Express: Lowering the Cost of Metadata-hiding Communication with Cryptographic Privacy

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Our Story

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How to Communicate Privately?

Option 1:

End to end encrypted messaging apps

E.g. Signal, WhatsApp

Problem: **metadata**

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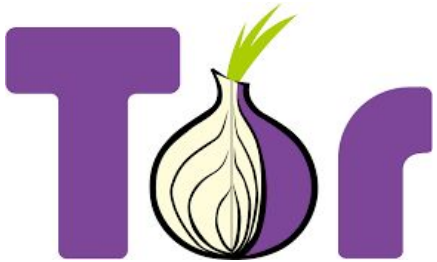
Option 2:

Anonymizing proxy

E.g. Tor, SecureDrop

Problem: **global adversaries**



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- Requirement to run in synchronized rounds
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Can we make metadata-hiding communication work for whistleblowing?

Introducing Express

Communication system designed for practical metadata-hiding whistleblowing

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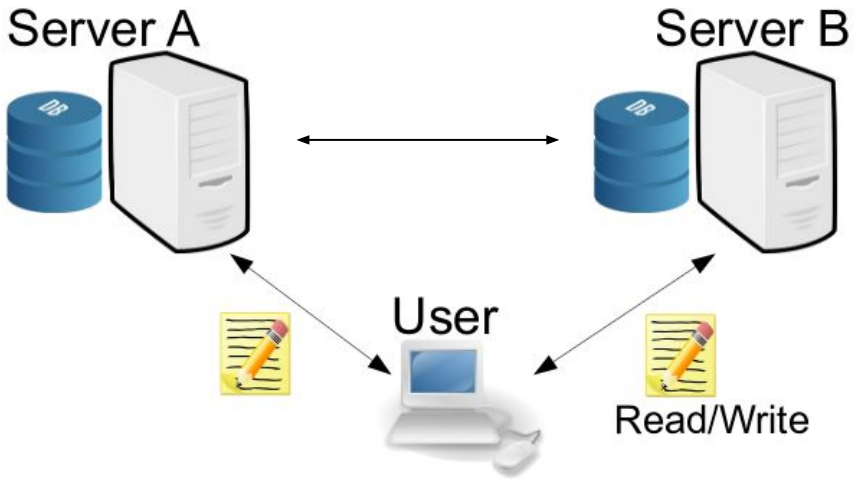
(both previously O(√N))

Practical improvements:
6x improvement in server computation time
8x improvement in client computation time
>10x improvement in communication costs
6x reduction in dollar cost to run system

Express Overview

2 server system, secure against:

- Arbitrarily many corrupt users
- Up to one corrupt server



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Supported operations:

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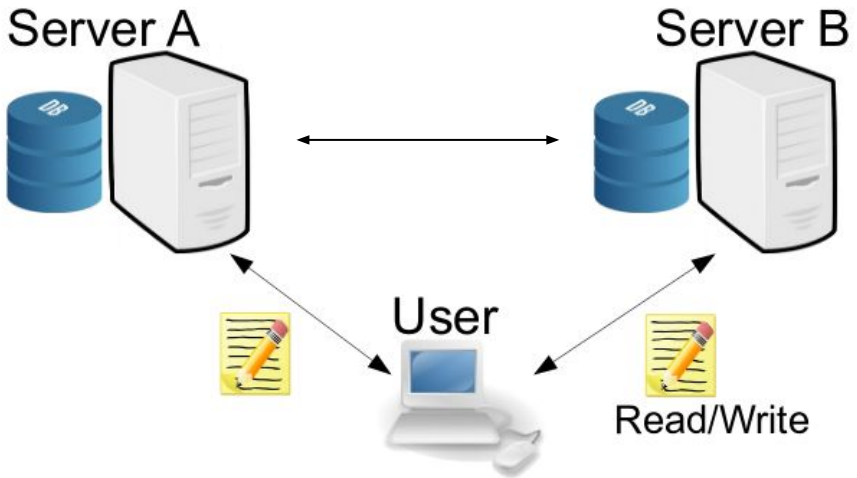

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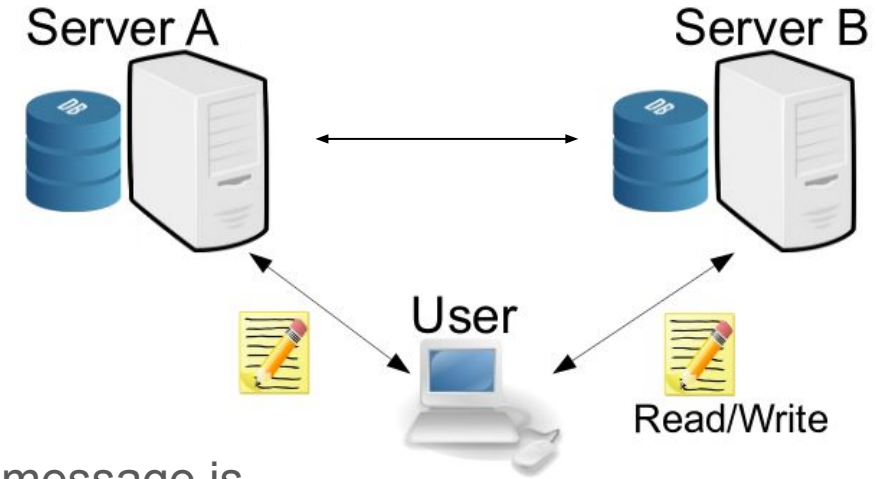

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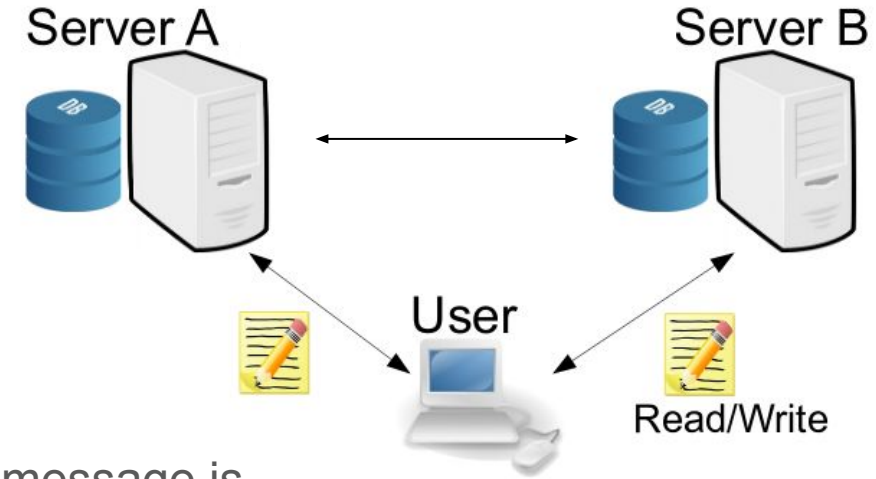

Security: can't tell who the *recipient* of a message is

Assumption: user knows "address" of mailbox to which it sends message

Tool: Private Writing with Distributed Point Functions

Point function: a function that is zero everywhere, except at one point

Distributed Point Functions and their Applications, Niv Gilboa, Yuval Ishai, *Eurocrypt'14.*

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Point function: a function that is zero everywhere, except at one point

x	f(x)
0	0
1	0
2	0
3	“Hi!”
4	0

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x	$f_1(x)$
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3	“!7≈”
4	“jhV”

$\oplus$

x	$f_2(x)$
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Distributed point function: technique for efficiently splitting a point function into two pieces, each a (non-point) function whose XOR is the original point function

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⊕

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Key features:

- concise representation
- fast to generate

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Addr	Data
0	0
1	0
2	0
3	0
4	0

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f_1

f_2

Addr	Data
0	$f_1(0)$
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2	$f_1(2)$
3	$f_1(3)$
4	$f_1(4)$

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0	$f_2(0)$
1	$f_2(1)$
2	$f_2(2)$
3	$f_2(3)$
4	$f_2(4)$

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Hiding Data

How to prevent curious clients from reading others' mailboxes?

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Encrypt each row with a different key held by the owner of the mailbox

Addr	Data	Key
0	“abc”	k_{NYT}
1	“xf$”	k_{WaPo}
2	“^tg”	k_{WSJ}
3	“!7≈”	$k_{Buzzfeed}$
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Different key sent to each server, encrypt in CTR mode to allow adding messages

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1	"xf$"	k_{WaPo1}
2	"^tg"	k_{WSJ1}
3	"!7≈"	$k_{Buzzfeed1}$
4	"jhV"	$k_{Inquirer1}$

Addr	Data	Key
0	"abc"	k_{NYT2}
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2	"^tg"	k_{WSJ2}
3	"'2!)"	$k_{Buzzfeed2}$
4	"jhV"	$k_{Inquirer2}$

Hiding *Meta*data

Construction thus far vulnerable to polling attack:

Attacker reads every row after each write to see which one was changed

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Solution: servers non-interactively re-randomize every row after each write

Additional cost is low since they already write to each row

Hiding *Meta*data

Data Server A

Addr.	Key	Data
0	k_{A0}	abc + f(k_{A0}, c)
1	k_{A1}	xf$ + f(k_{A1}, c)
2	k_{A2}	!7≈ + f(k_{A2}, c)
3	k_{A3}	^tg + f(k_{A3}, c)

logN bits 128 bits Data size

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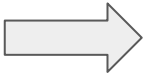

Data
(abc + f(k_{A0}, c)) - f(k_{A0}, c) +f(k_{A0}, c+1)
(xf$ + f(k_{A1}, c)) - f(k_{A1}, c) + f(k_{A1}, c+1)
(!7≈ + f(k_{A2}, c)) - f(k_{A2}, c) + f(k_{A2}, c+1)
(^tg + f(k_{A3}, c)) - f(k_{A3}, c) + f(k_{A3}, c+1)

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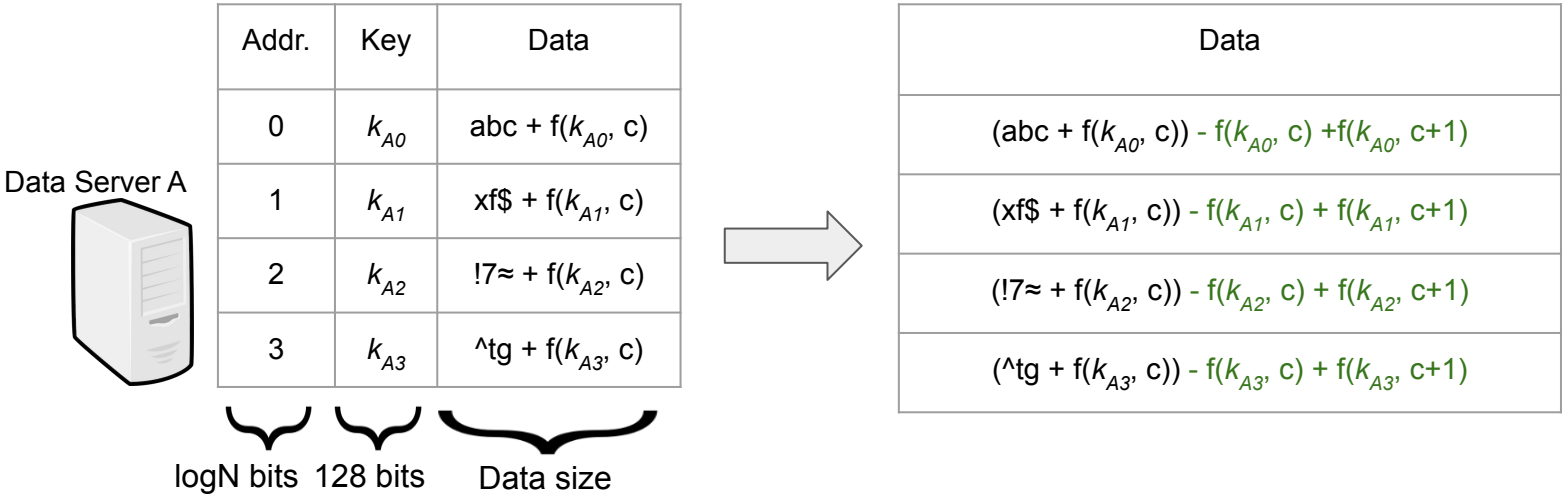

Optimization: only rerandomize just before a read, not after each write

Plausible Deniability

How to protect privacy of whistleblowers if *all users* are whistleblowers?

Conscript your friends into larger anonymity sets with JavaScript, Henry Corrigan-Gibbs, Bryan Ford, *WPES'13*

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Plausible Deniability

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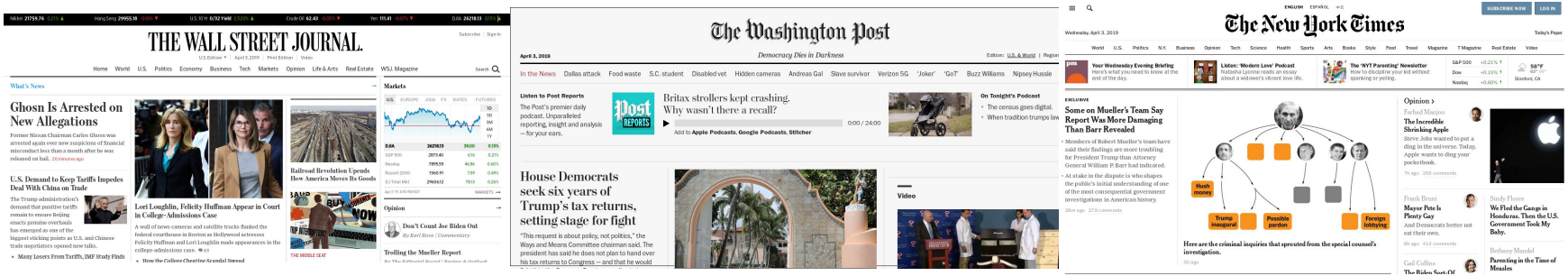
Idea: Cooperative web sites embed JS that sends dummy write requests

- Incentives properly aligned for news organizations
- Metadata-hiding means we only need 1 recipient mailbox for dummy writes
- Client-side costs low enough to not affect browsing experience



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Handling Disruptive Users

Any number of users can act maliciously in arbitrary ways

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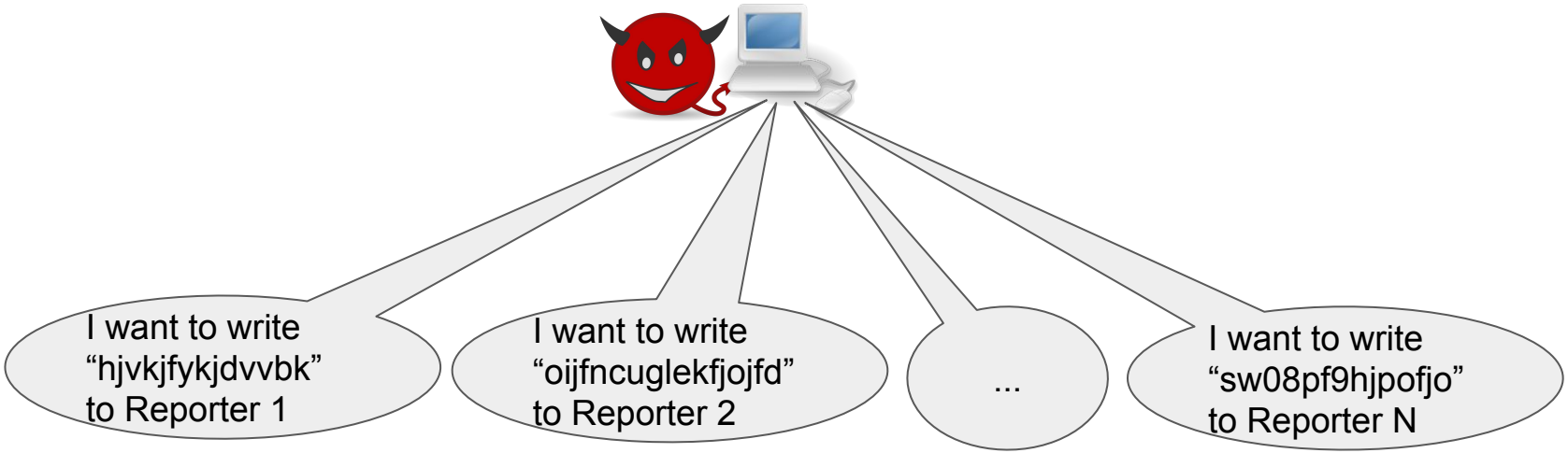
Two kinds of attacks:

1. Disruptive user writes to others' mailbox
2. Disruptive user sends malformed DPF to write to many mailboxes

Handling Disruptive Users

Problem: disruptive user writes to others' mailboxes



Virtual Addresses

Problem: disruptive user writes to others' mailboxes

Solution: hide mailboxes in exponentially large address space

Addr	Data
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...	...
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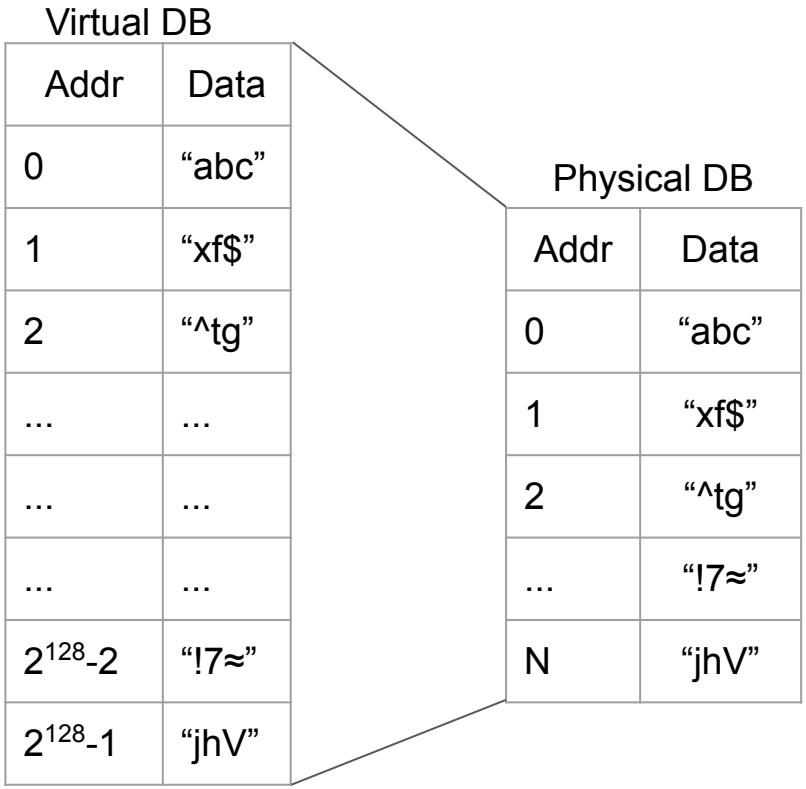

Auditing

Problem: disruptive user sends malformed DPF to write to many mailboxes

x	f(x)
0	989f4
1	dDf73
...	
2^{128}-2	08dji3
2^{128}-1	89hfif

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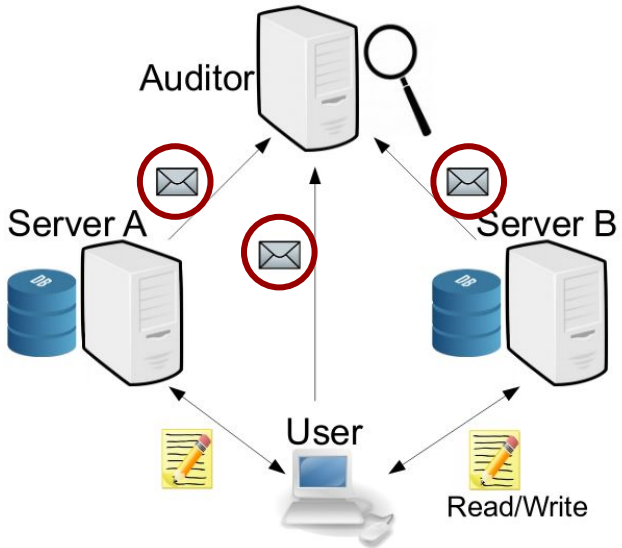
Prior work: third server audits requests

- O(√N) communication
- O(√N) client/auditor computation



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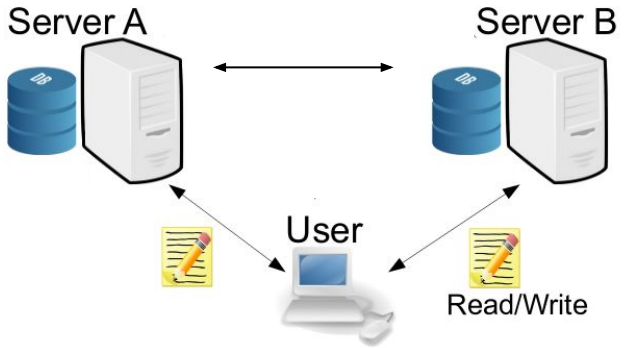
<u>New auditing protocol:</u>

- O(1) communication
- O(1) client computation
- No additional server!



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Goal: prove vectors of DPF evaluations only differ at one point

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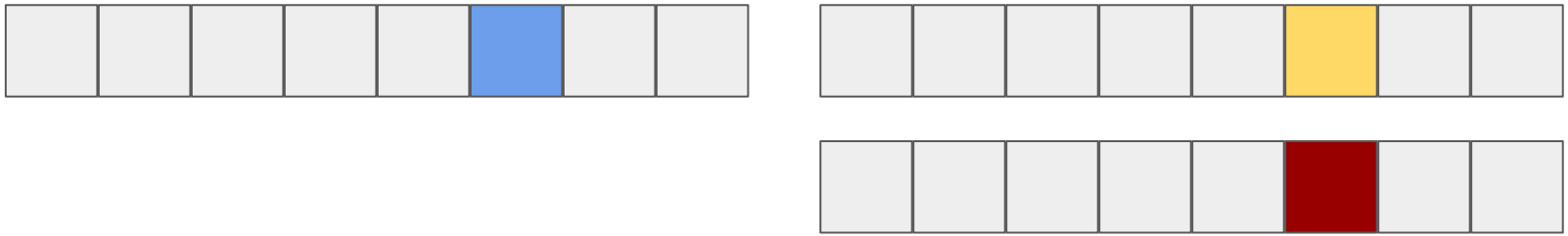

Issue: malicious server can guess & check the nonzero entry

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Auditing

Tool: secret-shared non-interactive proofs (SNIPs)

Idea: client sends SNIP proof to servers that honest evaluation of the semihonest protocol accepts the DPF

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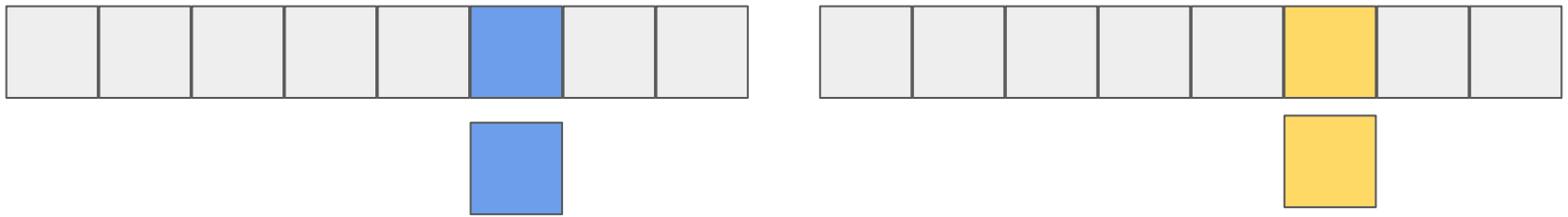
Idea: client sends SNIP proof to servers that honest evaluation of the semihonest protocol accepts the DPF

Key new trick: client knows the nonzero index & value, only needs O(1) work to prove things about non-zero entry, even though servers did O(N) work.



Evaluation

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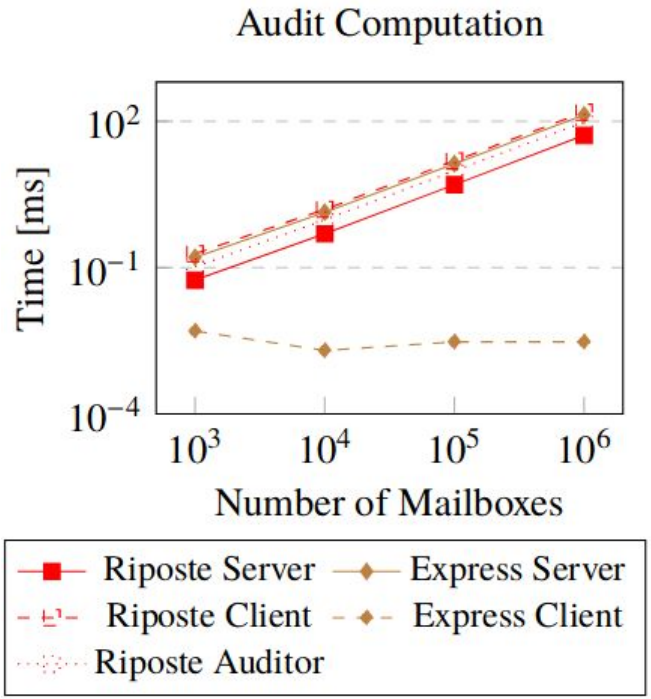
Auditing Protocol

- Client runs in under 5 *micro*seconds always



Evaluation

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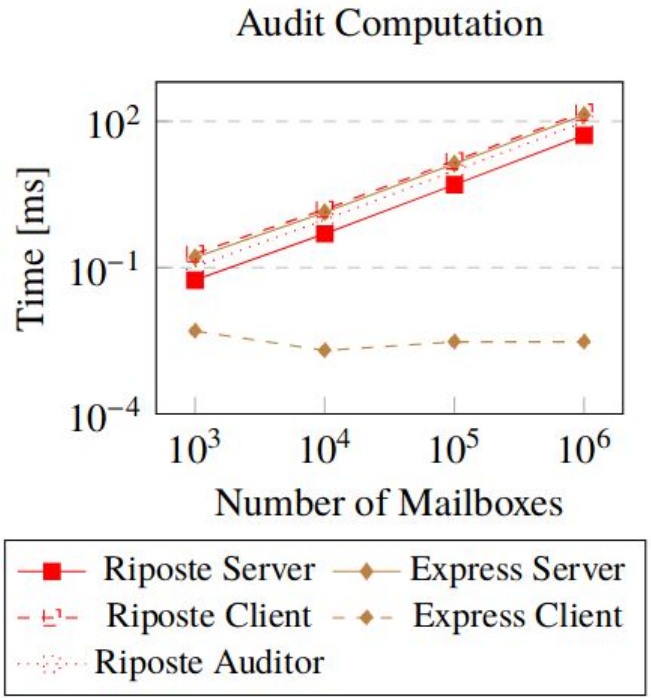

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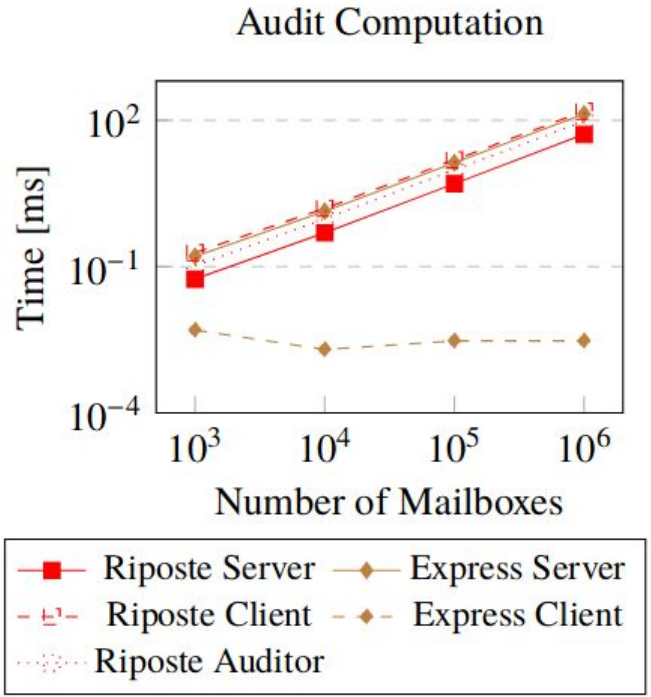

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Auditing Protocol

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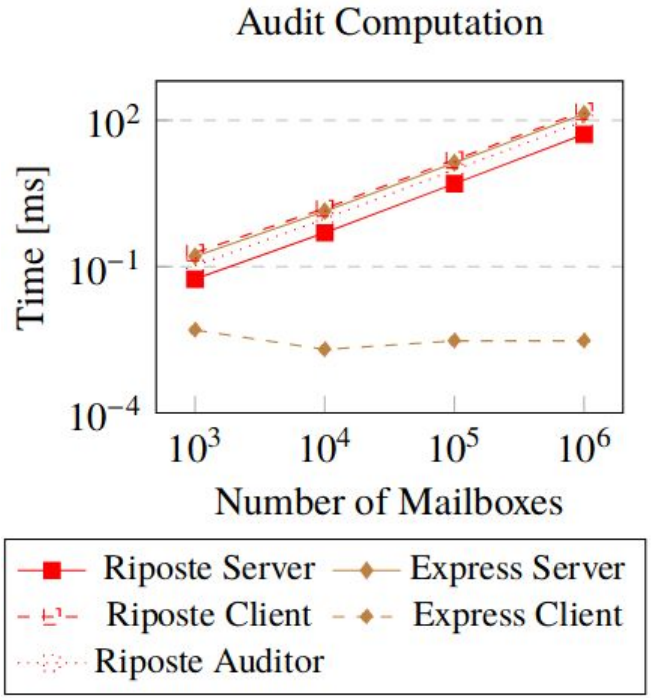
- Enables 8x reduction in overall client computation (now 20ms)
- Comparable on server, where auditing is not the bottleneck



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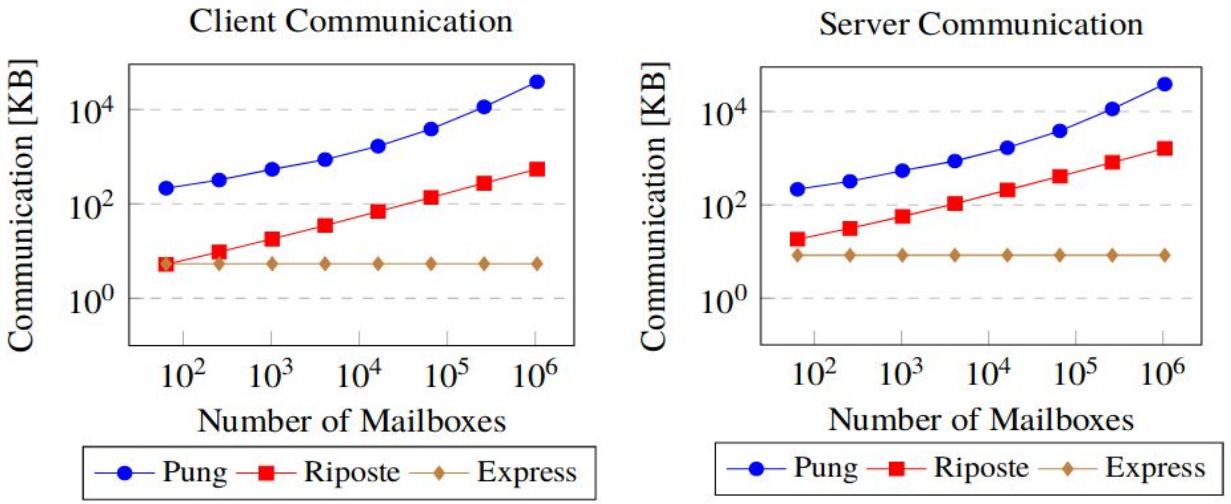
Communication Costs



(Sending 160B messages)

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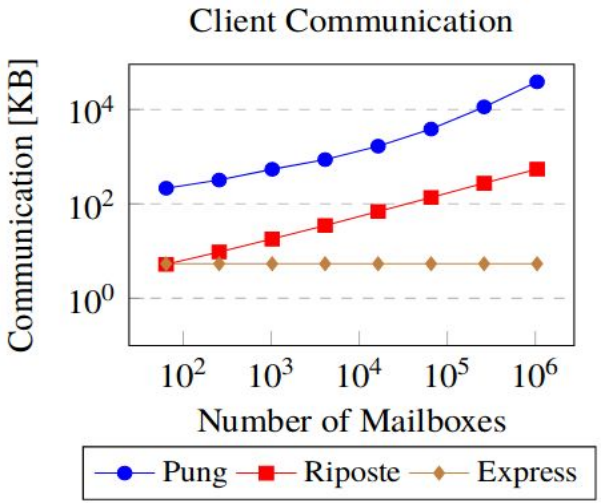
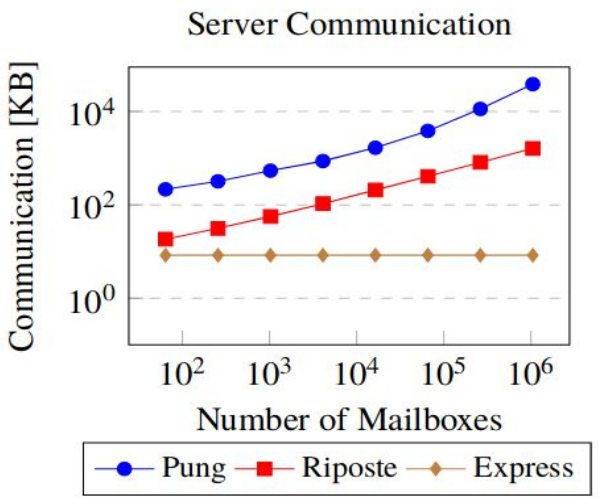
Unobservable Communication over Fully Untrusted Infrastructure, Sebastian Angel, Srinath Setty, *OSDI'16.*

Evaluation

Communication Costs

For 2^{14} mailboxes:
13x improvement on client, 25x on server





(Sending 160B messages)

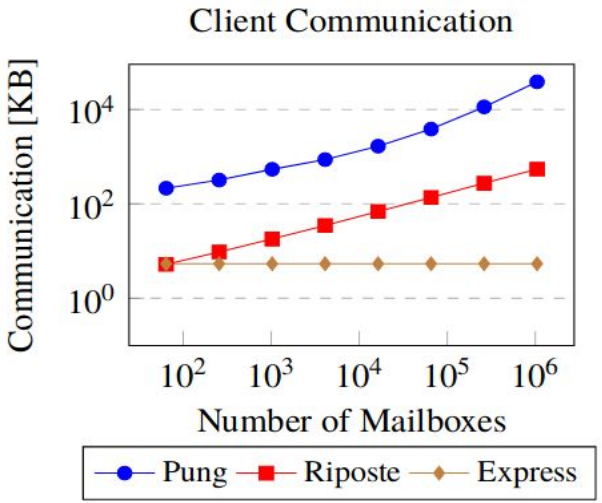
Riposte: An Anonymous Messaging System Handling Millions of Users, Henry Corrigan-Gibbs, Dan Boneh, David Mazieres, *Oakland'15.*
Unobservable Communication over Fully Untrusted Infrastructure, Sebastian Angel, Srinath Setty, *OSDI'16.*

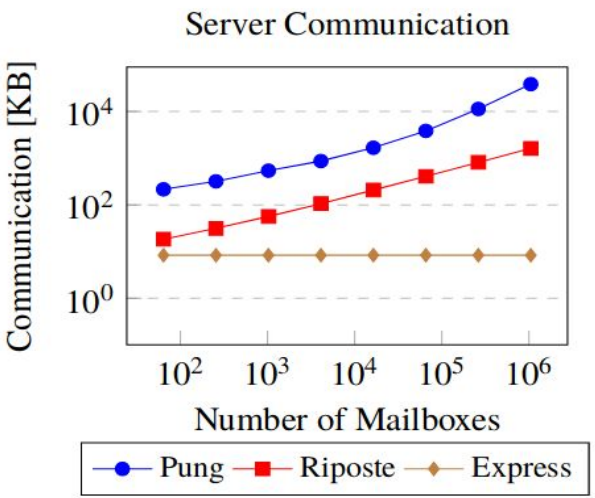
Evaluation

Communication Costs

For 2^{14} mailboxes:
13x improvement on client, 25x on server

For 2^{20} mailboxes:
101x improvement on client, 195x on server





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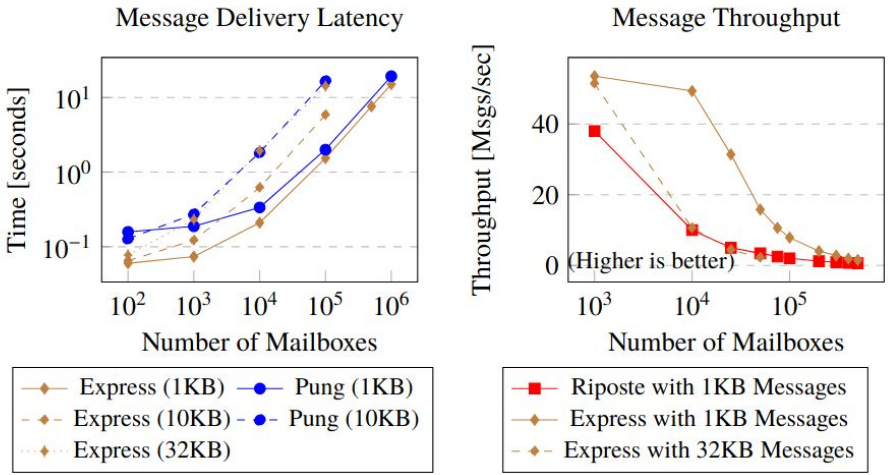
Evaluation

Server-side costs

Modest improvements in server-side performance

- 1.4-6.3x throughput of Riposte (1KB msg)
- 1.3-2.6x faster than Pung (1KB msg)
- 2-2.9x faster than Pung (10KB msg)

32KB message performance still comparable to prior work on smaller sizes



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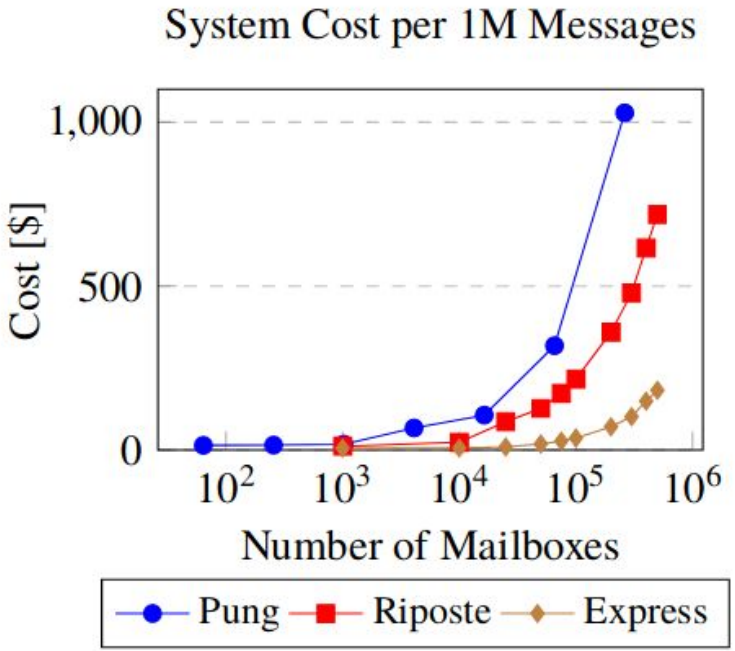
Evaluation

Dollar Cost

Estimate based on GCP prices for servers and data egress

Cost per 1M messages for 100K registered mailboxes 6x less than Riposte



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Express

Metadata-hiding communication system with application to private whistleblowing

- Asymptotic speedup from $O(\sqrt{N})$ to $O(1)$ for auditing
- Speedup of 8x on client, up to 6x on server (compared to Riposte)
- 6x lower dollar cost to operate system
- 13-7,000x or more reduction in communication costs

Paper: https://arxiv.org/pdf/1911.09215.pdf
Code: https://github.com/SabaEskandarian/Express
Contact: saba@cs.stanford.edu