:: Privacy Pass ::

Bypassing internet challenges anonymously

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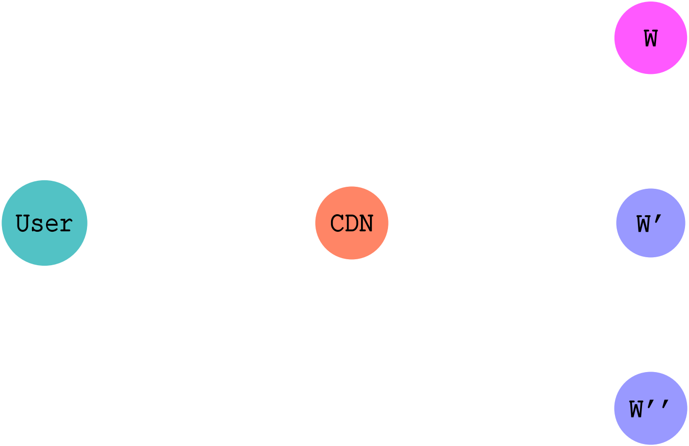
Background

Anonymous authentication protocol

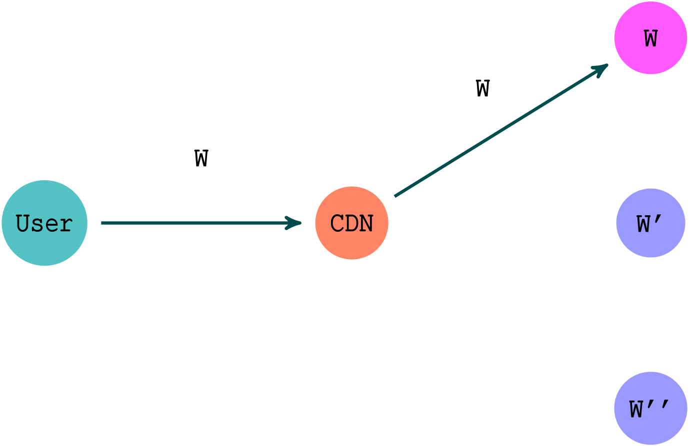
Privacy Pass

Summary

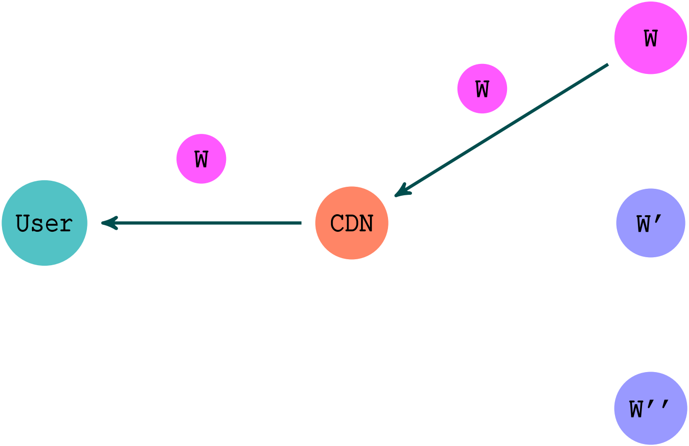
Content delivery networks



Content delivery networks



Content delivery networks



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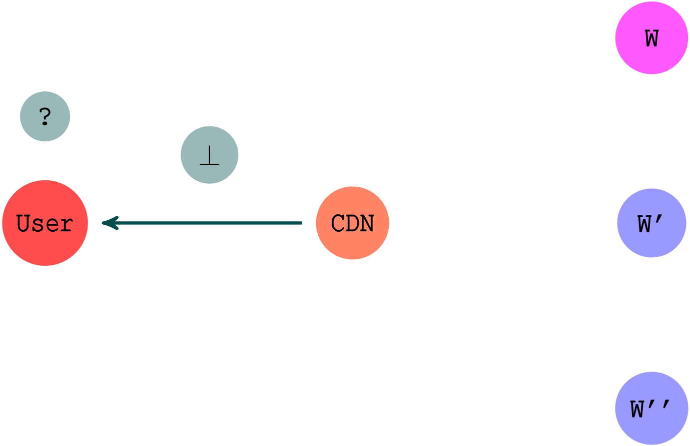
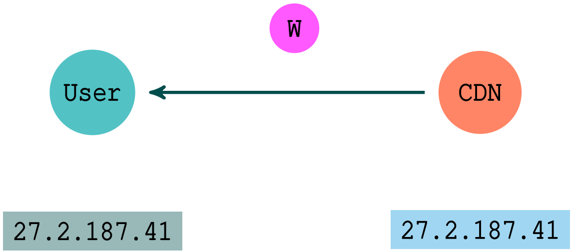
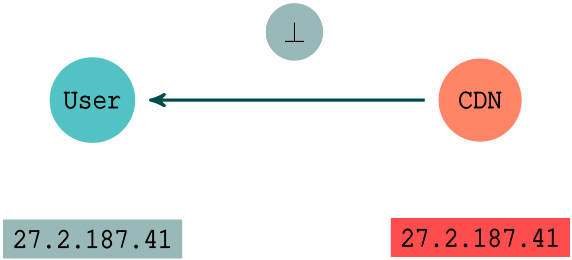


e.g. DDoS, spam filtering, content scraping etc...

IP reputation



IP reputation



Is this a good system?

::false negatives::

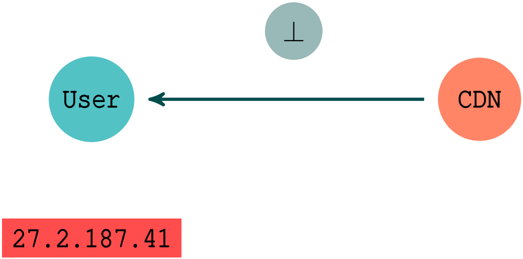
particularly users of static, shared IP addresses

Is this a good system?

::affected users::

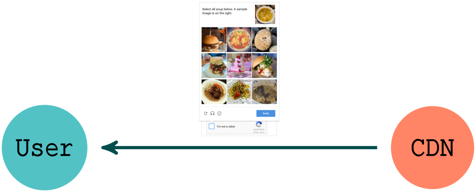
Is this a good system?

::worst case::



Is this a good system?

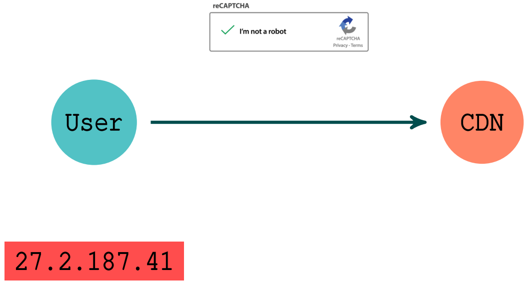
::average case::



27.2.187.41

Is this a good system?

::average case::



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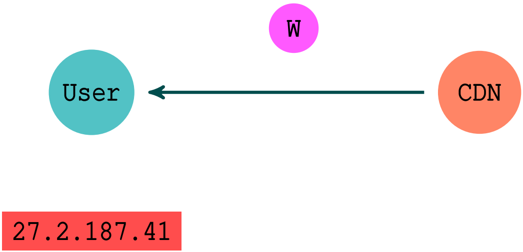
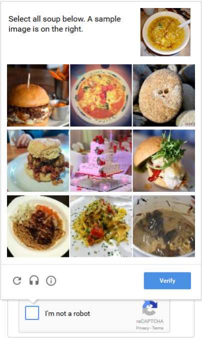


Problems with challenges (aka CAPTCHAs)



::: Heavily JS reliant

::: Potentially block access

::: Annoying/hard

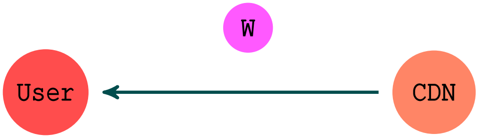
::: Slow

::: Questionable protection

::: More round trips

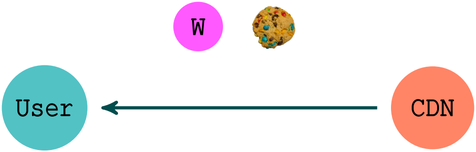
Possible solutions

::no blocking::



Possible solutions

::cookies?::



Possible solutions

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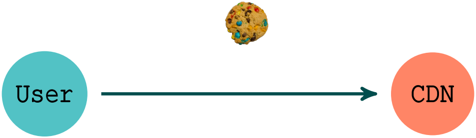

problem: linkability

Contributions

::: Anonymous authentication protocol

:: based on elliptic curves and oblivious prfs

:: combination of prior techniques [JKK14, Hen14]

::: Client-side implementation in browser extension

::: Server-side deployment in Cloudflare edge servers

::: Empirical survey of results

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Privacy Pass

Summary

Oblivious pseudorandom function (OPRF)

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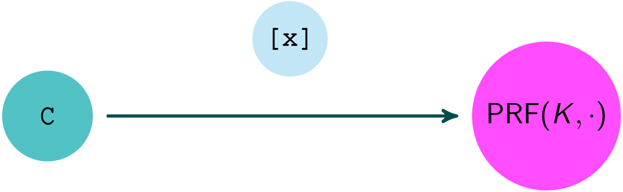
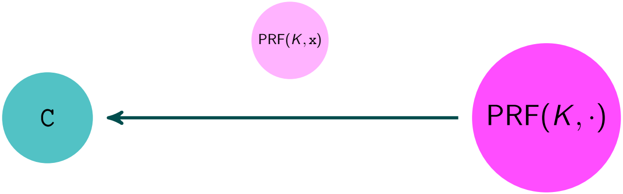


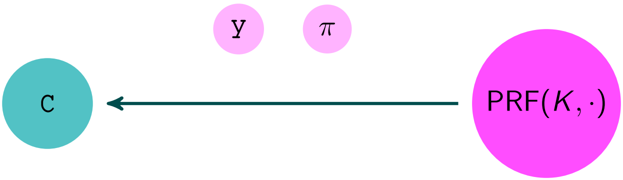
x is hidden from the PRF evaluator

Oblivious pseudorandom function (OPRF)



K is not revealed to C

Verifiable OPRF (VOPRF)



π is a NIZK proof that $\mathtt{y} \leftarrow \mathsf{PRF}(K,\mathtt{x})$

Elliptic curve VOPRF (EC-VOPRF)

$$[x] = H(x)^r$$

$$y = [x]^k$$

$$\pi = \text{DLEQ}$$

H hashes x to an elliptic curve

π is a discrete log equivalence (DLEQ) proof

DLEQ proofs

::summary::

public commitments: g, $h = g^k$

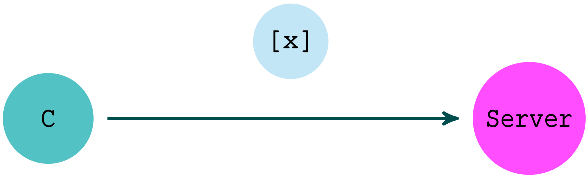
signed token pair: x, y

show that $\log_g(h) = \log_x(y) = k$

without revealing k

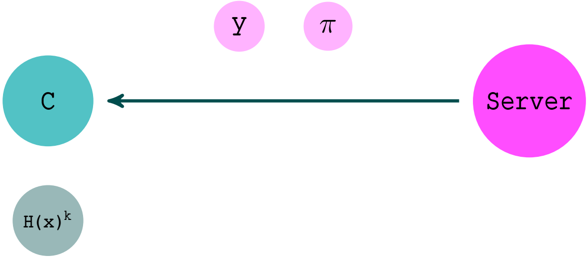
Anonymous authentication protocol

::signing::



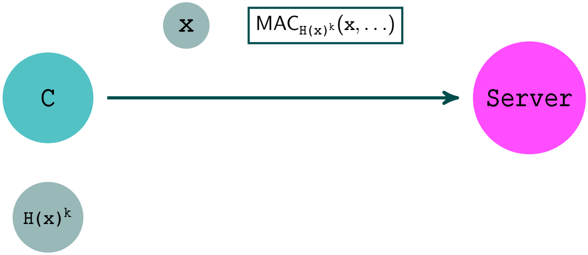
Anonymous authentication protocol

::signing::



Anonymous authentication protocol

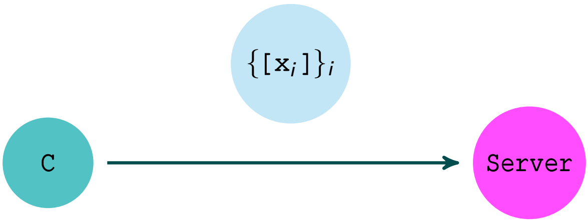
::redemption::



server verifies MAC to authenticate C

Anonymous authentication protocol

::multiple tokens::



Anonymous authentication protocol

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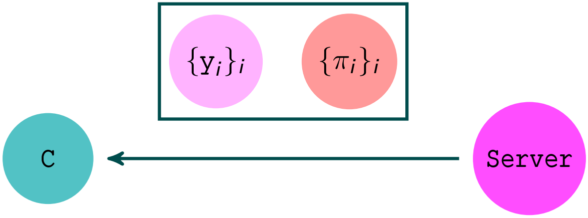
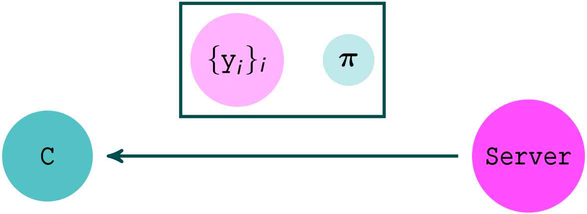


similar design to [JKK14]

Anonymous authentication protocol

::multiple tokens::



batched DLEQ proofs! [Hen14]

Security properties

::unlinkability::

::: any x should be unlinkable from any signing phase

::: prevents server from linking authentication sessions

::: $H(x)^r$ uniformly blinds x from Server

Security properties

::one-more-token security::

::: for N signed tokens, hard to create $N+1$ signed tokens

::: prevents client from forging signed tokens

::: reduction from one-more-decryption security of El Gamal

Security properties

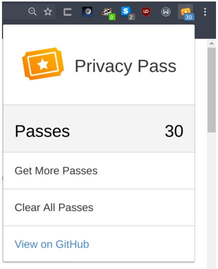
::Key consistency::

::: ensures that all tokens are signed by one key k

::: prevent server deanonymisation using different keys

::: soundness of batch DLEQ proof [Hen14]

Privacy Pass



::browser extension::

Privacy Pass

::Cloudflare::

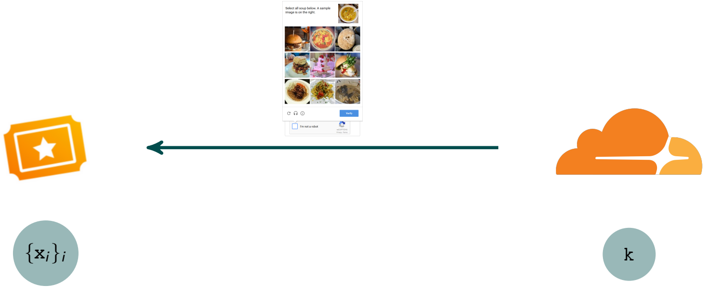
::: CDN serves 10% of internet traffic

::: use CAPTCHAs to prevent bots accessing origins

::: use IP reputation to decide challenging or not

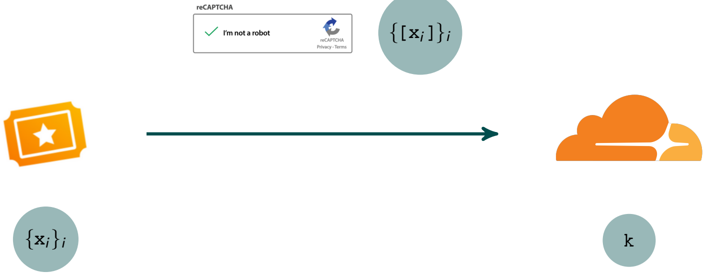
Privacy Pass

::acquiring signed tokens::



Privacy Pass

::acquiring signed tokens::



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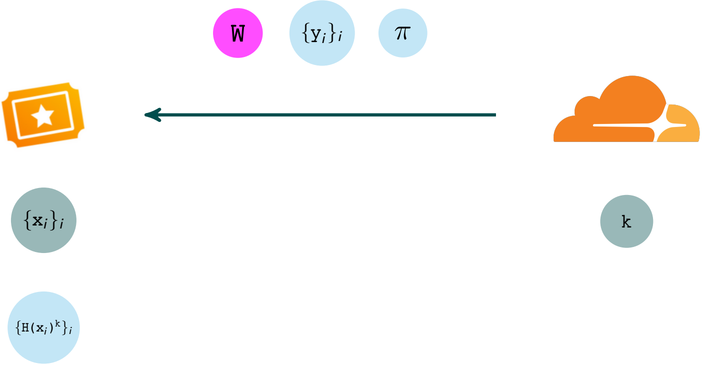
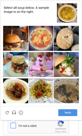


Privacy Pass

::bypassing challenges::



$\{x_i\}_i$

k

$\{H(x_i)^k\}_i$

Privacy Pass

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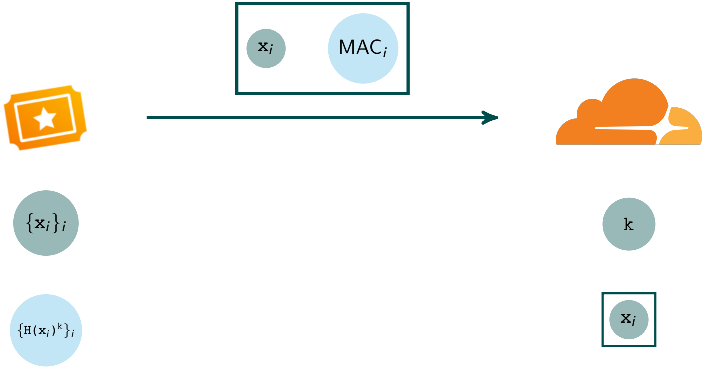

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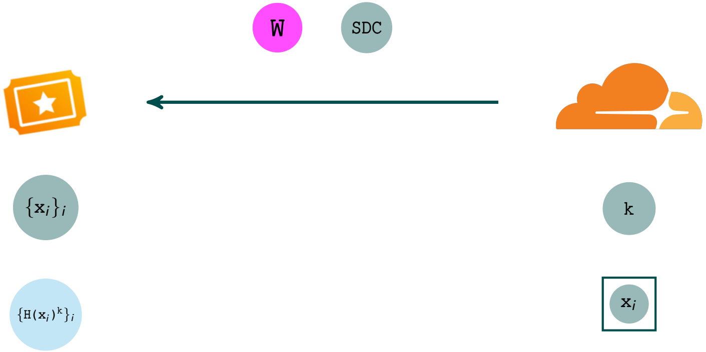

Specifics

::: Elliptic curve: NIST P256

::: $\boxed{\text{Public commitments } (g, g^k) \text{ for DLEQ verification}}$

::: Batch DLEQ PRNG: SHAKE-256

::: Default # of signed tokens (client-side): 30

::: $\boxed{\text{Max signed tokens (server-side): 300}}$

::: Triggers: $\{\text{status codes}, \text{headers}\}$

::: Code:

:: https://github.com/privacypass/challenge-bypass-extension
:: https://github.com/privacypass/challenge-bypass-server
:: https://privacypass.github.io/protocol (protocol summary)

Benchmarks

::Timings (ms)::

	Operation	Timings
Client	Token generation	$120 + 64 \cdot N$
	Verify DLEQ	$220 + 110 \cdot N$
	Total signing request	$340 + 180 \cdot N$
	Total redeem request	57
Server	Signing	$0.04 + 0.20 \cdot N$
	DLEQ generation	$0.32 + 0.55 \cdot N$
	Total signing	$1.48 + 0.87 \cdot N$
	Total redemption	0.8

$N =$ # of tokens batch signed

Benchmarks

::Request size (bytes)::

Operation	Size (bytes)
Signing request (U $\rightarrow$ CDN)	$57 + 63 \cdot N$
Signing response (CDN $\rightarrow$ U)	$295 + 121 \cdot N$
Redemption request (U $\rightarrow$ CDN)	396

$N =$ # of tokens batch signed

Cloudflare deployment (Nov 2017)

::Release::

::: Extension released: 8 Nov 2017

::: Downloads (28 Nov 2017)

:: Chrome extension: 8499

:: Firefox add-on: 3489

::: Downloads (Jul 2018)

:: Chrome extension: 61578

:: Firefox add-on: 16375

Cloudflare deployment (Nov 2017)

Metric	Global	Tor
Total requests (per week)	1.6 trillion	700 million
Total challenged requests	1.04%	17%
Signs (peak per hour)	$\sim$600	$\sim$100
Redeems {Nov 2017} (peak per hour)	$\sim$2000	$\sim$200
Redeems {Jul 2018} (peak per hour)	$\sim$3300	$\sim$600
Single-domain cookies (Nov 2017)	515 million	34 million

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Conclusion and links

::: Privacy Pass extension is still in beta

::: Further analysis of protocol/code would be welcome!

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::: Protocol spec:

:: https://tinyurl.com/pp-protocol

::: Website:

:: https://privacypass.github.io

::: Code (contribute!):

:: https://github.com/privacypass/challenge-bypass-extension

:: https://github.com/privacypass/challenge-bypass-server

::: Support:

:: privacy-pass-support@cloudflare.com

Final notes

::: See paper for:

{ more analysis of out-of-band attacks, comparison with existing research, security proofs, implementation details }

::: EC-VOPRF IETF standardisation

:: https://github.com/chris-wood/draft-sullivan-cfrg-voprf

::: Future work:

{ DLEQ update, more integrations, better documentation, PQ VOPRF }

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Thanks for listening!

https://privacypass.github.io

References

[Hen14] Henry, Ryan.
Efficient Zero-Knowledge Proofs and Applications.
PhD thesis, University of Waterloo, 2014.
http://hdl.handle.net/10012/8621.

[JKK14] Stanislaw Jarecki, Aggelos Kiayias, and Hugo Krawczyk.
Round-optimal password-protected secret sharing and T-PAKE in the password-only model.
In Palash Sarkar and Tetsu Iwata, editors, *ASIACRYPT 2014, Part II*, volume 8874 of *LNCS*, pages 233--253. Springer, Heidelberg, December 2014.