CDN Judo : Breaking the CDN DoS Protection with Itself

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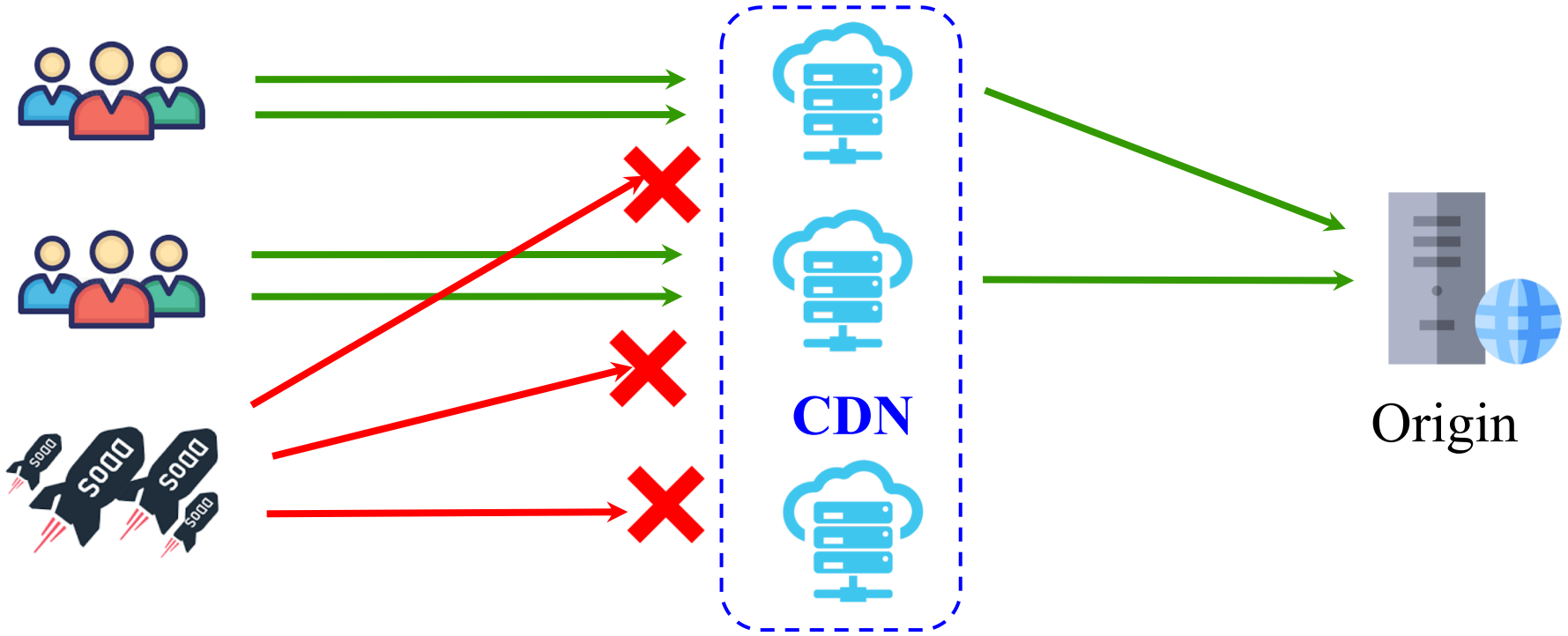
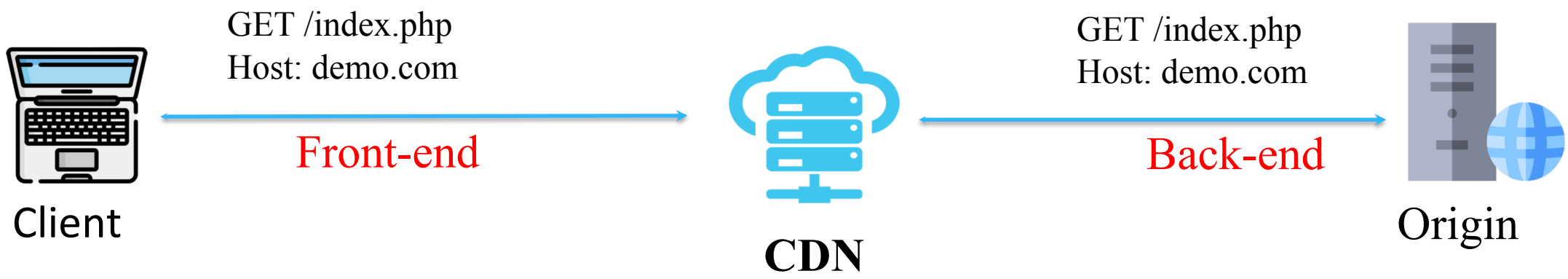
Content Delivery Network

- Infrastructure for access acceleration and DoS defense
  - 38.98% of top 10K websites use CDN [Your Remnant Tells Secret-DSN'18]
  - We find CDN itself can be abuse to break its DoS protection



CDN Forwarding Process

End-to-end connection ⇨ **Front-end and back-end connections**



Previous Works

Front-end connection security
[HTTPS meet CDN, IEEE S&P '14]
[TLS private key sharing, CCS '16]
[Host of troubles, CCS '16]
[Cache fallen, CCS '19]
[End user maneuvered, USENIX security '18]
[Cached and Confused, USENIX security '20]

CDN internal security
[Forwarding loop attack, NDSS '16]

Back-end connection security
[Protection or Threat, ESORICS '09]

Origin IP exposure
[CloudPiercer, CCS '15]
[Residual Resolution, DSN '18]

Client

Front-end

CDN

Back-end

Origin

Our work: abuse CDN-forwarded requests to attack the origin.

Our Work

- Exploiting CDN forwarding features to attack the origin

Attack-1	HTTP/2 amplification attack
Attack-2	Pre-POST slow HTTP attack
Attack-3	Egress IP blocking attack

- Performed real-world evaluations on six vendors

Attack-1

HTTP/2 Amplification Attack

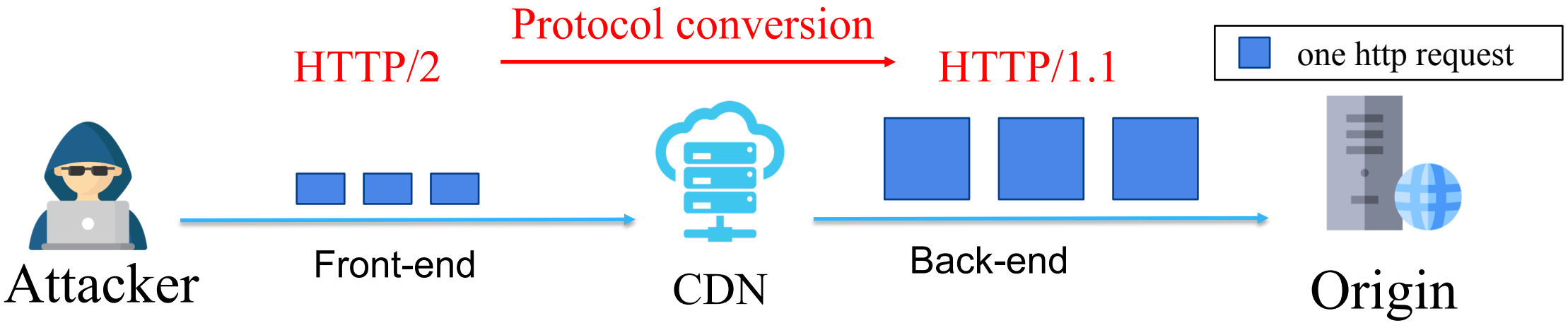
HTTP/2 Protocol

- Designed to improve HTTP performance
  - RFC7540, released in 2015
- Compression (to reduce header redundancy)
  - Binary protocol, HPACK header compression
- Connection reuse (to reduce TCP connections)
  - Request -> Stream
  - Streams are multiplexed

- *Deployment: Over 43.2% of Alexa top 1M websites (w3techs.com, 12 Feb 2020)*

Concept of HTTP/2 Amplification attack

- Our study
  - **Identify that HTTP/2-1.1 conversion of CDN will cause amplification attack.**
  - **Improve the attack with the feature of Huffman encoding.**
  - **Real-world measurement and evaluation**



- [HTTP/2 Tsunami Attack, EST '17]
  Show bandwidth amplification attack in local proxies built with Nginx and Nghttp2.

CDN Vendors Claim to Support HTTP/2

- HTTP/2 is supported by most major CDNs
- The backend connection still uses HTTP/1.1

	CloudFront	Cloudflare	CDNSun	Fastly	KeyCDN	MaxCDN
Frontend Connection	Default on Configurable	Default on	Default on	Default off Configurable	Default on	Default on Configurable
Backend Connection	Only support HTTP/1.1					

Next we describe three amplification attack techniques.

HPACK Static Table

- An indexed table of common header fields
- pre-defined in both HTTP/2 client and server.

Raw Request

```
GET / HTTP/1.1
host: demo.com
scheme: https
```

49 Bytes

Static Table

1	:authority	
2	:method	GET
3	:method	POST
4	:path	/
...	...	...
7	:scheme	https
...	...	...
61	www-authenticate	

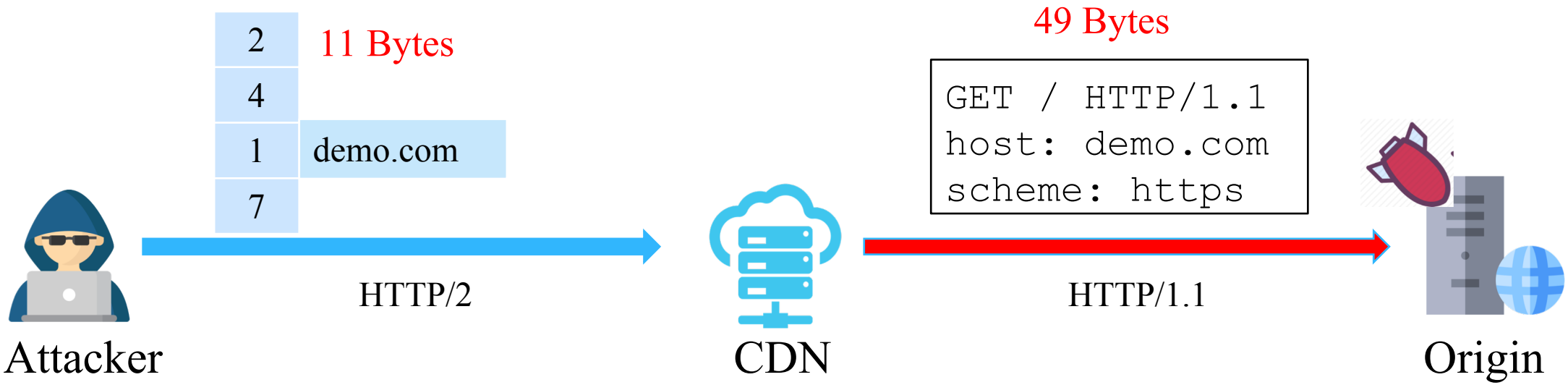
Encoded Data

2	
4	
1	demo.com
7	

11 Bytes

Attack-1.1: Using HPACK Static Table

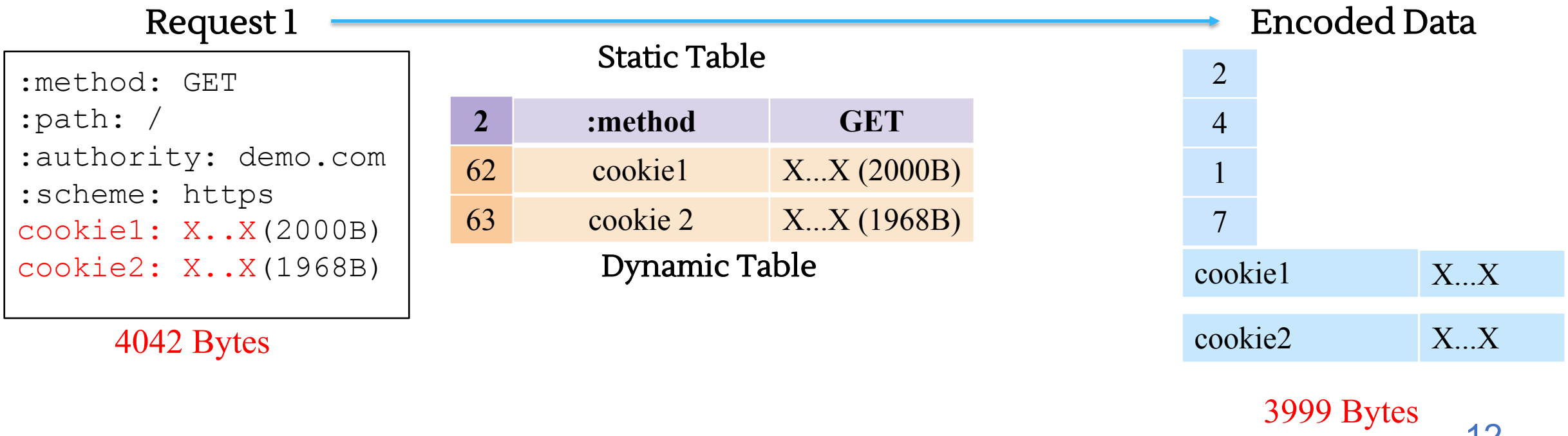
- HTTP/2-1.1 conversion of CDN causes a bandwidth amplification.



Bandwidth amplification factor: 49B / 11B = 4.45

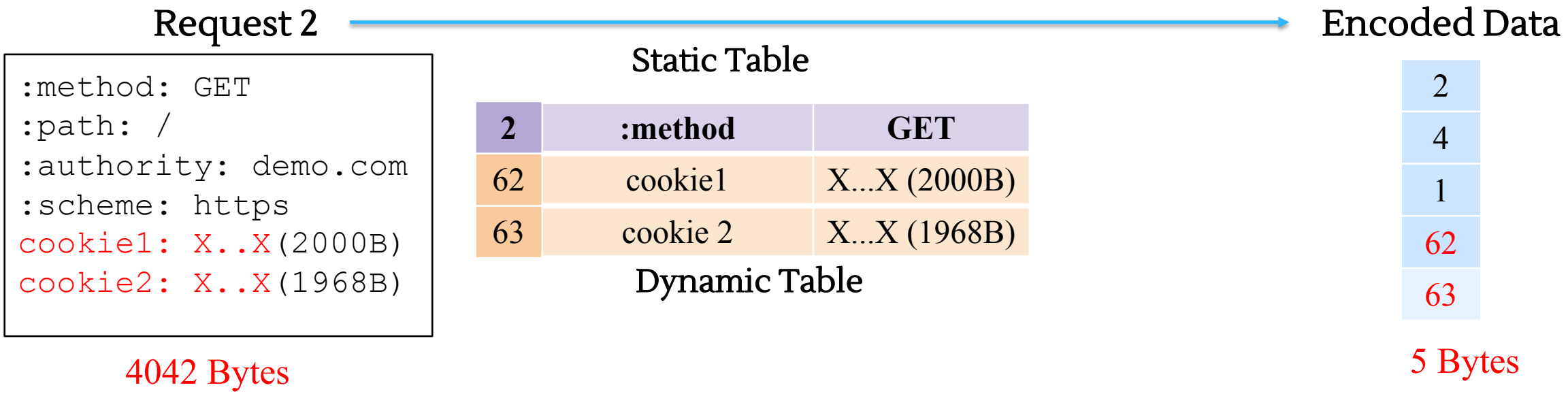
HPACK Dynamic Table (1/2)

- An indexed table of previously seen headers to avoid repeatedly transferring headers.
  - ➢Step 1: The firstly seen headers will be inserted into the dynamic table.



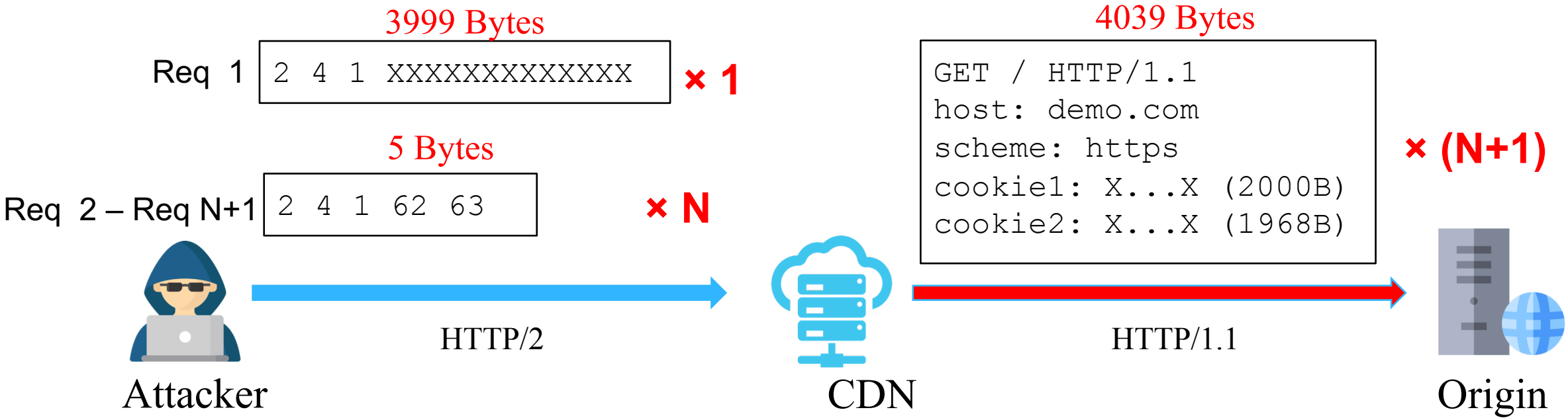
HPACK Dynamic Table (2/2)

- An indexed table of previously seen headers to avoid repeatedly transferring headers.
  - ➢Step 2: The subsequently repeated headers will be substituted as an index.



Attack-1.2: Using HPACK Dynamic Table

- The dynamic table enhances this kind of bandwidth amplification.

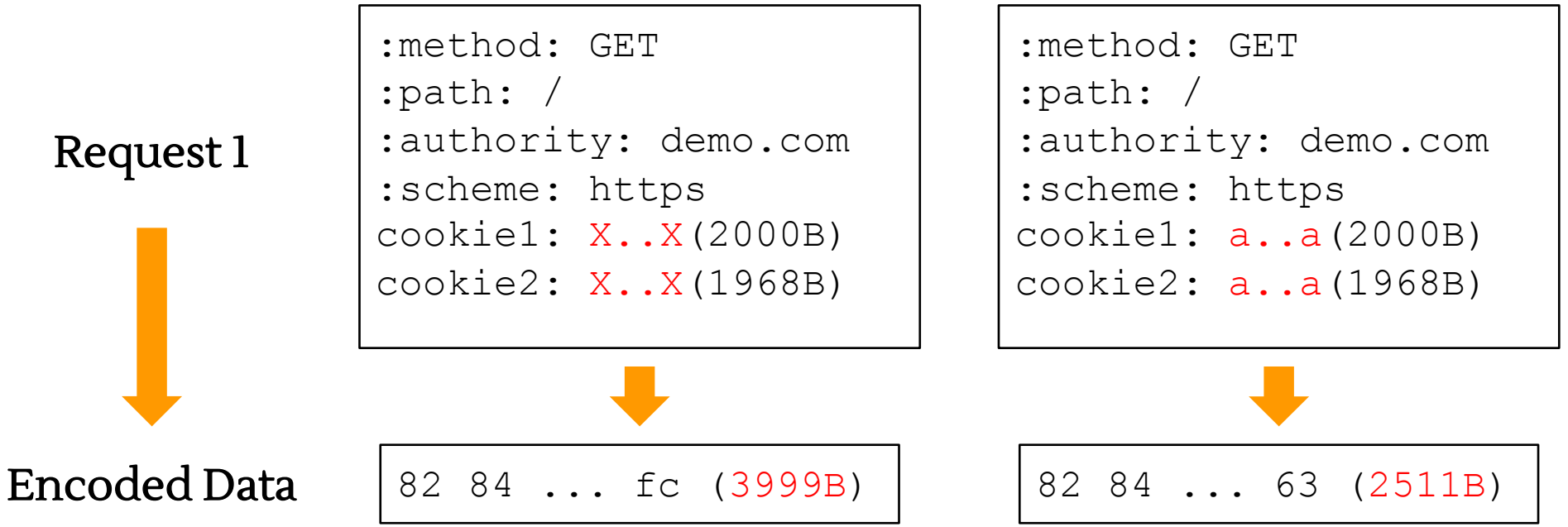


Bandwidth amplification factor: 4039B × **(N+1)** / 3999B + 5B × **N** = $\frac{4039 + 4039N}{3999 + 5N}$

For example, when N is 100, the factor is 88.70.

Attack-1.3: Improve with Huffman Encoding

- Some special characters can have short Huffman encodings
  - The Huffman encoding of 'X' is 8 bits in length.
  - Characters {0, 1, 2, a, c, e, i, o, s, t} have the shortest Huffman encoding (5 bits).



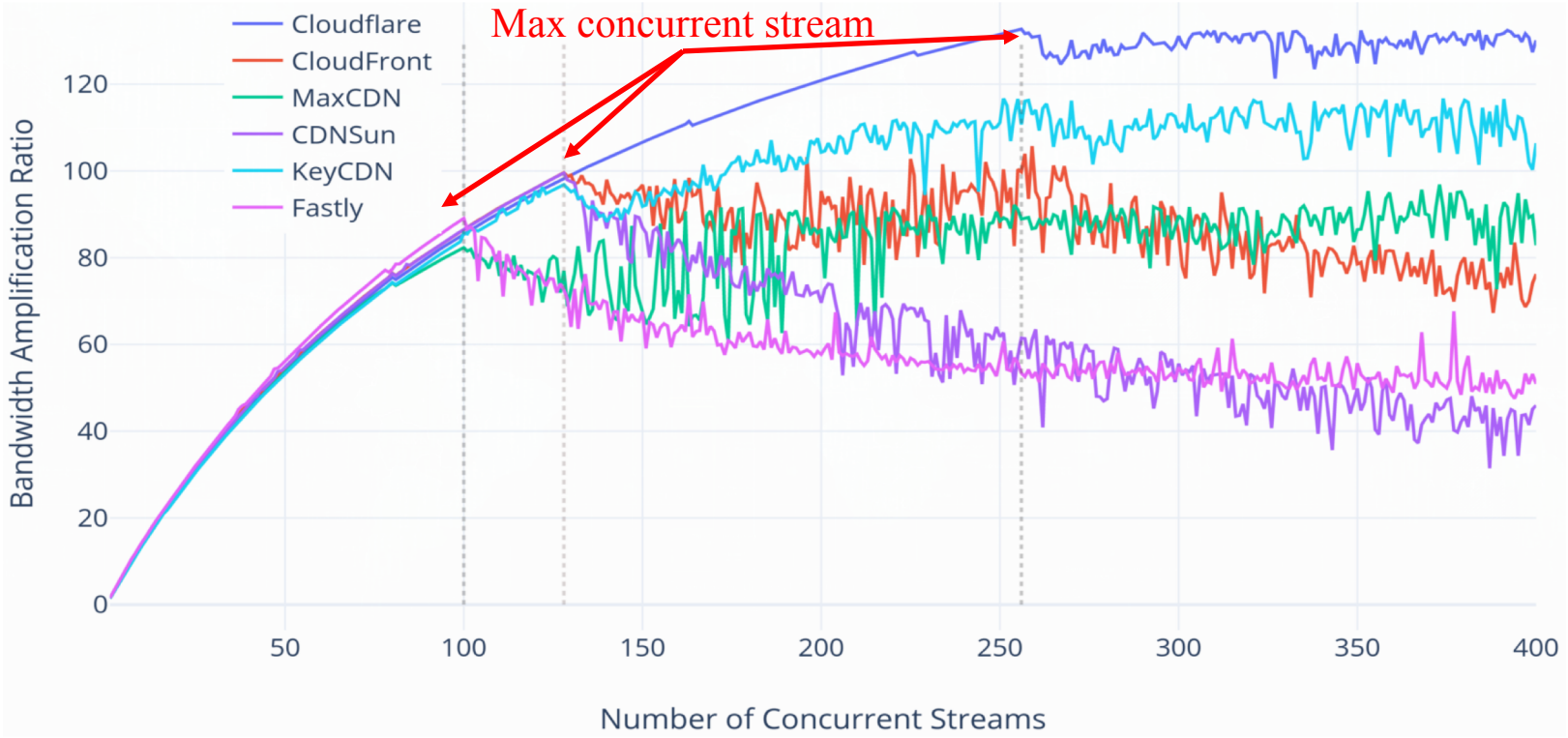
Attack-1.3: Improve with Huffman Encoding

- The shorter the Huffman encoding, the larger the amplification factor.

	Huffman Encoding Length	Amplification Factor	
Character 'X'	8 bits	$\frac{4039 + 4039\mathbf{N}}{3999 + 5N}$	88.70 when N is 100
Character 'a'	5 bits	$\frac{4039 + 4039\mathbf{N}}{2511 + 5N}$	131.13 when N is 100
Note: N is the concurrent streams in the same HTTP/2 connection.			

Bandwidth Amplification Evaluation

- Create multiple concurrent requests in one HTTP/2 connection.
  - The amplification factor grows with the number of concurrent streams.
  - The max factor is got at the position of the max concurrent streams.



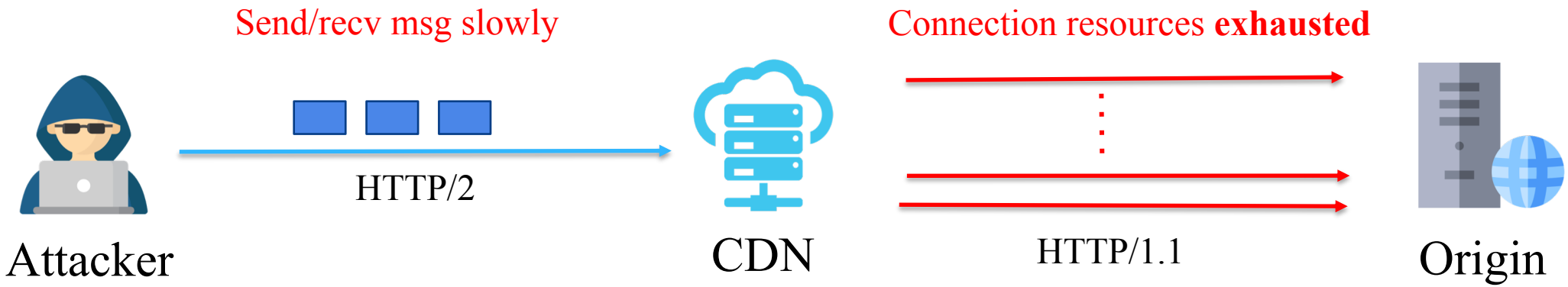
Comparison with previous work

- Our work achieved larger amplification factors than previous work.

	Max Streams	100		128			256
Our Attack	Evaluation Platform	MaxCDN	Fastly	CDNsun	CloudFront	KeyCDN	Cloudflare
	Amplification Factor	94.7	97.9	118.7	116.9	105.5	166.1
HTTP/2 Tsunami Attack	Evaluation Platform	HTTP/2 Proxies built with Nginx and Nghttp2					
	Amplification Factor	79.2		94.4			140.6

HTTP/2 Connection Amplification Attack

- concurrent streams in one HTTP/2 connection → multiple HTTP/1.1 connections



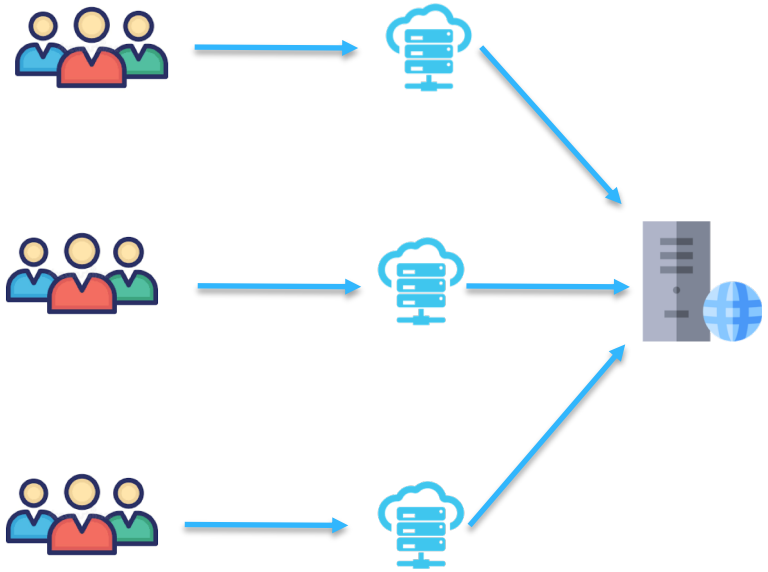
	CloudFront	Cloudflare	CDNSun	Fastly	KeyCDN	MaxCDN
Max concurrent streams per HTTP/2 connection	128	256	128	100	128	100
Connection Amplification	Yes	Yes	-	-	-	Yes

Attack-3

Egress IP Blocking Attack

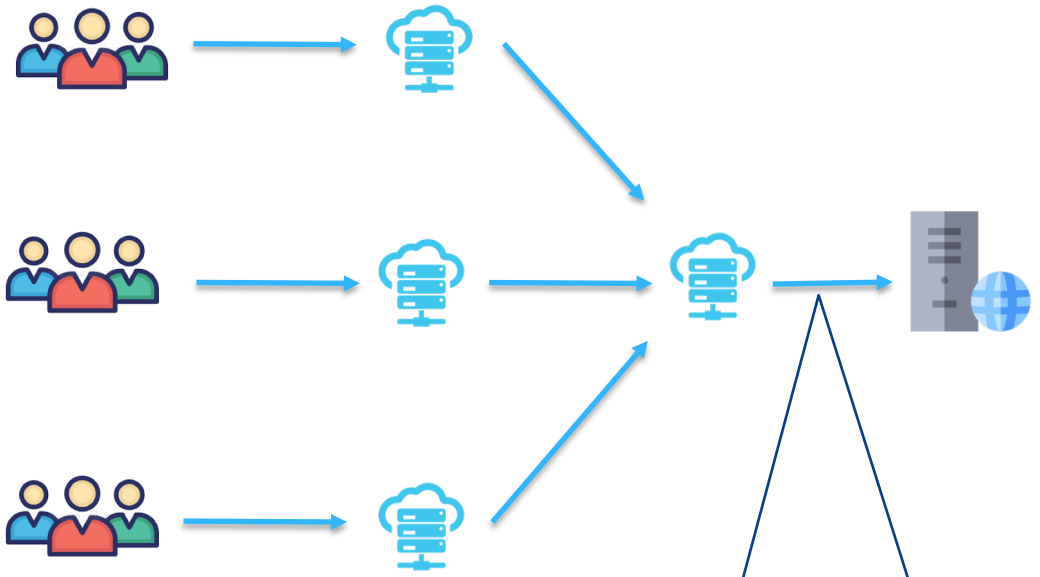
Origin Shield

Without Origin Shield



With Origin Shield

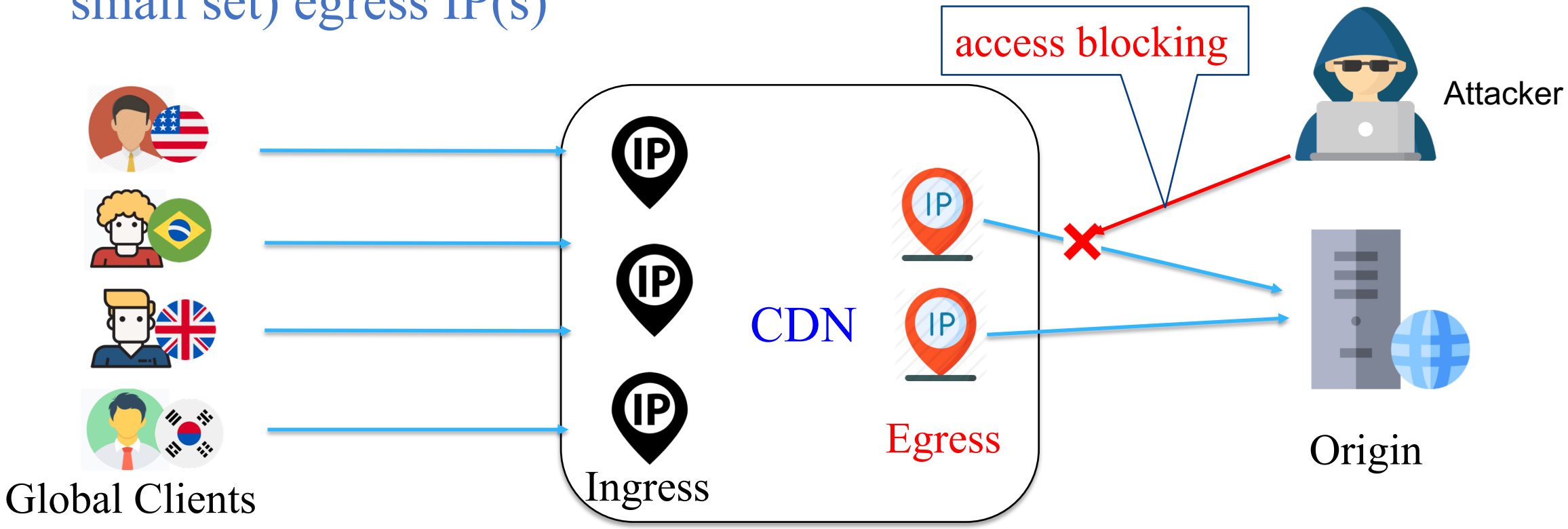
- reduce origin workload
- speed up cache-miss responses



- *https://docs.fastly.com/en/guides/shielding*

Threat Model

- Global clients will be affected when an attacker just block one (or a small set) egress IP(s)



Next we describe our measurement of CDN IP distribution, and evaluation experiments.

Characteristics of Egress IP distribution

- Observation 1: Fewer egress IPs than ingress IPs

	Ingress IPs	Egress IPs	Egress/Ingress
CloudFront	128,906	862	0.67%
Cloudflare	490,309	242	0.05%
Fastly	64,659	1,136	1.7%
MaxCDN	300	12	4%

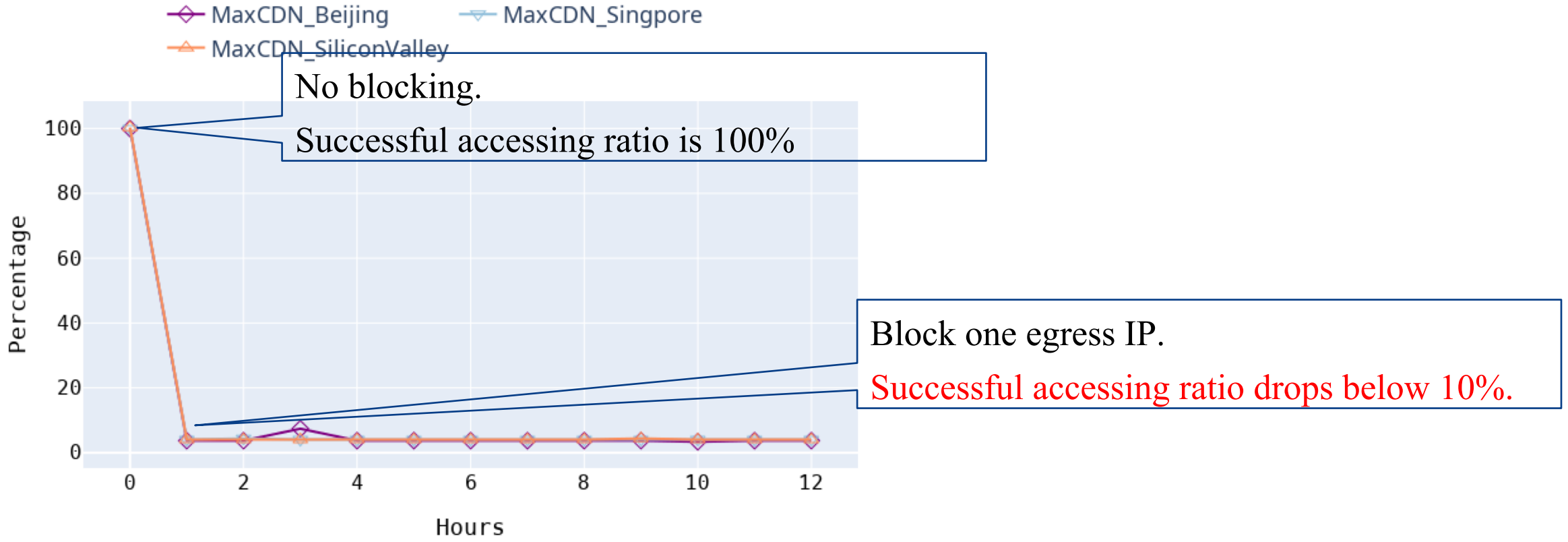
- Observation 2: Churning rate of egress IPs are low
  - ➢ MaxCDN: 96.32% of the backend connections originated from the same egress IP.
  - ➢ Other CDNs churn egress IPs more fast, < 10% of the backend connections originated form the same egress IP.

- *Results are consistent with [Unveil the hidden presence, ICNP '19]*

Egress IP Blocking Evaluation

MaxCDN

- We block one single egress IP at our origin for 12 hours
- Access the website from global ingress IPs



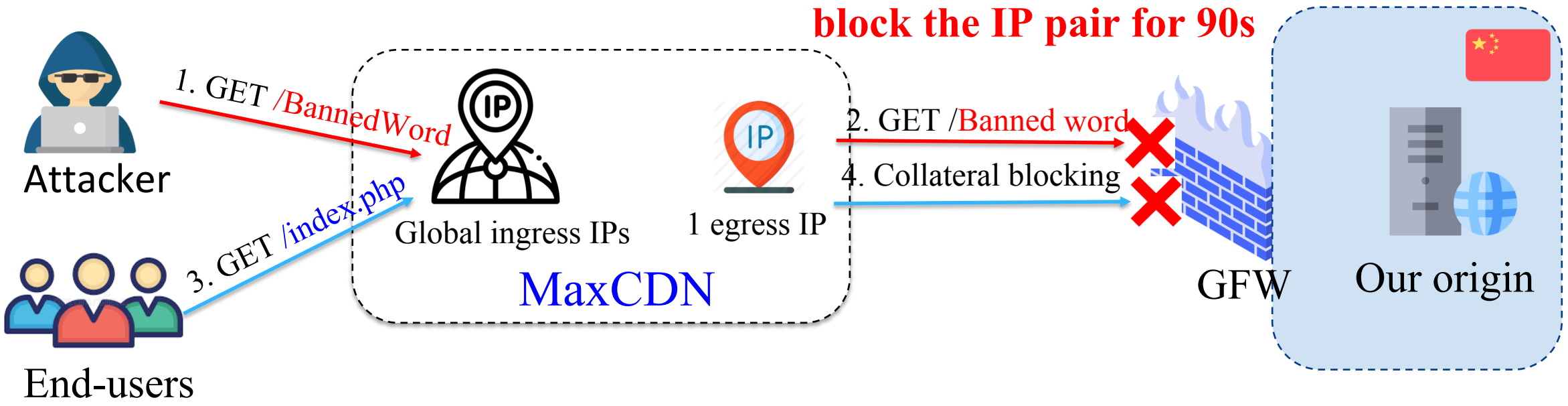
Real-world Case Study

Censorship (e.g., Great Firewall of China)

- locate between CDN and origin
- inspect censored bad words
- block the IP pair for 90s

Collateral blocking

- Attacker sends requests to ingress IPs
- Global end-users are collaterally blocked



Mitigation

Threats	Recommendation
HTTP/2 attack	HTTP/2 support for back-end connection limit the back-end network traffic.
Pre-POST attack	limit the number of CDN back-to-origin connections enforce strict forwarding (store-then-forward).
Egress IP blocking	apply unpredictable egress IP churning strategy.

Responsible Disclosure

- **Cloudflare:** reproduced HTTP/2 amplification with 126x and rewarded us $200 bonus.
- **Fastly:** confirmed our report and offered us T-shirts.
- **CloudFront:** suggested HTTP/2 amplification is a feature of HTTP/2 standard, and would like to use rate-based WAF rules to mitigate the attack.
- **MaxCDN:** stated the egress IP blocking is out of scope as it involves with additional GFW infrastructure.
- **CDNSun** and **KeyCDN:** received our report but no further comments so far.

Summary

- A empirical security study on CDN back-end connections
  - HTTP/2 amplification attack
  - pre-POST slow HTTP attack
  - Egress IP blocking attack
- Real-world evaluation on six CDN vendors
  - Received positive feedback from some CDNs
- How to balance performance and security

Thank you!