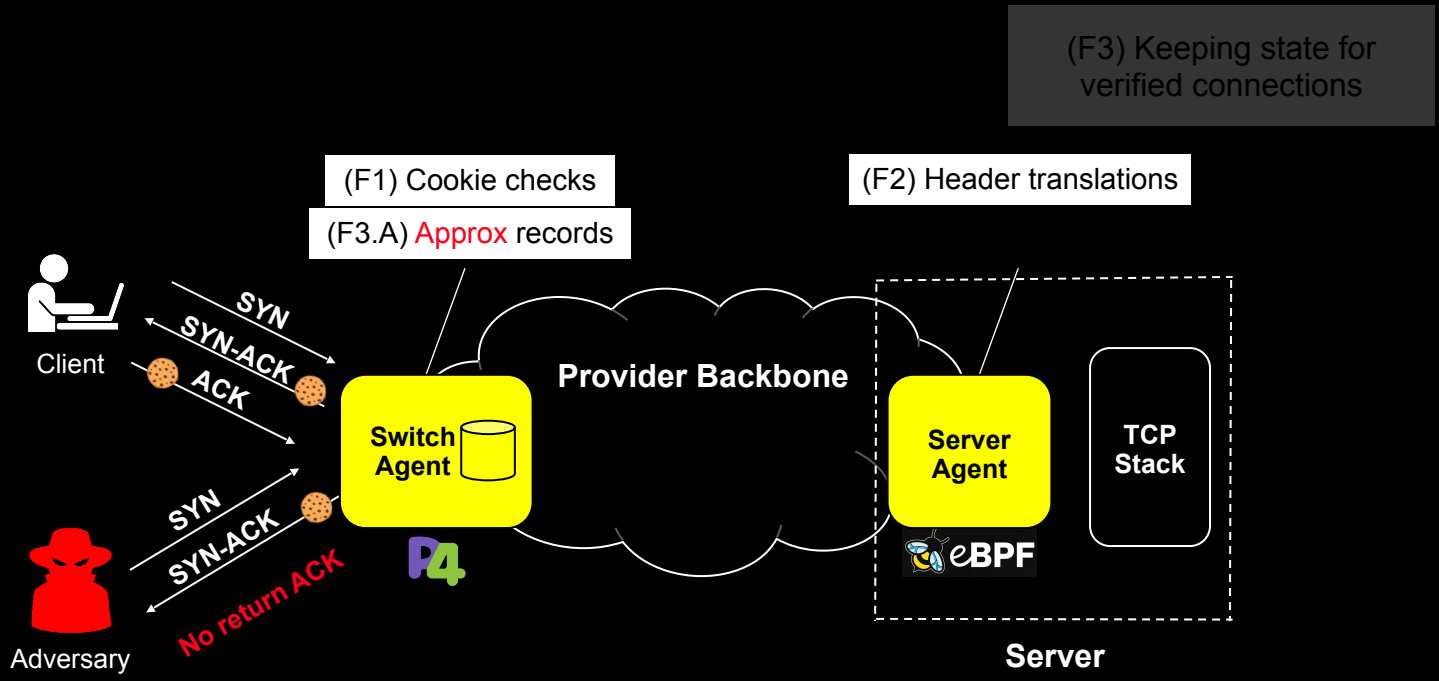
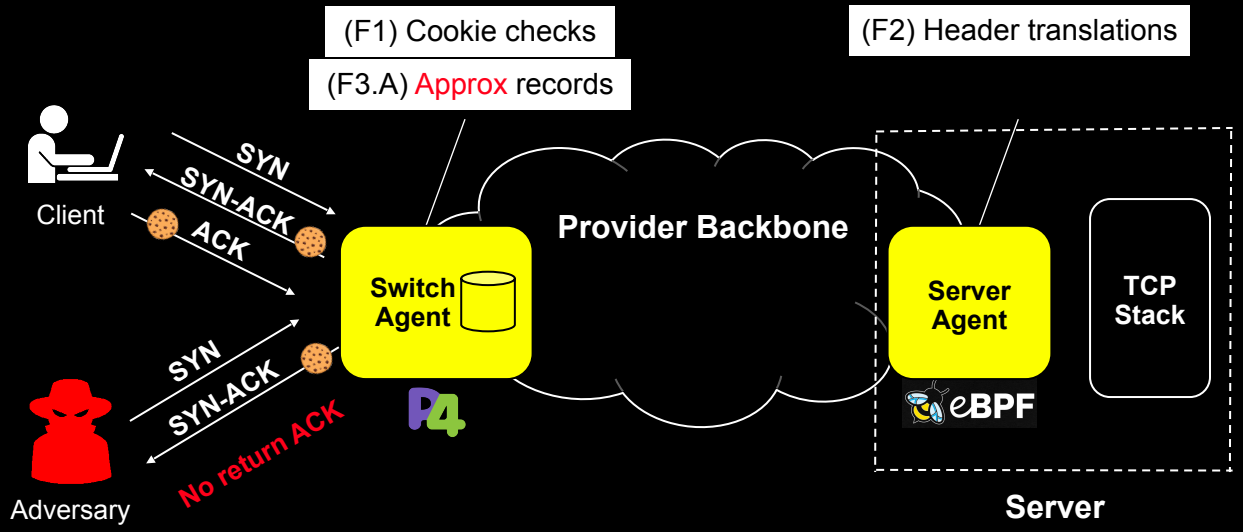


SmartCookie's Split-Proxy Architecture

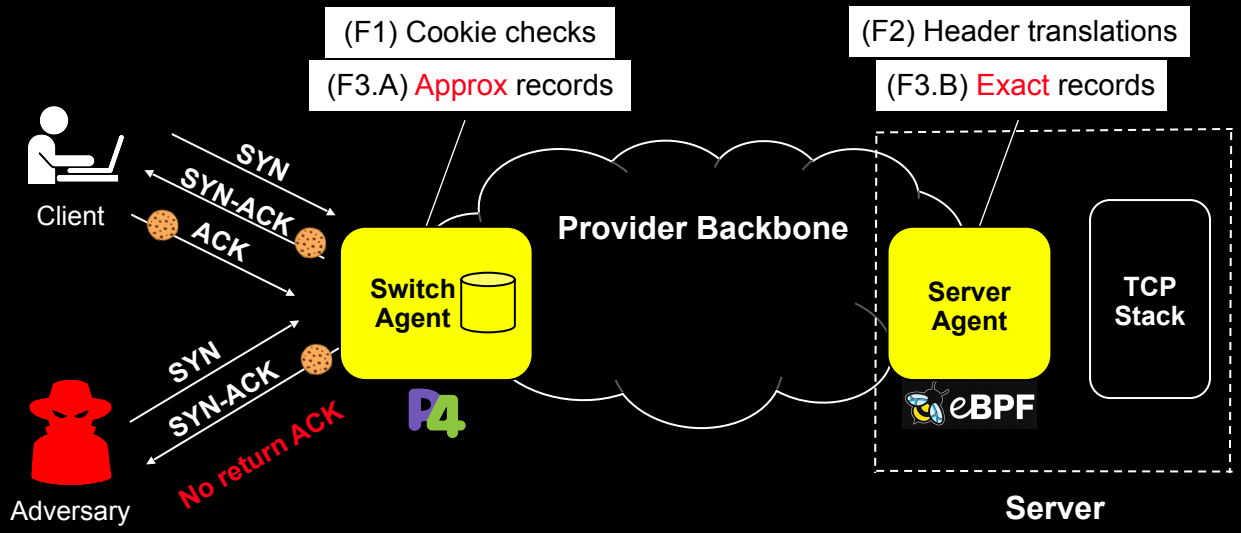
Server agent *exactly* tracks verified connections (F3.B)

(F3) Keeping state for verified connections



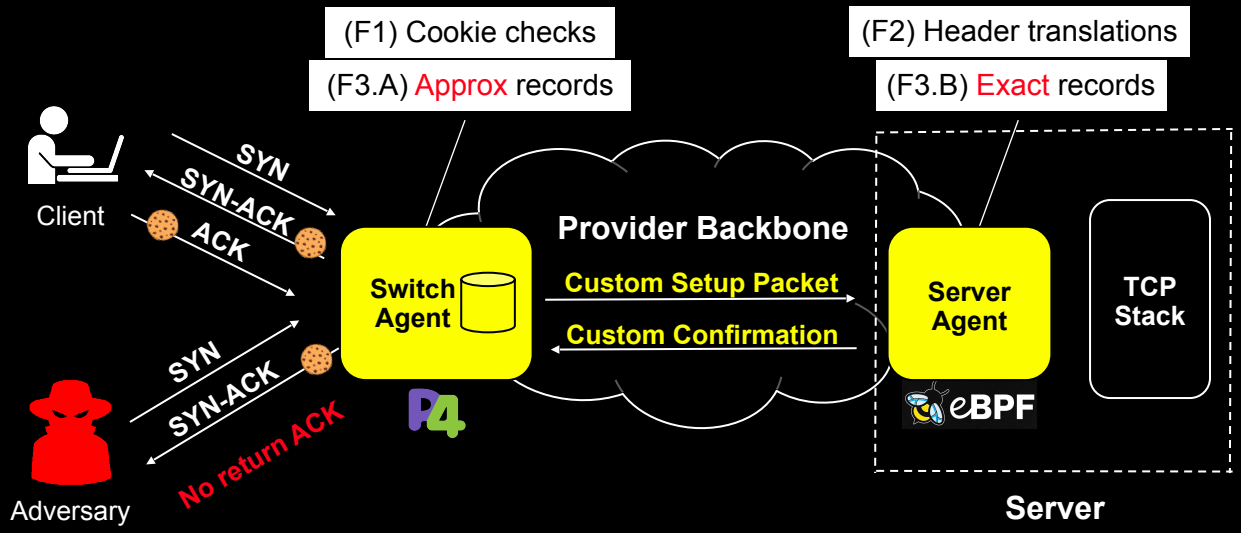
SmartCookie's Split-Proxy Architecture

Server agent *exactly* tracks verified connections (F3.B)



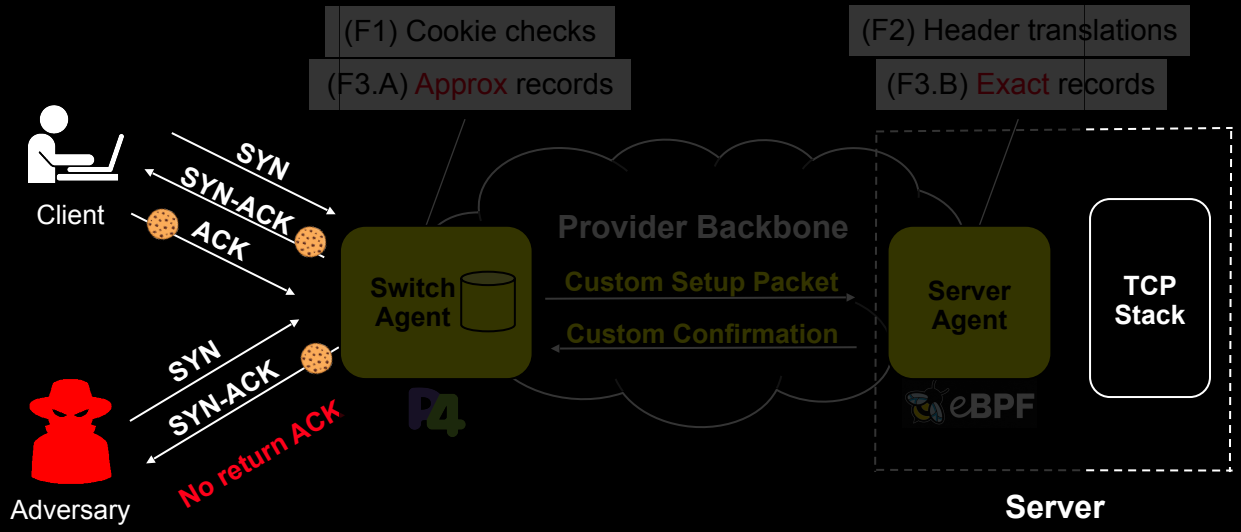
SmartCookie's Split-Proxy Architecture

Custom collaborative protocol between SmartCookie components



SmartCookie's Split-Proxy Architecture

…does not require any modifications to the client or server's network stack



SmartCookie delivers security, scalability, and performance

Robust hashing for **secure cookies** on switch (F1), §5

Approximate data structures for switch memory scalability (F3.A), §6.3 - §6.4

Efficient server-side eBPF support with **exact** memory (F2) + (F3.B), §6.1 - §6.2

Please read our paper for more details!

Outline

Motivation

SmartCookie

Results

Conclusion

Evaluation

Can SmartCookie deliver *security* at high attack rates?

Can SmartCookie protect CPU capacity for *scalability*?

Can SmartCookie maintain client *performance* under attack?

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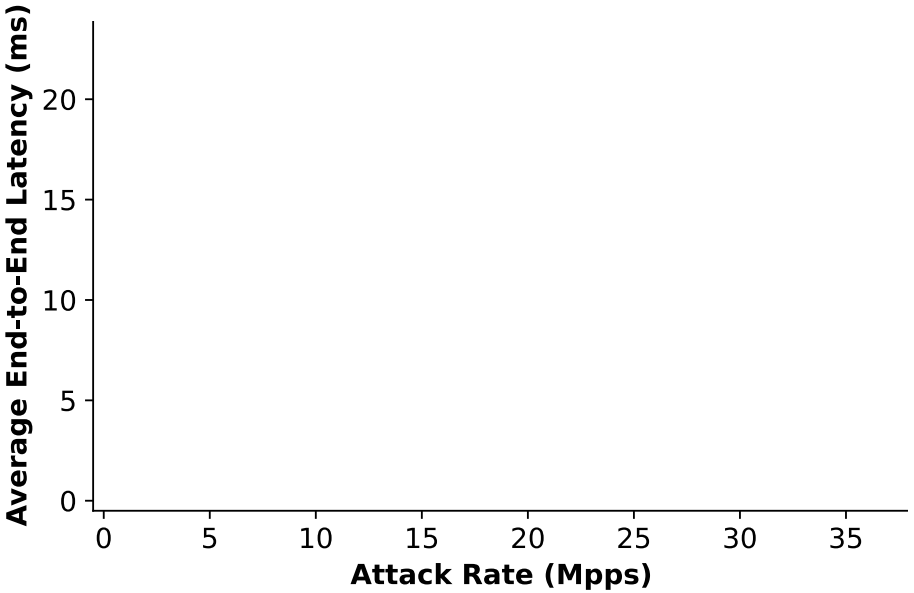
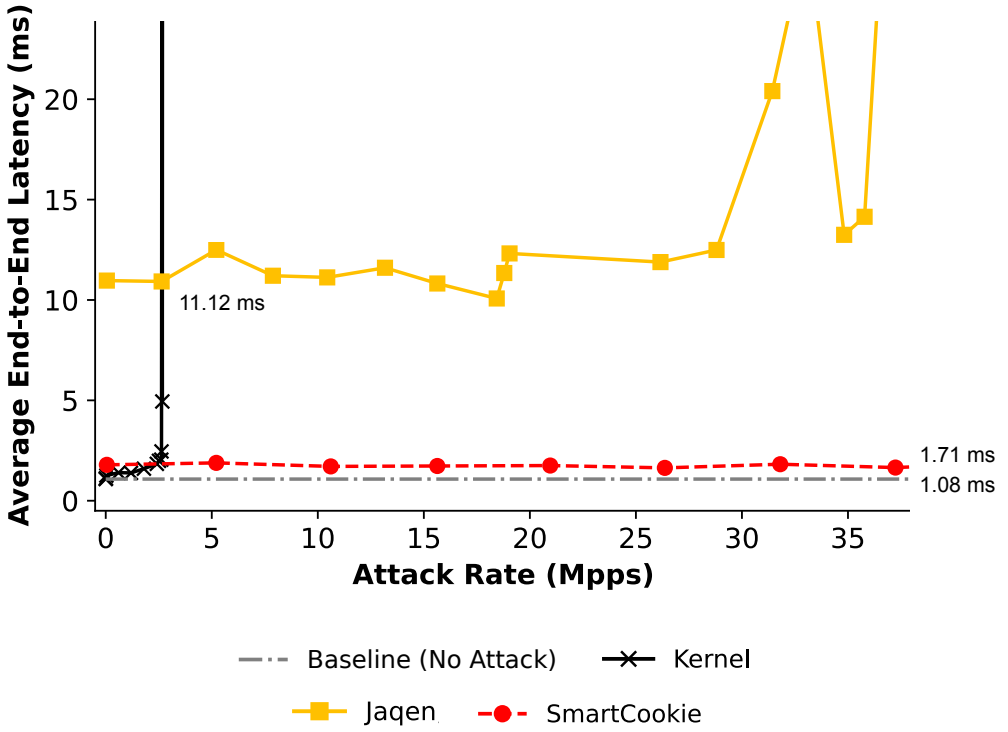
Can SmartCookie protect CPU capacity for *scalability*?

Can SmartCookie maintain client *performance* under attack? this talk

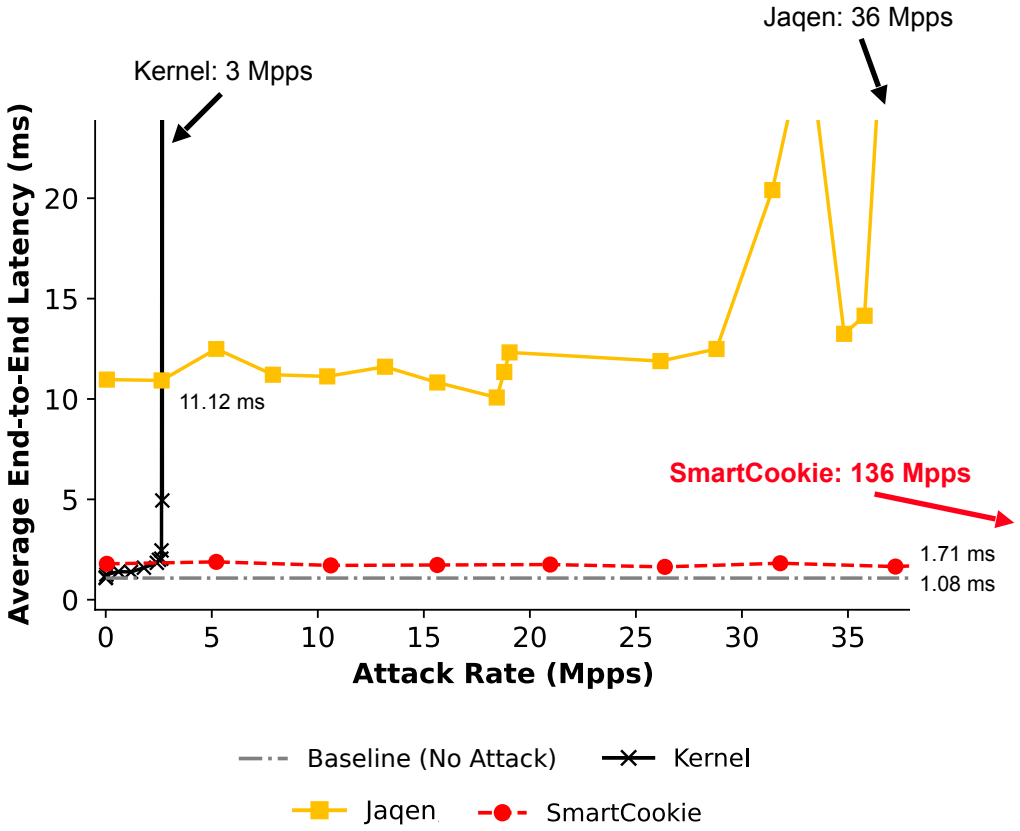
Protecting performance



Protecting performance



Protecting performance



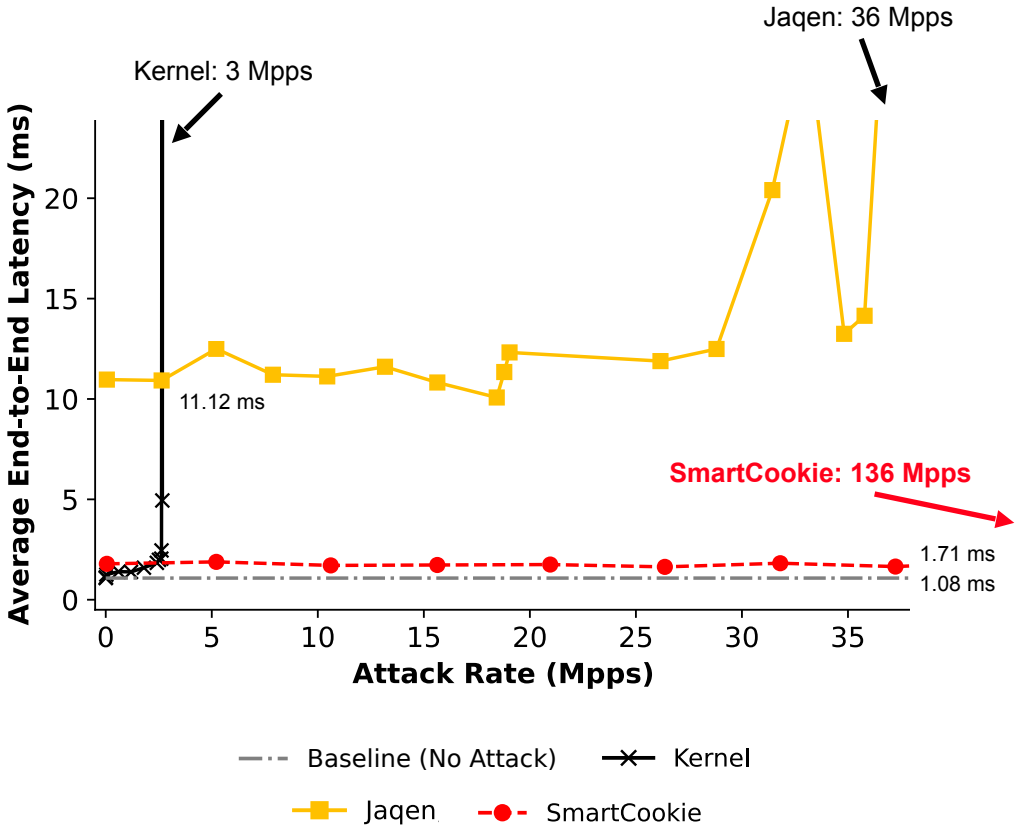
Protecting performance

Latency reduced 48-84% vs. Jaqen

Close to baseline latency without attack

In fact, zero packet loss until 136 Mpps

Throughput outperforms
- Jaqen by one order of magnitude
- Kernel by two orders of magnitude



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SmartCookie: Layered Hardware+Software Codesign

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https://github.com/Princeton-Cabernet/p4-projects/tree/master/SmartCookie

Live demo video on YouTube

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SmartCookie: Layered Hardware+Software Codesign

A split-proxy defense approach that

(i) exploits division of labor across targets;

(ii) with approximation in early layers but exact overall results;

(iii) to provide security, scalability, *and* performance

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Vision for future work

Split-layer design for other protocols, volumetric attacks, and IDS/IPS systems

…reducing processing and traffic inspection loads by moving parts earlier on path

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