Keeping Authorities "Honest or Bust" with Decentralized Witness Cosigning

Ewa Syta, Iulia Tamas, Dylan Visher, David Isaac Wolinsky
– **Yale University**

Philipp Jovanovic, Linus Gasser, Nicolas Gailly, Ismail Khoff, **Bryan Ford**
– **Swiss Federal Institute of Technology Lausanne (EPFL)**

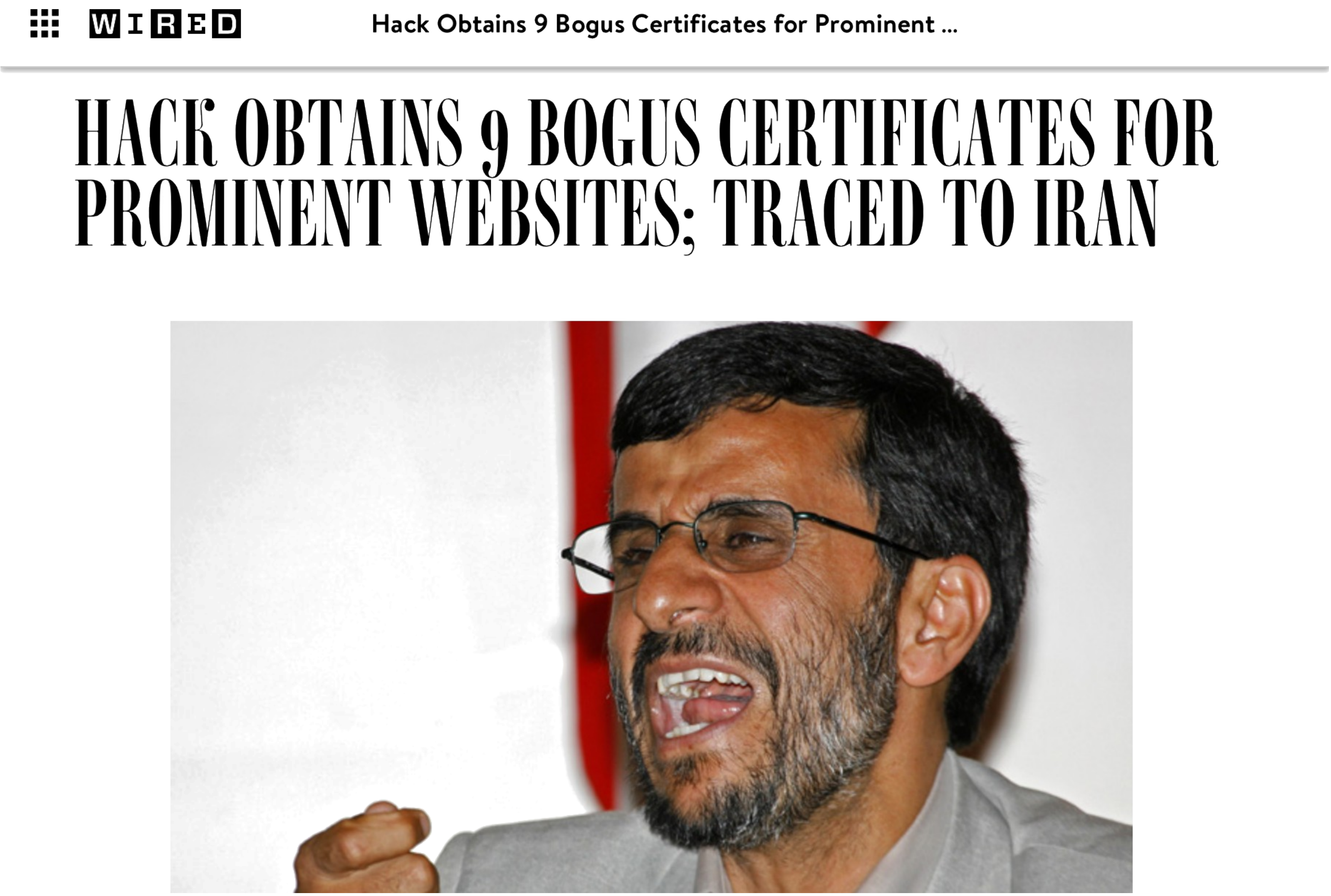
IEEE Security & Privacy – May 24, 2016

We depend on many authorities

Conceptually simple but **security-critical** services

- Time Services (NTP)
- Digital Notaries
- Naming Authorites
- Certificate Authorities
- Randomness Authorities (e.g., Lotteries)
- Software Update Services

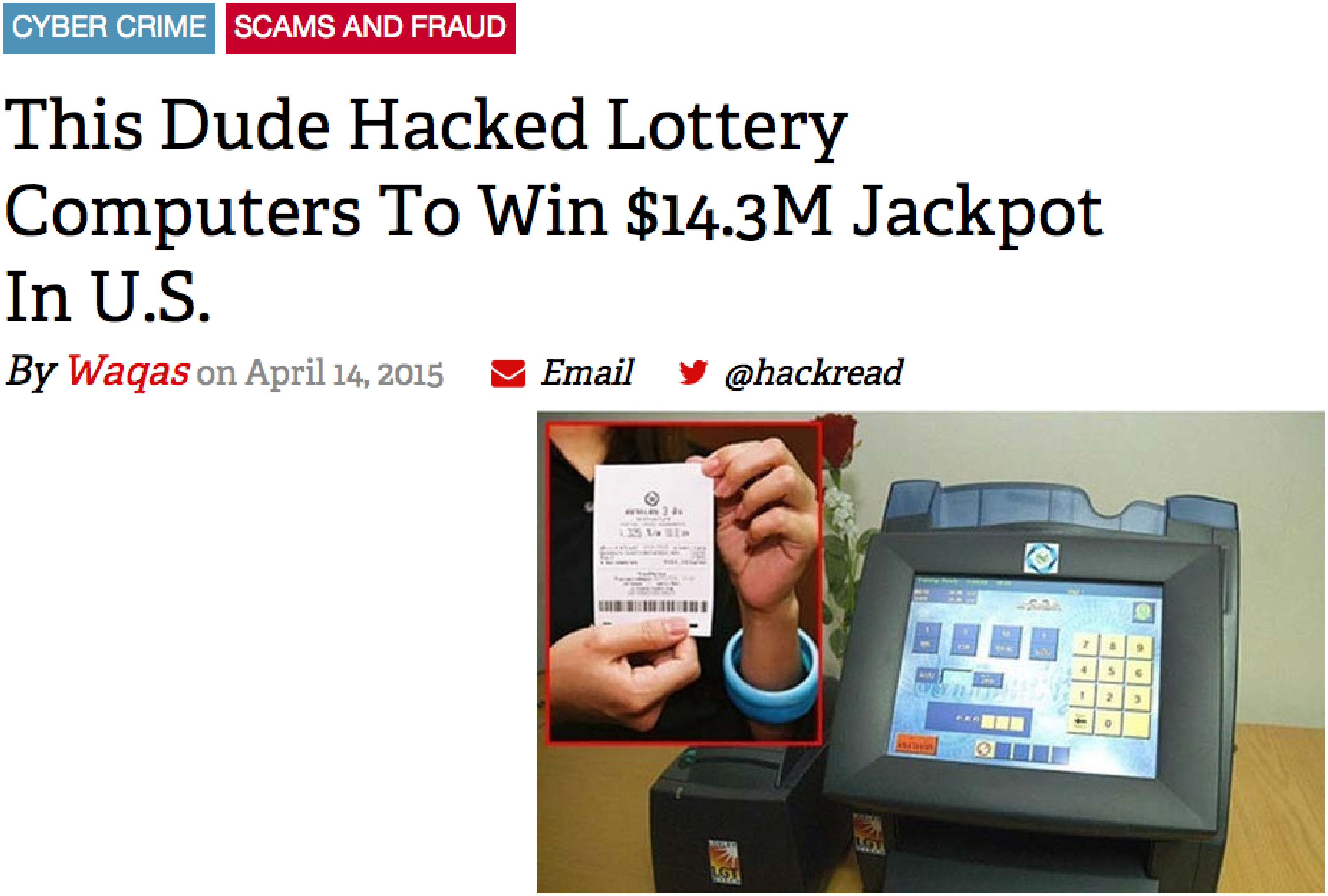
But are authorities trustworthy?



Hack Obtains 9 Bogus Certificates for Prominent ...

HACK OBTAINS 9 BOGUS CERTIFICATES FOR PROMINENT WEBSITES; TRACED TO IRAN

But are authorities trustworthy?

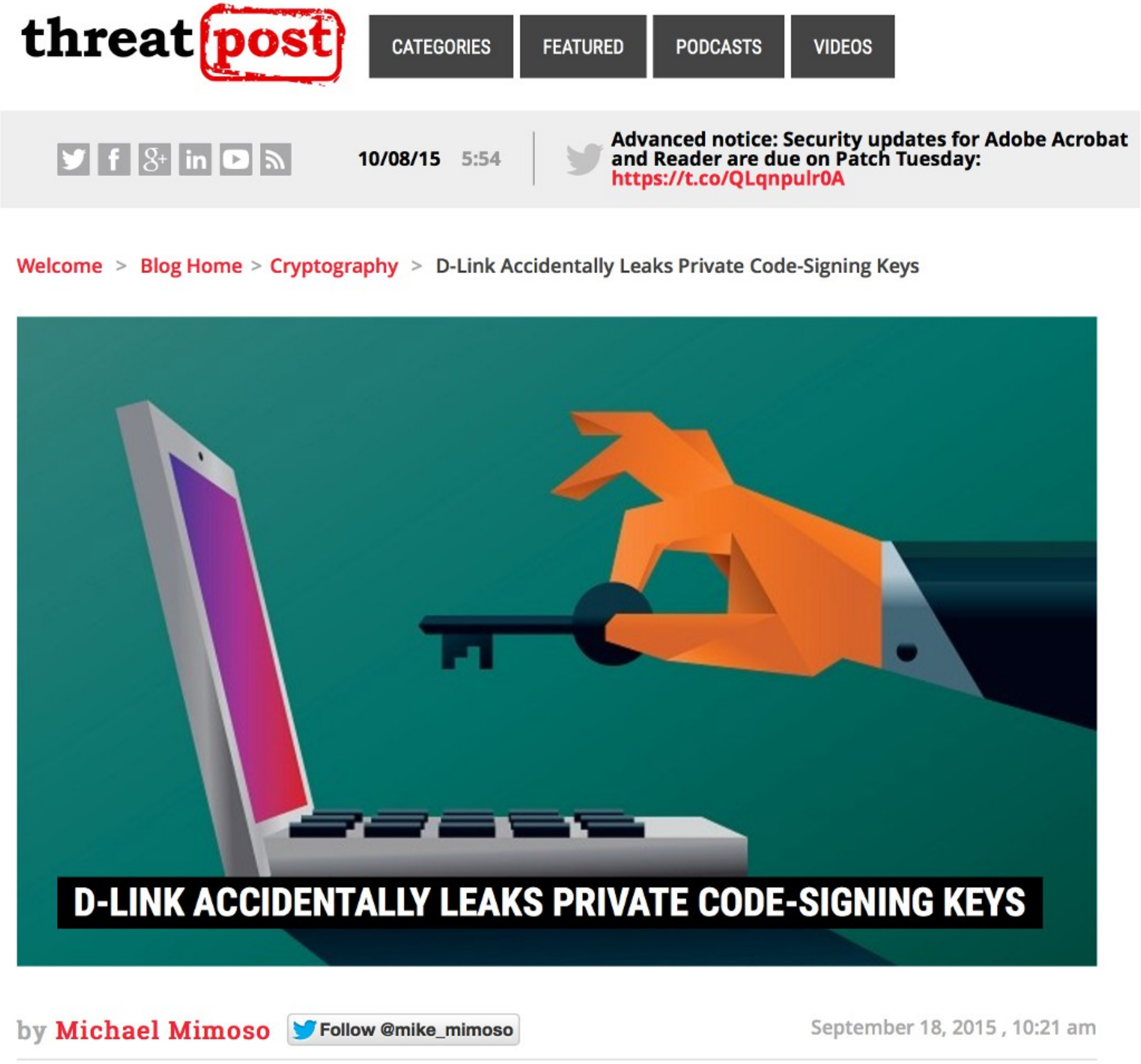


CYBER CRIME SCAMS AND FRAUD

This Dude Hacked Lottery Computers To Win $14.3M Jackpot In U.S.

By Waqas on April 14, 2015 Email @hackread

But are authorities trustworthy?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Welcome > Blog Home > Cryptography > D-Link Accidentally Leaks Private Code-Signing Keys
Follow @mike_mimoso

10/08/15 5:54

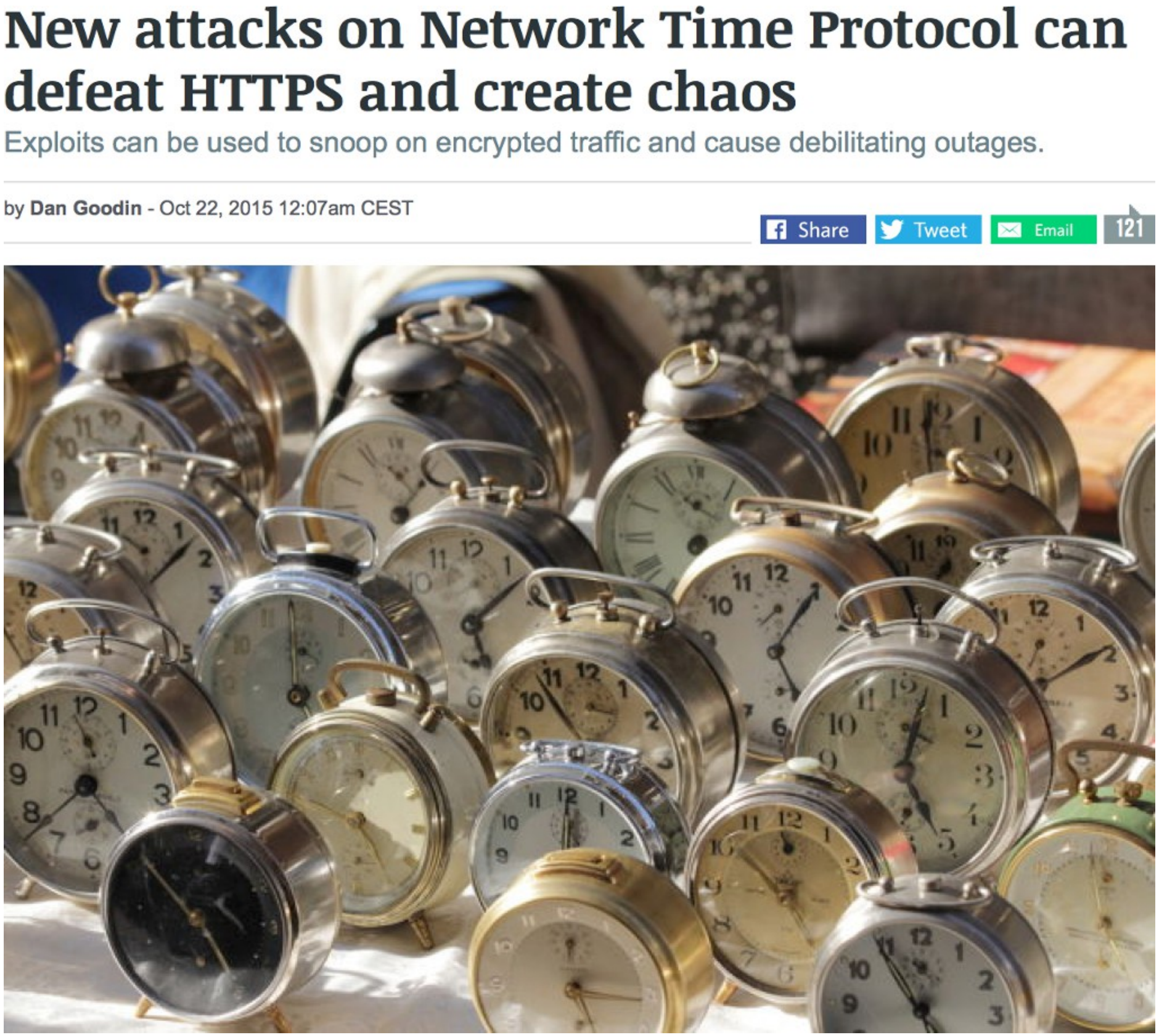
Advanced notice: Security updates for Adobe Acrobat and Reader are due on Patch Tuesday: https://t.co/QLqnpulr0A

D-LINK ACCIDENTALLY LEAKS PRIVATE CODE-SIGNING KEYS

by Michael Mimoso

September 18, 2015 , 10:21 am

But are authorities trustworthy?



New attacks on Network Time Protocol can defeat HTTPS and create chaos

Exploits can be used to snoop on encrypted traffic and cause debilitating outages.

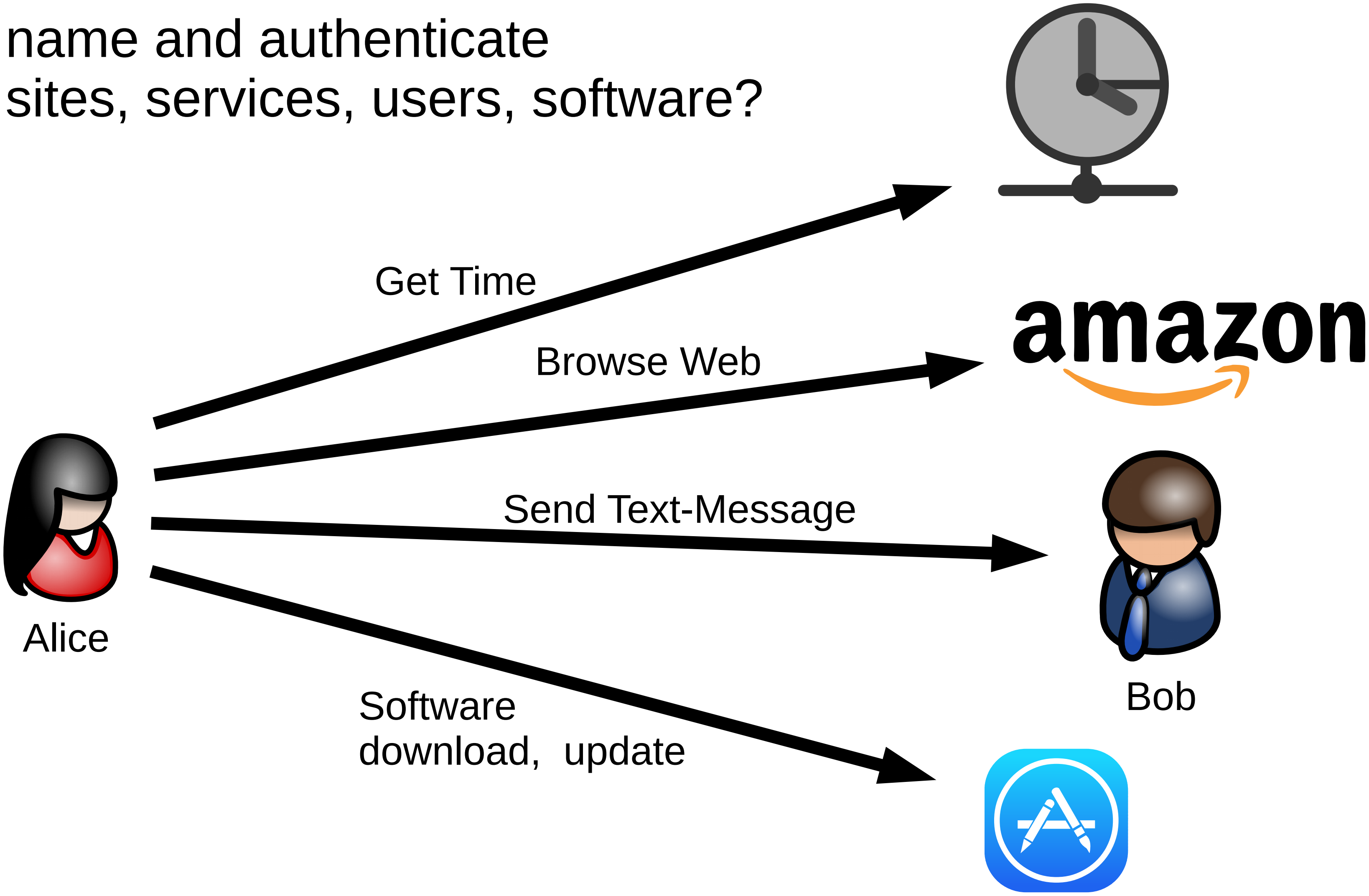
by **Dan Goodin** - Oct 22, 2015 12:07am CEST

Talk Outline

- **The trouble with trusting authorities**
- Grand challenge: decentralize the authorities!
- Baby step: decentralized witness cosigning
- CoSi: scalable collective Schnorr/Ed25519 signatures
- Experimental evaluation: scalability, signature size
- Comparison with prior transparency approaches
- Status, future work, and conclusions

Deep Dependence on Authorities

How does an Internet client
name and authenticate
sites, services, users, software?



Get Time

Browse Web

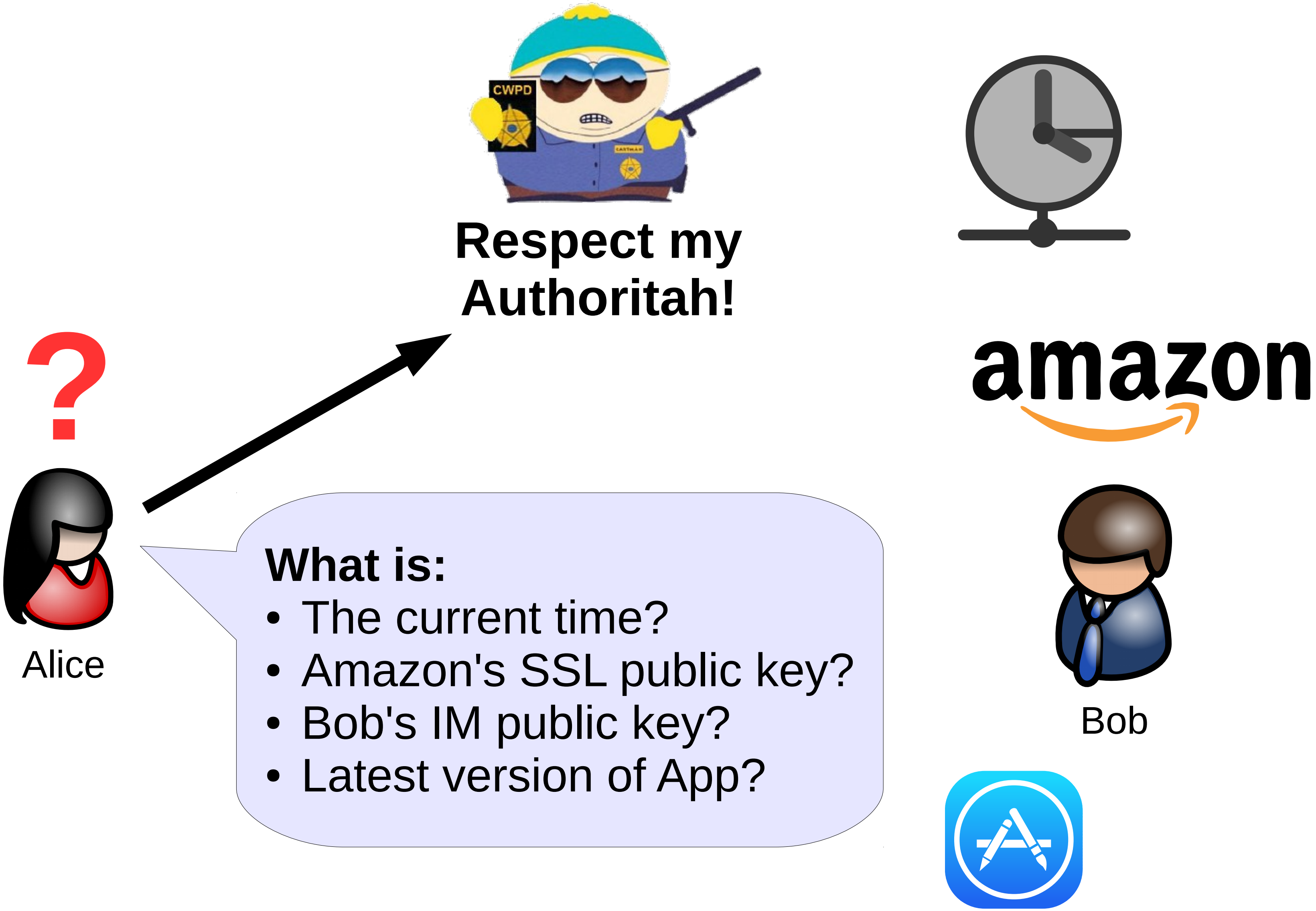
Send Text-Message

Software
download, update

Alice

Bob

Deep Dependence on Authorities



Respect my Authoritah!

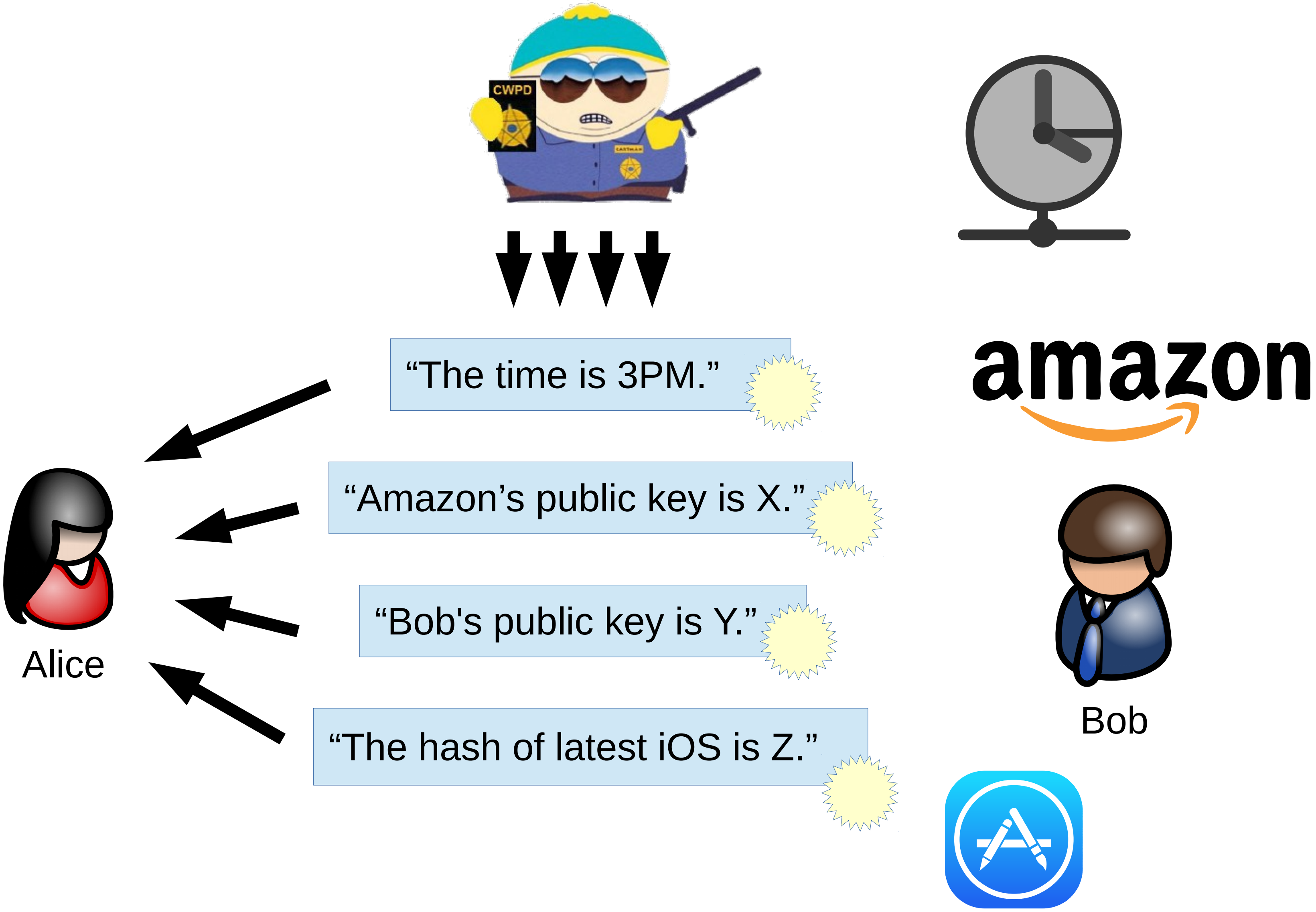
Alice

Bob

What is:

- The current time?
- Amazon's SSL public key?
- Bob's IM public key?
- Latest version of App?

Authorities Make & Sign Statements



“The time is 3PM.”

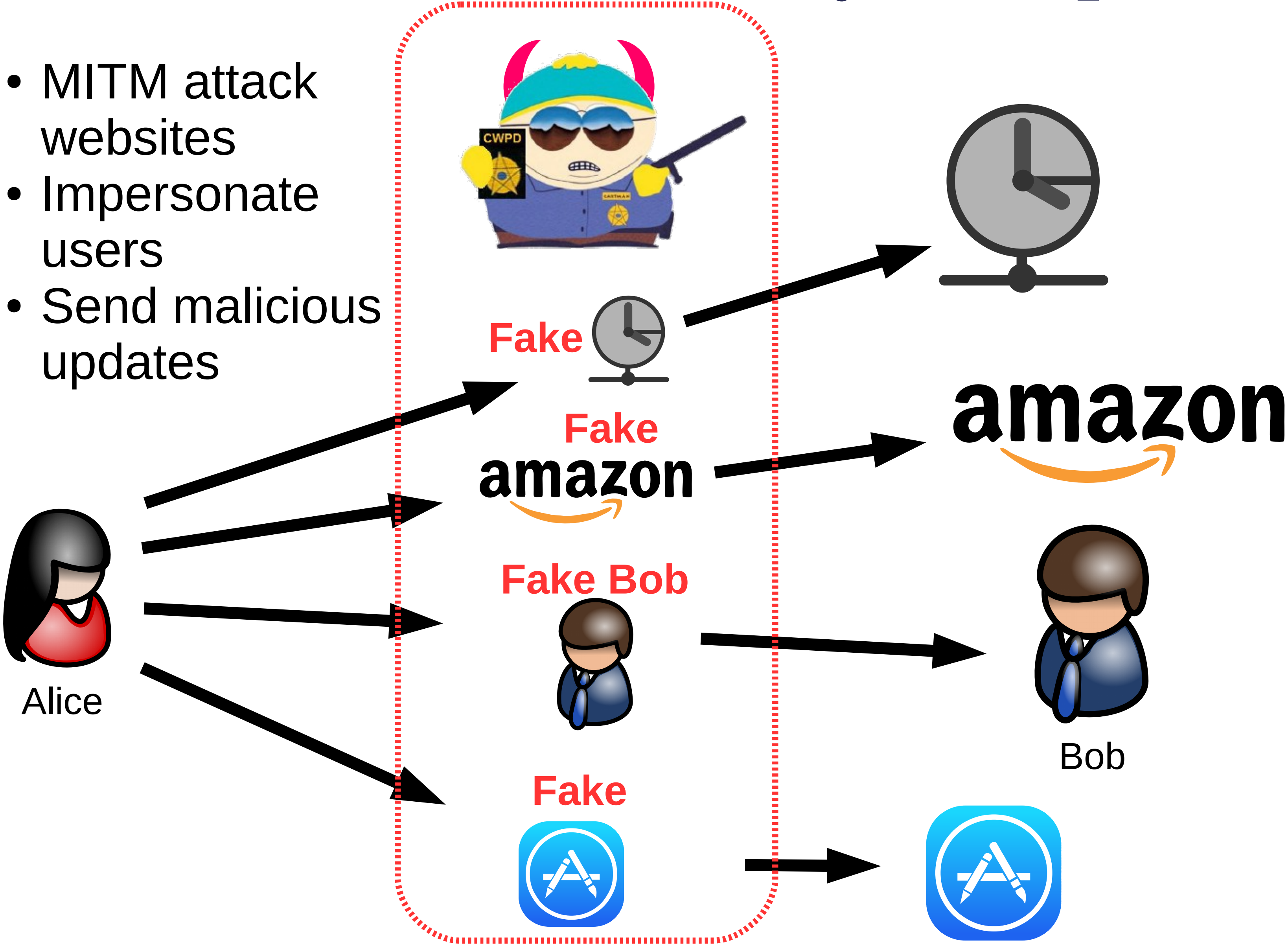
“Amazon’s public key is X.”

“Bob's public key is Y.”

“The hash of latest iOS is Z.”

Problem #1: Authority Compromise

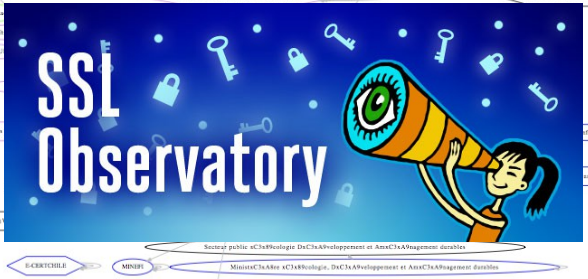
- MITM attack websites
- Impersonate users
- Send malicious updates



Problem #2: Weak Links

Clients often depend on **many** authorities:
e.g., hundreds of CAs trusted by web browsers

- Any CA can issue cert for any domain name

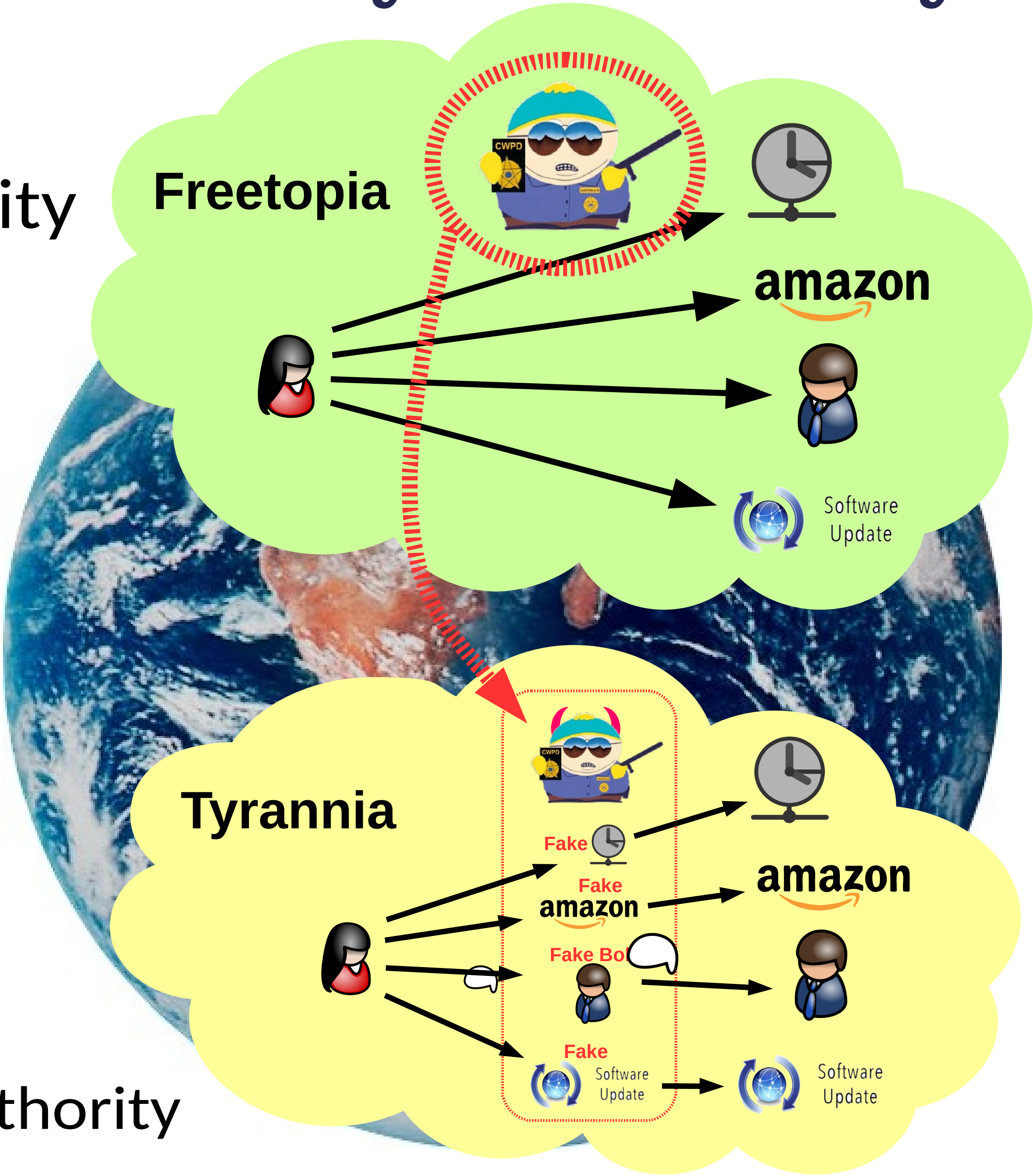


Attacker often needs to **compromise only one**

- **Weakest-link** security
- @#$% happens
  - DigiNotar, Comodo, CNNIC/MCS

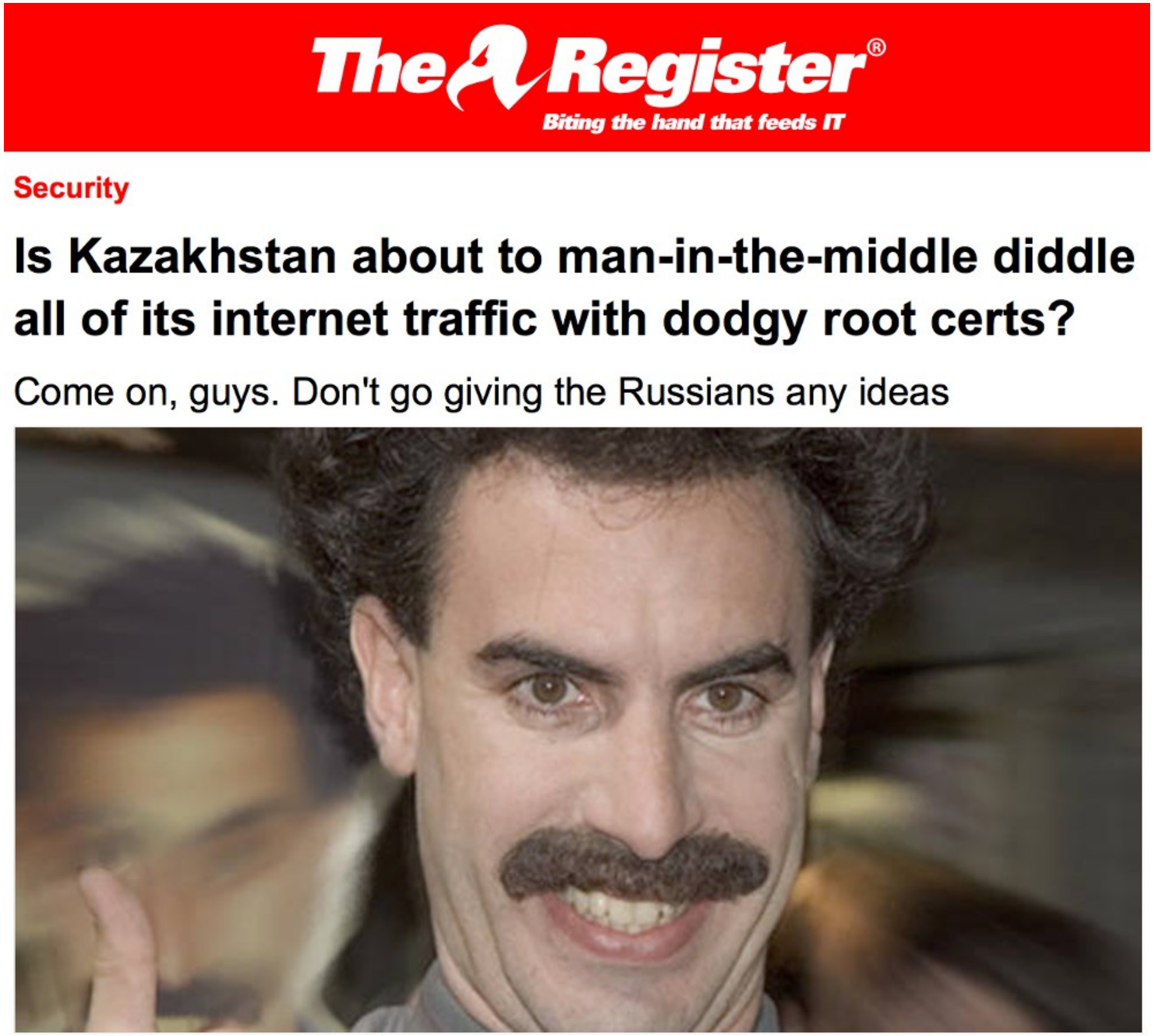
Problem #3: Secret Key Portability

- Attacker need not compromise authority "in-place"
- Instead steal the authority's **secret key**
  - Use it to create an "evil twin" on attacker's turf
  - Avoid detection by confining use to specific targets
  - Block targets from reporting to real authority



Problem #4: Everybody Wants In

Hackers, organized crime, governments…



The Register®

Biting the hand that feeds IT

Security

Is Kazakhstan about to man-in-the-middle diddle all of its internet traffic with dodgy root certs?

Come on, guys. Don't go giving the Russians any ideas

Problem #4: Everybody Wants In

Hackers, organized crime, governments…

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What To Do?

We have to assume that no individual…

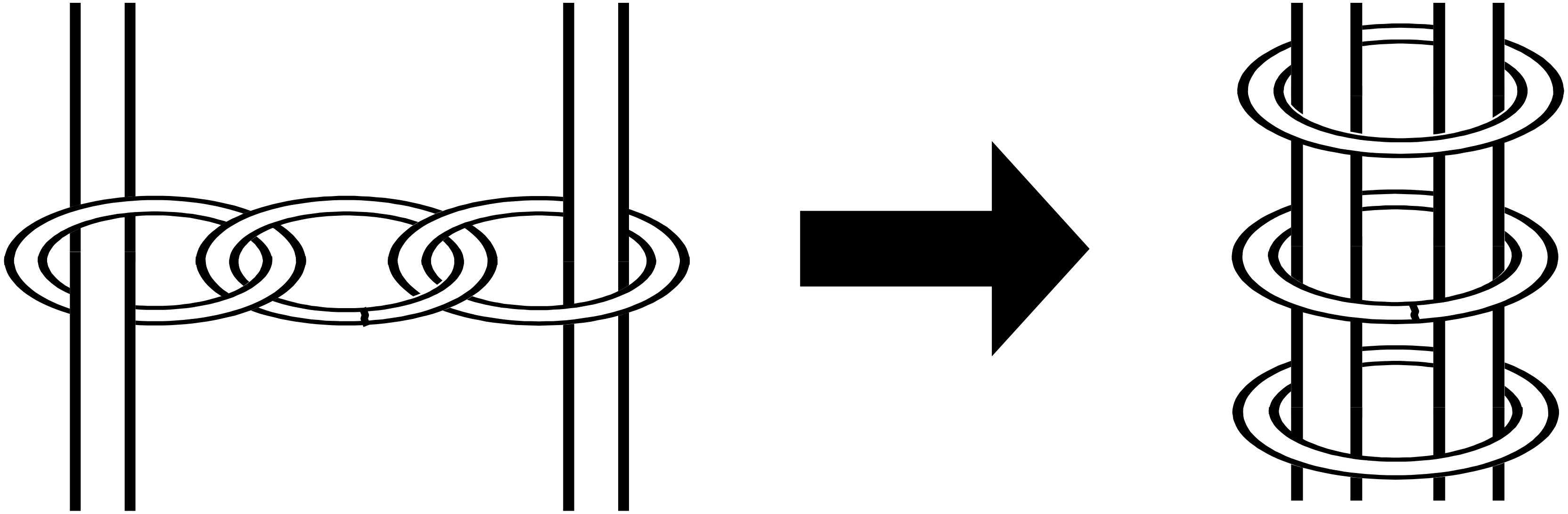
- Hardware platform
- Software system
- System/network administrator
- Authoritative organization

…is invulnerable to compromise (or coercion)

Decentralize the Authorities!

Split trust across independent parties

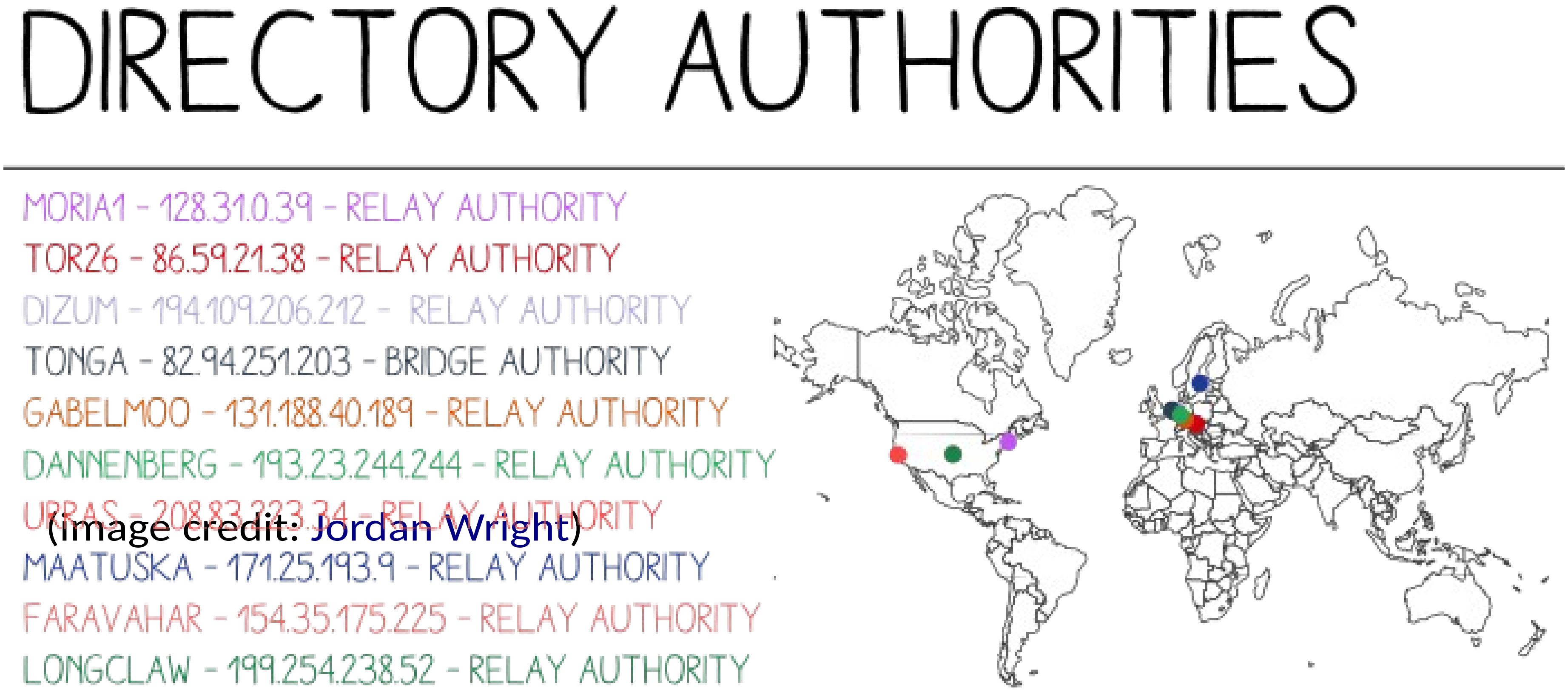
- So system resists compromise by individuals
- From **weakest-link** to **strongest-link** security
- Decentralized resistance to failure, coercion



Example: Tor Directory Authority

Split across ~10 servers – **but is this enough?**

- Could attacker hack or coerce ~5 operators?



MORIA1 - 128.31.0.39 - RELAY AUTHORITY
TOR26 - 86.59.21.38 - RELAY AUTHORITY
DIZUM - 194.109.206.212 - RELAY AUTHORITY
TONGA - 82.94.251.203 - BRIDGE AUTHORITY
GABELMOO - 131.188.40.189 - RELAY AUTHORITY
DANNENBERG - 193.23.244.244 - RELAY AUTHORITY
URRAS - 208.83.223.34 - RELAY AUTHORITY
MAATUSKA - 171.25.193.9 - RELAY AUTHORITY
FARAVAHAR - 154.35.175.225 - RELAY AUTHORITY
LONGCLAW - 199.254.238.52 - RELAY AUTHORITY

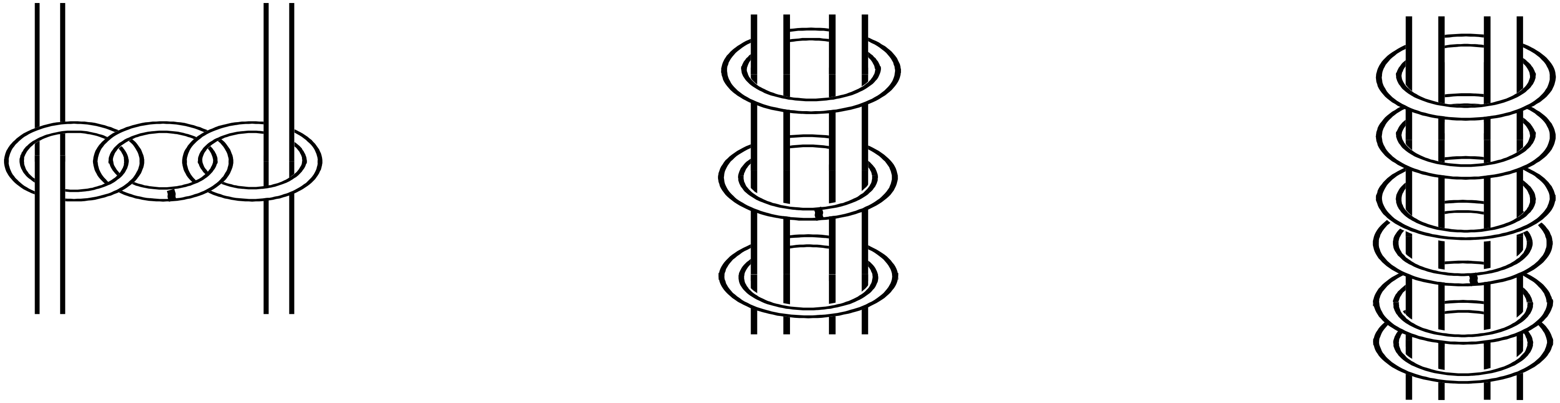
(image credit: Jordan Wright)

Trust-splitting needs to scale

Weakest-link:
T = 1

Strongest-link:
T = 2-10

Collective authorities:
T = 100s,1000s



Trust-splitting needs to scale

Must incorporate **all diversity that makes sense**

- Not just ~10 parties "picked by someone"

Could we decentralize…

- **TLS certificate validation and signing** across the hundreds of certificate authorities?
- **DNSSEC root zone maintenance and signing** across the 1000+ worldwide TLD operators?
- **A national cryptocurrency** across the thousands of US national banks?

Make overall security **grow** as scale increase?

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Not Gonna Happen Overnight…

A First Step: **Transparency**

More readily achievable near-term

- Who watches the watchers?
  Public **witnesses**!

Ensure that **any** authoritative statement:

- Is exposed to **public scrutiny**
- Conforms to **checkable standards**

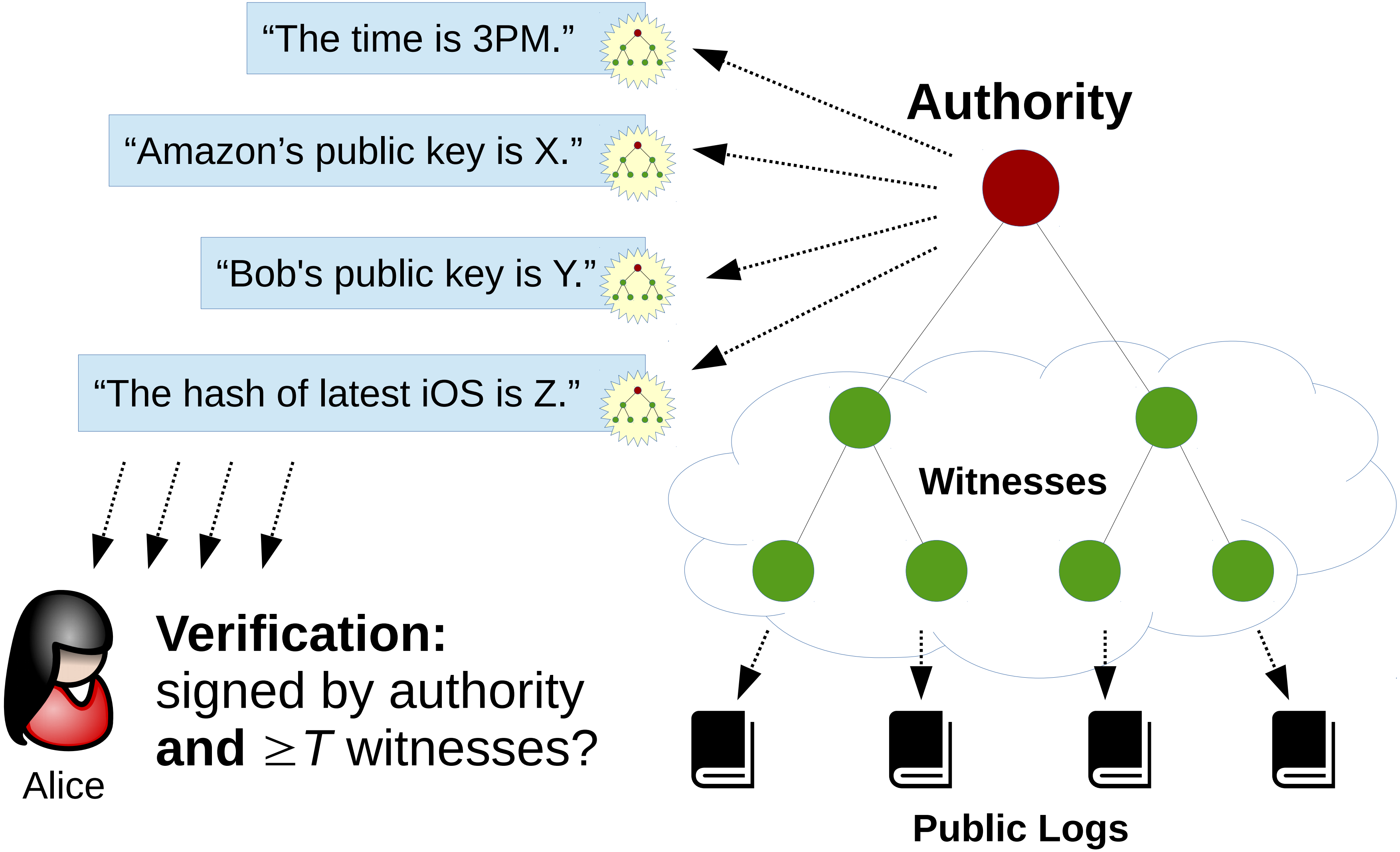
before clients will accept statement

Respect my Authoritah!

Witnesses

Key: **practical to “retrofit” existing authorities**

Decentralized Witness Cosigning



“The time is 3PM.”

“Amazon’s public key is X.”

“Bob's public key is Y.”

“The hash of latest iOS is Z.”

Authority

Witnesses

Public Logs

Alice

Verification:
signed by authority
and $\geq T$ witnesses?

Is the Signed Statement “Good”?

In general, **witnesses don’t (and can’t) know for sure**

- Does public key X really belong to Bob?
- Does software image Y have a secret backdoor?

But witnesses can still ensure **all signatures are public**

- If authority coerced or its keys used to produce bad statement, attacker can’t ensure its secrecy
  - Backdoors possible but must “hide in plain sight”
- Creates “Ulysses Pact” deterrent against coercion
  - “the point…is to keep governments from even trying to put secret pressure on tech companies, because the system is set up so that the secret immediately gets out”
    - Cory Doctorow, 10-March-2016

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Setup: Keypairs and CoSi Groups

Individual Keypairs:

Standard Schnorr (Ed25519)

- Private key: k
- Public key: $K = g^k$

CoSi group:

List of public keys

- $K_1, K_2, \ldots, K_N$

Assumptions:

- Verifier has full list
  - (nonessential)
- All keys self-signed
  - (important to avoid related-key attacks)

Schnorr Signature

- Generator *g* of prime order *q* group
- Public/private key pair: $(K=g^k, k)$

	Signer		Verifier
Commitment	$V=g^v$	$\longrightarrow$	V
Challenge	c	$\longleftarrow$	$c = H(M\|V)$
Response	$r = (v - kc)$	$\longrightarrow$	r

Signature on M: (c, r)

Commitment recovery	$V' = g^r K^c = g^{v-kc} g^{kc} = g^v = V$
Challenge recovery	$c' = H(M\|V')$
Decision	$c' = c$? ✓

Schnorr Multisignature

- Key pairs: $(K_1=g^{k_1}, k_1)$ and $(K_2=g^{k_2}, k_2)$

	Signer 1	Signer 2	Verifier		
Commitment	$V_1=g^{v_1}$	$V_2=g^{v_2}$ →	V_1	V_2	$V=V_1*V_2$
Challenge	c	c ←	$c = H(M\|V_1)$	$c = H(M\|V)$	
Response	$r_1 = (v_1 – k_1c)$	$r_2 = (v_2 – k_2c)$ →	r_1	r_2	$r=r_1+r_2$

Signature on M: (c, r_1)

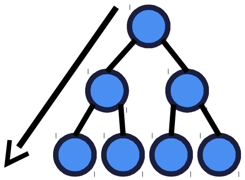
Signature on M: (c, r)

Same signature!

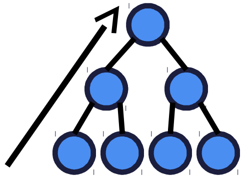
Commitment recovery	Same verification!	$V' = g^rK^c$	$K=K_1*K_2$
Challenge recovery	Done once!	$c' = H(M\|V')$	
Decision		$c' = c$?	

CoSi Protocol Signing Rounds

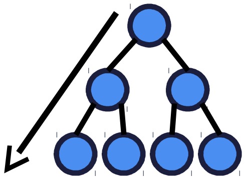
1. Announcement Phase



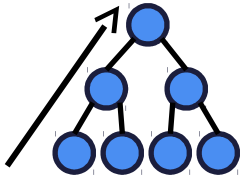
2. Commitment Phase



3. Challenge Phase



4. Response Phase

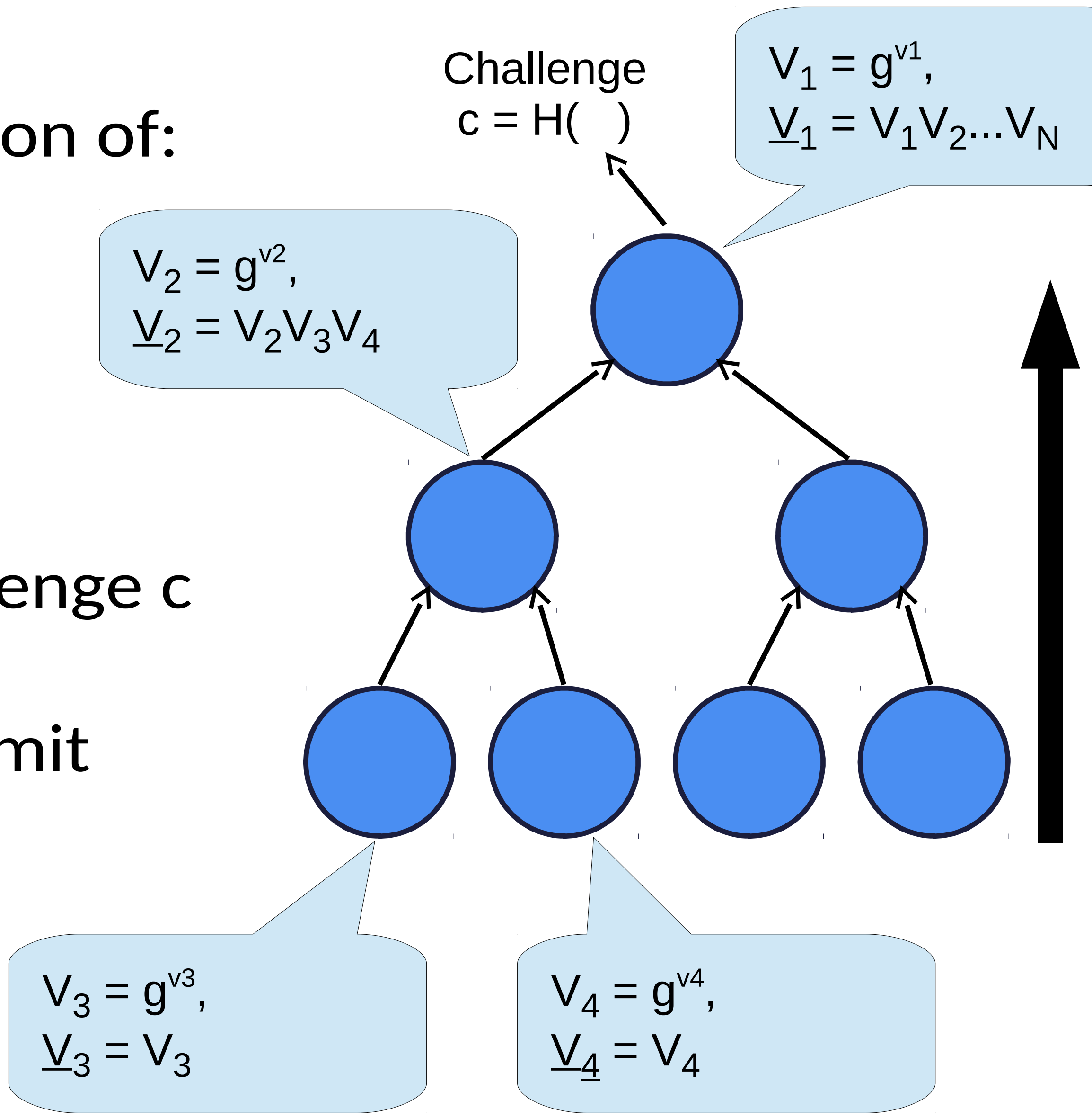


CoSi Commit Phase

Tree computation of:

- Commits V_i
- Aggregate commits $\underline{V}_i$

Collective challenge c is hash of aggregate commit



Challenge
c = H( )

$V_1 = g^{v1}$,
$\underline{V}_1 = V_1V_2 \ldots V_N$

$V_2 = g^{v2}$,
$\underline{V}_2 = V_2V_3V_4$

$V_3 = g^{v3}$,
$\underline{V}_3 = V_3$

$V_4 = g^{v4}$,
$\underline{V}_4 = V_4$

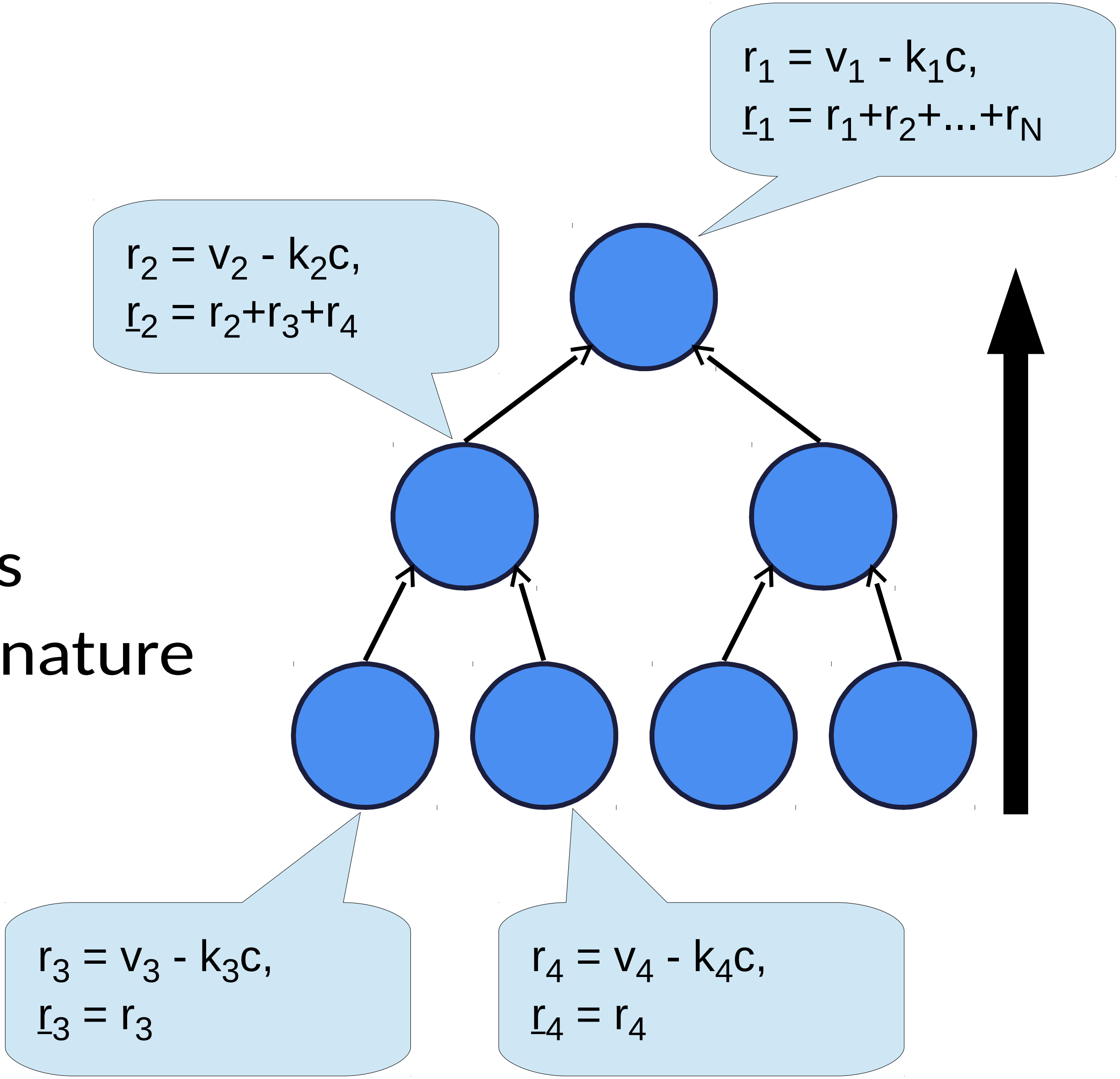
CoSi Response Phase

Compute

- Responses r_i
- Aggregate responses $\underline{r}_i$

Each $(c,\underline{r}_i)$ forms valid **partial** signature

$(c,\underline{r}_1)$ forms **complete** signature



$r_1 = v_1 - k_1c,$
$\underline{r}_1 = r_1+r_2+\ldots+r_N$

$r_2 = v_2 - k_2c,$
$\underline{r}_2 = r_2+r_3+r_4$

$r_3 = v_3 - k_3c,$
$\underline{r}_3 = r_3$

$r_4 = v_4 - k_4c,$
$\underline{r}_4 = r_4$

Unavailable Witness Servers

Assume server failures are **rare** but **non-negligible**

- *Persistently bad* servers get administratively booted

Exceptions: If a server A is down, proceed anyway

- Modified collective key: $K' = K * K^{-1}_{A}$
- Modified commitment: $V' = V * V^{-1}_{A}$
- Modified response: $r' = r - r_{A}$

Verification: CoSi signature includes roll-call bit-vector

- Enables verifier to recompute modified public key K'
- Can use **any** criteria to decide if “too many” missing

Variations (see paper for details)

- Complex/contextual verification predicates
  - Witness subgroups, weights, expressions, …
- Minimizing cothority certificate size
  - Via Merkle key-trees
- Tolerating network churn
  - Via binomial swap forests (Cappos, San Fermin)
- Tolerating cosigner churn
  - Avoiding restarts via commit trees
- Single-pass CoSi for asynchronous networks
  - Via BLS signatures, opportunistic signature combining

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Experimental Evaluation

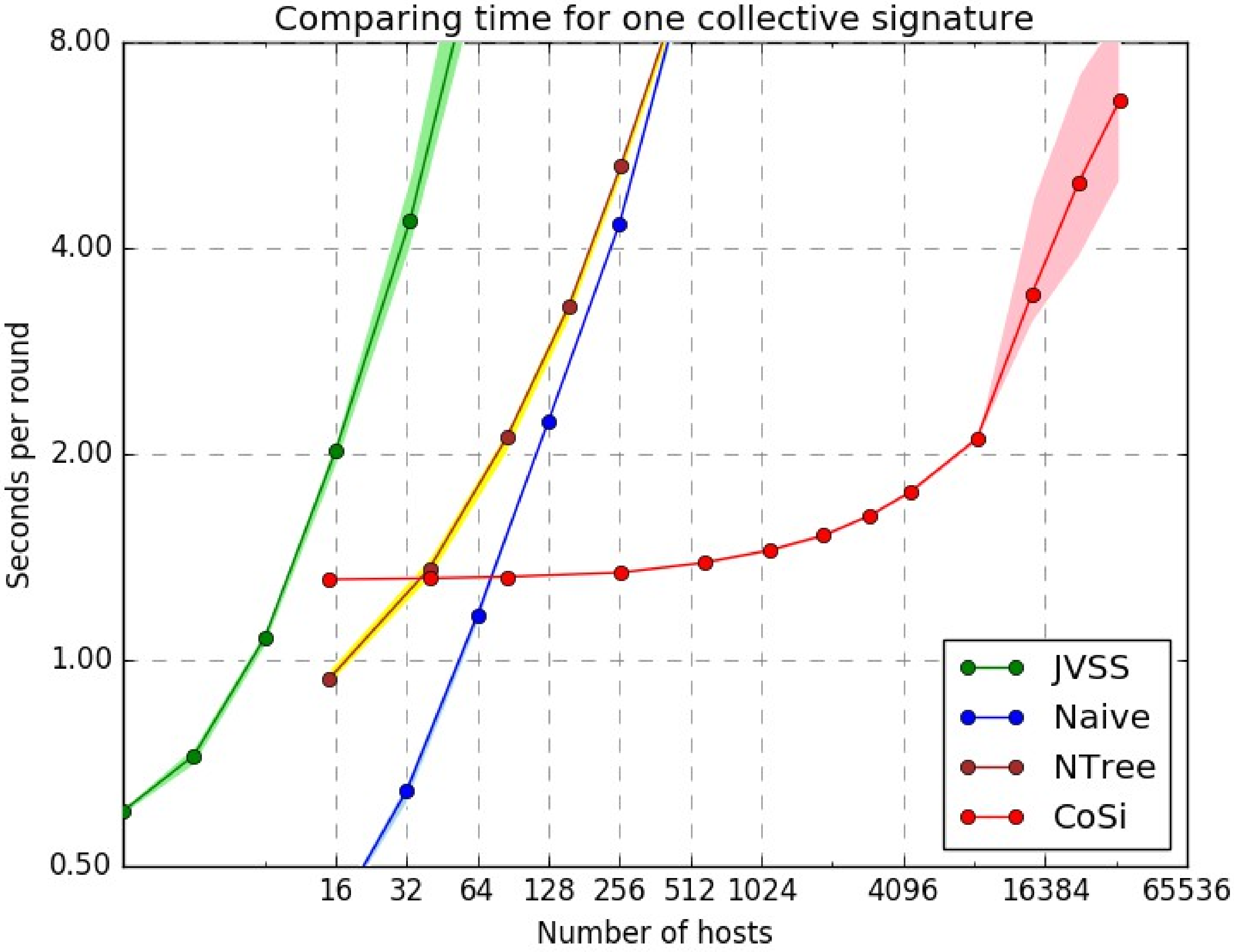
Experiments run on DeterLab network testbed

- Up to **32,768** virtual CoSi witnesses
- Multiplexed atop up to 64 physical machines
  - introduces oversubscription overhead, unfortunately
  - Conservative results, likely worse than "real" deployment
- Impose 200ms roundtrip latencies between all servers
  - to simulate **globally-distributed** witness group

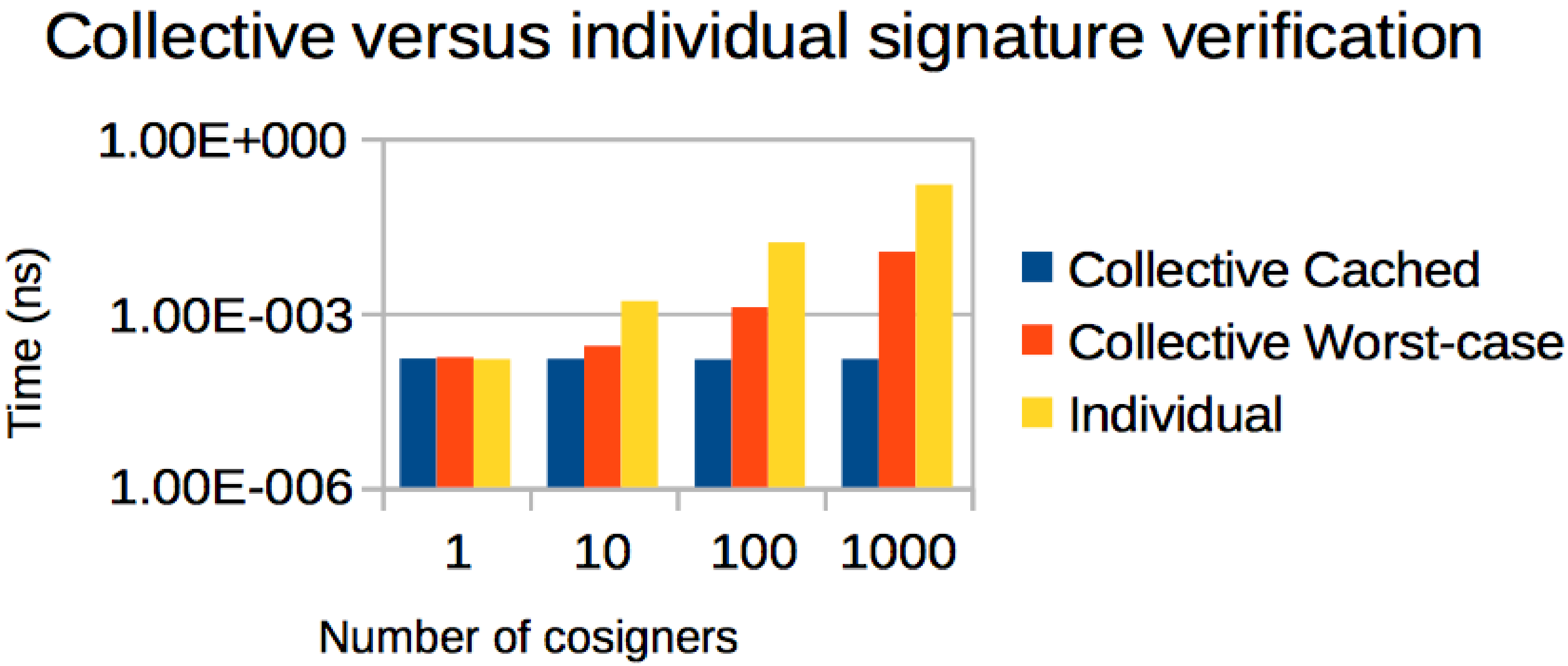
Future: deploy, evaluate at scale on "real Internet"

- Evaluate impact of high node, network churn
- See paper for approaches to handling if/when needed

Results: Collective Signing Time

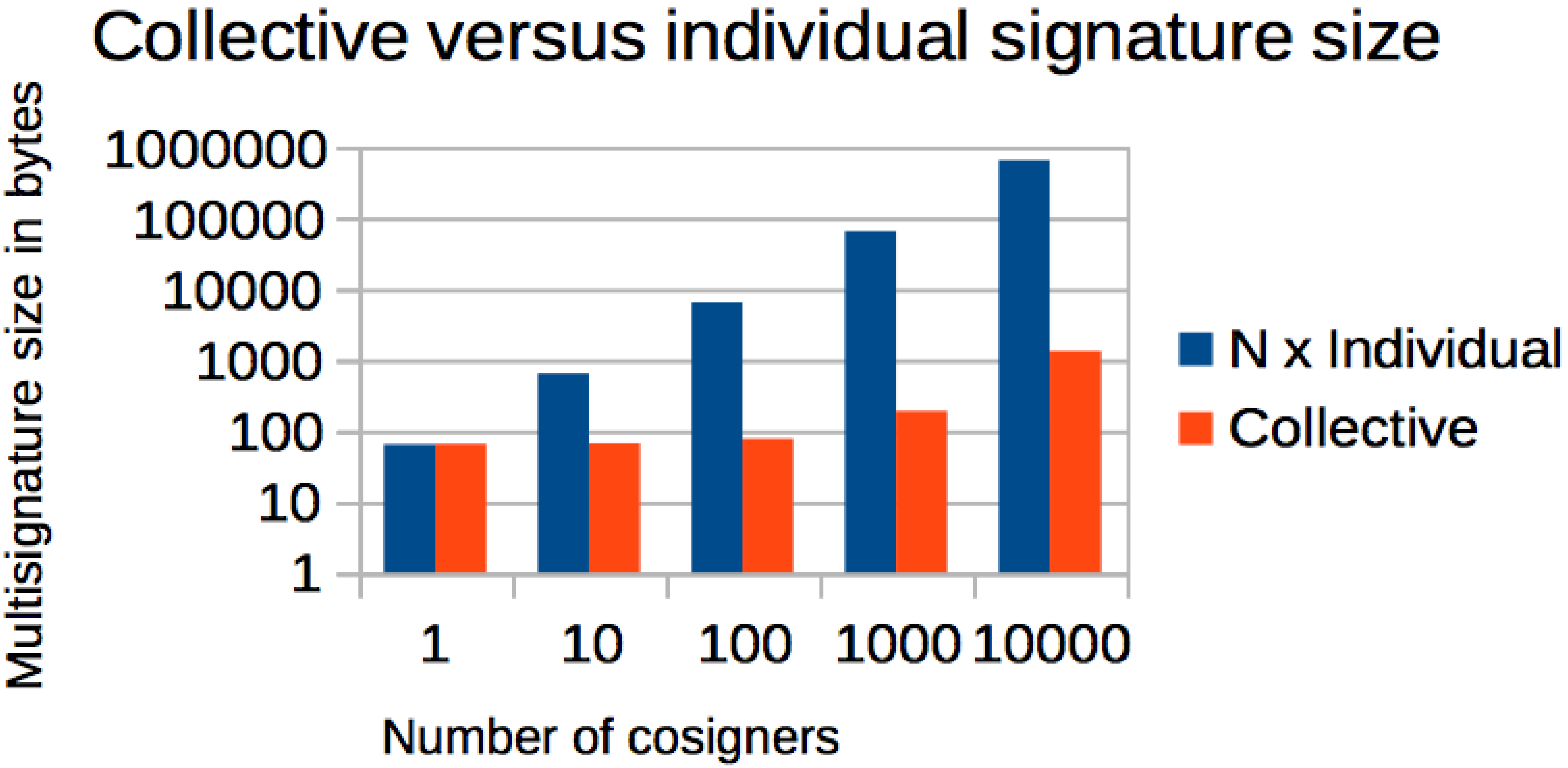


Results: Verification Cost



Results: Collective Signature Size

Ed25519: up to 512x smaller than N signatures



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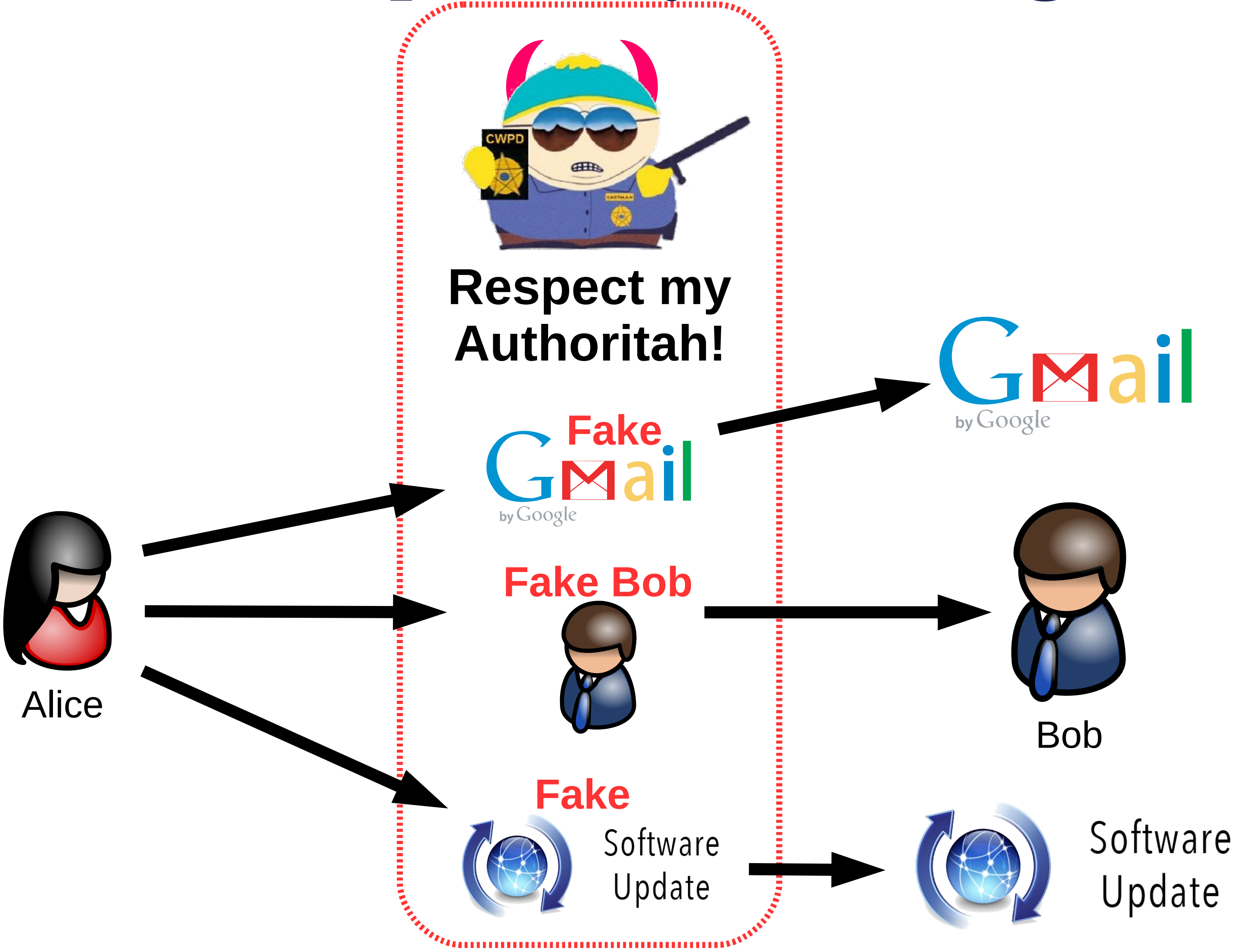
The Transparency Challenge



Respect my Authoritah!

Fake Gmail

Fake Bob

Fake Software Update

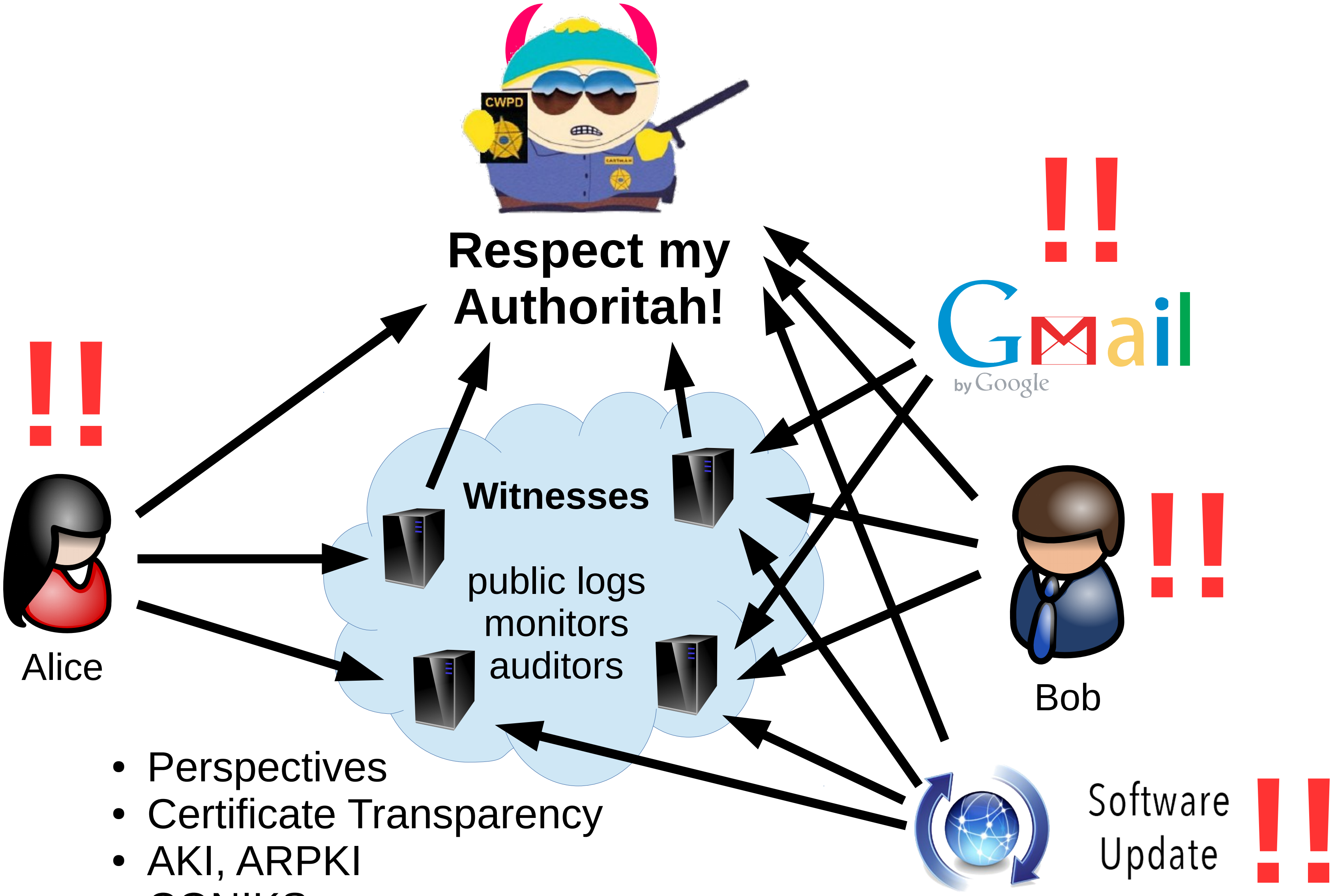
Alice

Gmail

Bob

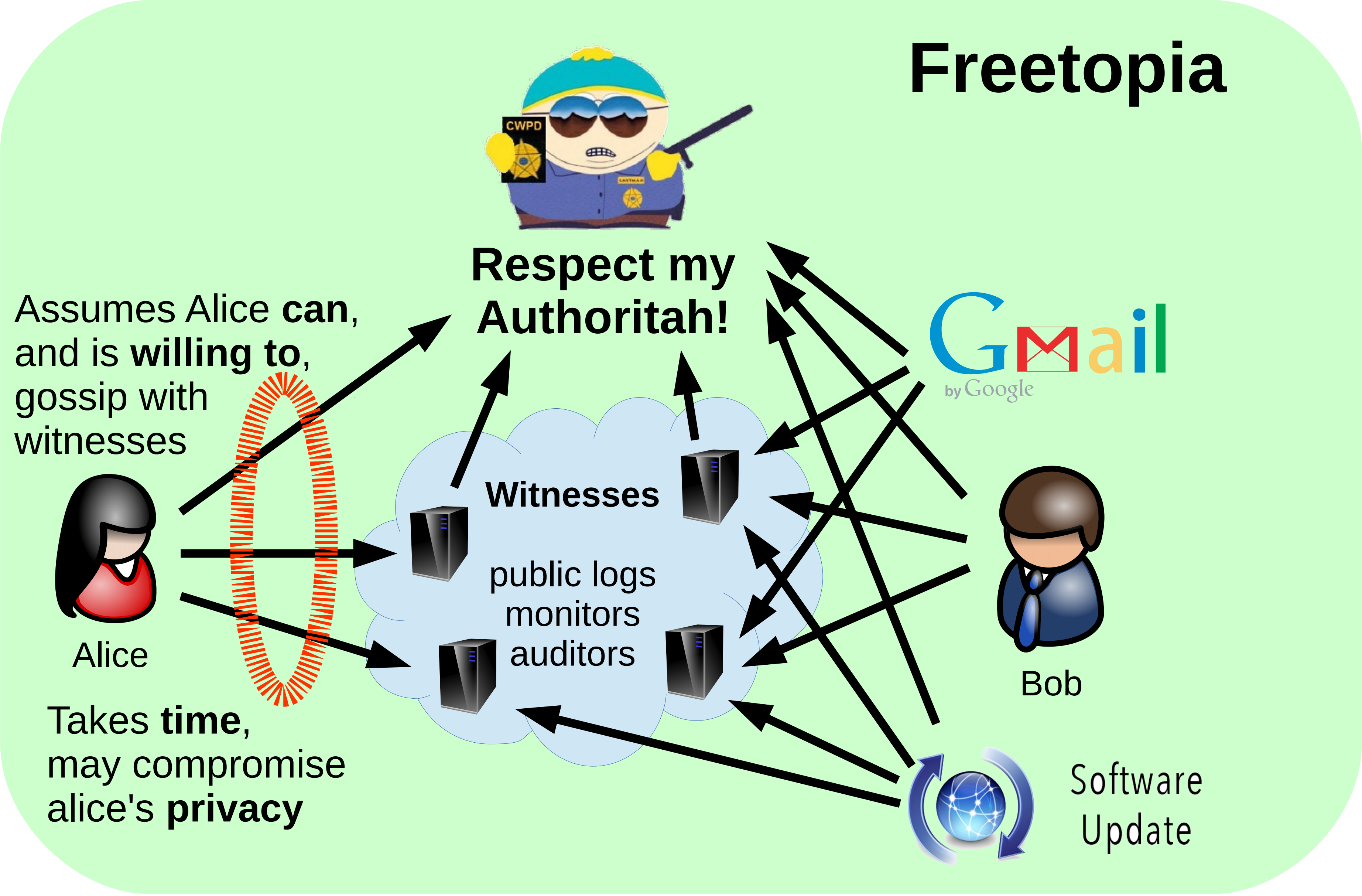
Software Update

Existing Transparency Solutions



- Perspectives
- Certificate Transparency
- AKI, ARPKI
- CONIKS

An Important Assumption



Freetopia

Respect my Authoritah!

Assumes Alice **can**, and is **willing to**, gossip with witnesses

Alice

Takes **time**, may compromise alice's **privacy**

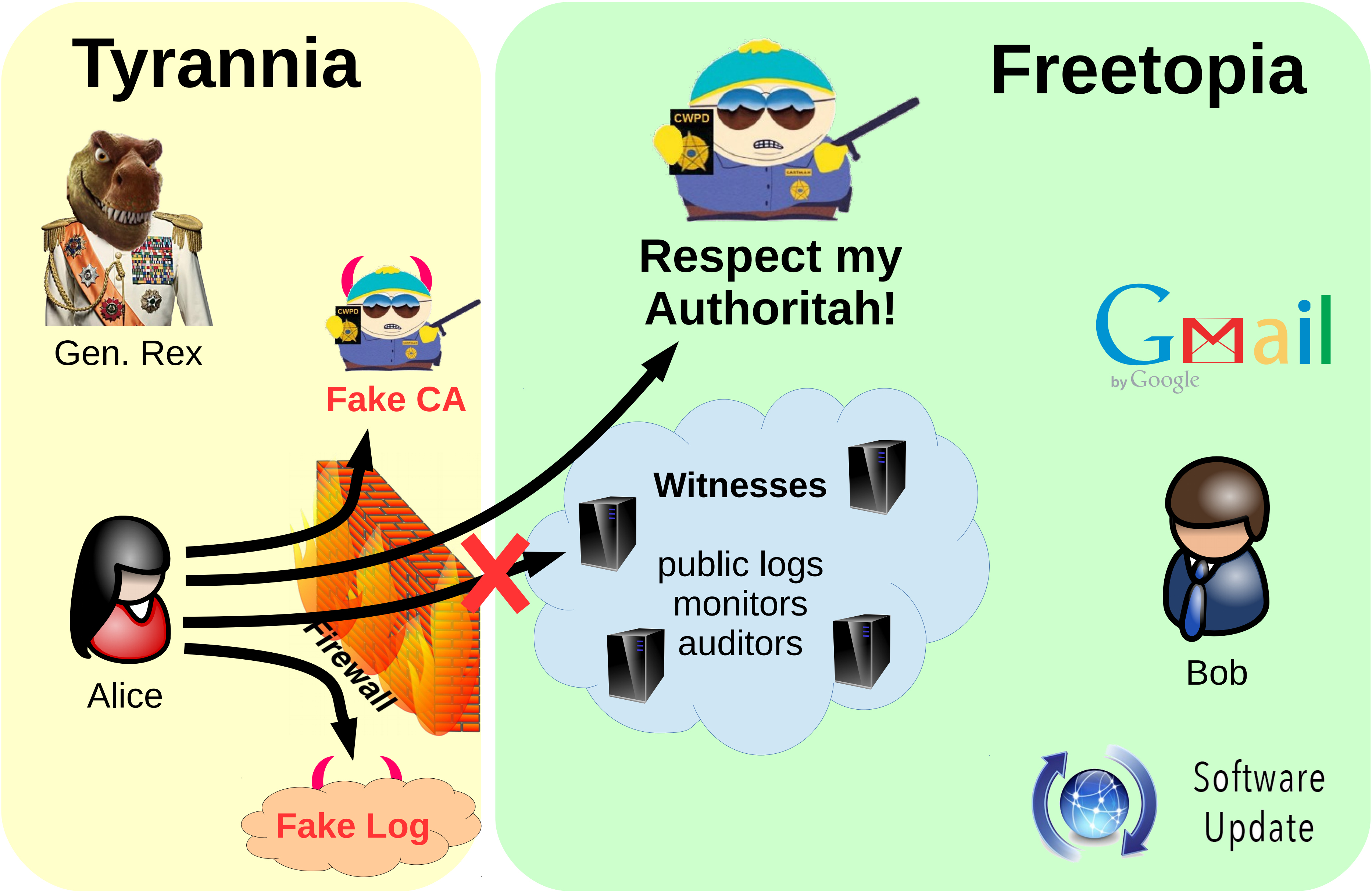
Witnesses

public logs
monitors
auditors

Bob

Software Update

A Different Scenario



Tyrannia

Gen. Rex

Fake CA

Alice

Firewall

Fake Log

Freetopia

Respect my Authoritah!

Witnesses

public logs
monitors
auditors

Bob

Software Update

Gossip versus Collective Signing

Gossip can't protect Alice if she...

- **Can't** (because she's in Tyrannia)
- **Doesn't want to** (for privacy), or
- **Doesn't have time to**

cross-check each authoritative statements.

Collective signing **proactively** protects her
from secret attacks even via her access network.

- Attacker can't secretly produce valid signature

An “Extreme” Scenario

What if an attacker **controls the target device,** wants to secretly coerce the device’s vendor to sign a back-doored operating system image?

- A phone **sealed in a forensics lab** can’t gossip!
  - Certificate Transparency can’t reveal its existence
- Only protection is to bind the transparency **proactively** into the device-verified signature

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Prototype available; give it a try!

Go to https://github.com/dedis/cosi

- Binaries: see releases
- Source: `go get -u github.com/dedis/cosi`

```
cosi sign -g group.toml -o sig msg_file
cosi verify -g group.toml -s sig msg_file
```

Run your own witness server: `cosi server`

Standalone verifiers for C, Go – see README

Status, Incremental Deployment

Still experimental! But…

- DEDIS lab committed to supporting, assisting with integration/deployment efforts
- Don’t want to trust collective signatures yet? Add in extension field alongside individual sig
- Don’t want to trust protocol, server liveness? Fork/exec ‘`cosi sign`’, set timer, kill if needed
- Don’t want to trust `cosi` software? Sandbox it! Needs almost nothing to run.

Send feedback privately or discuss publicly on https://groups.google.com/forum/#!forum/cothority

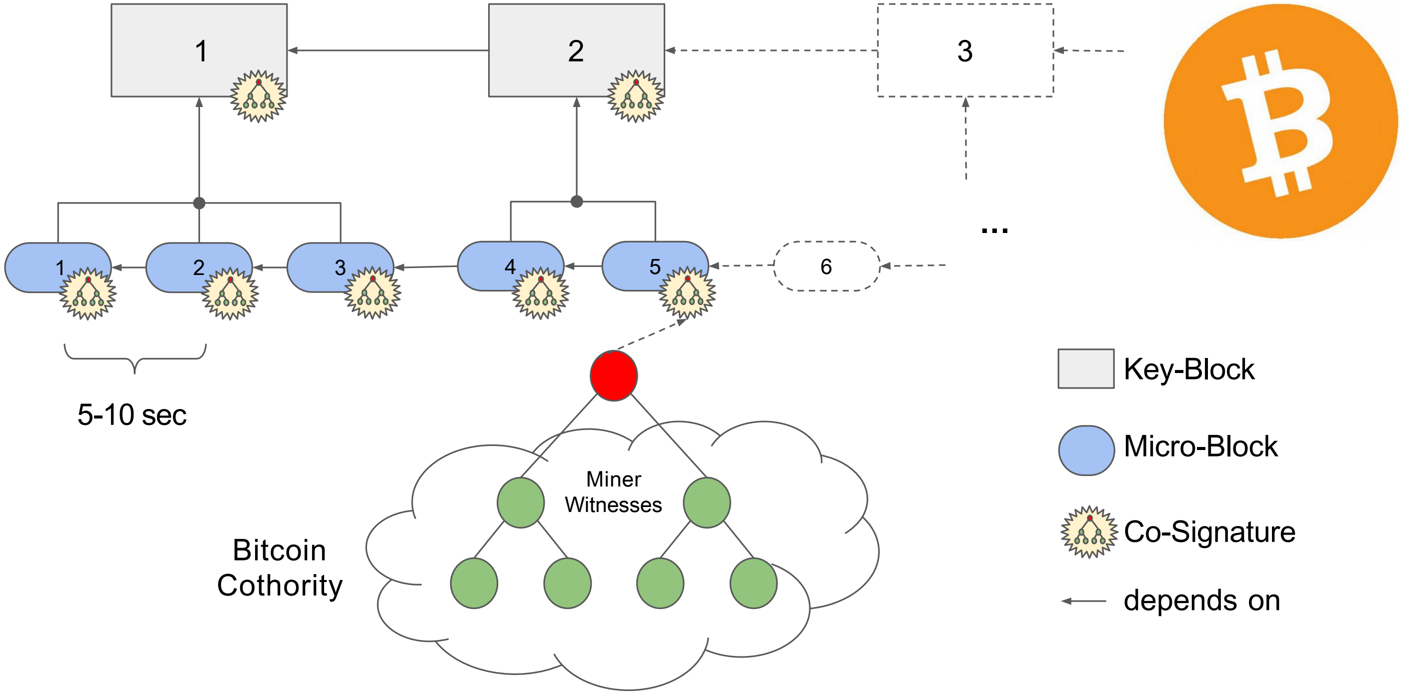
Other uses of collective signing

(credit: Tony Arcieri)

Other uses of collective signing

“Enhancing Bitcoin Security and Performance with Strong Consistency via Collective Signing”

- To appear at USENIX Security 2016
- Draft: http://arxiv.org/abs/1602.06997



Conclusion

Grand challenge: **decentralize all the authorities!**

Practical baby step: **decentralized witness cosigning**

- Ensures that for **any** signed statements that exists, **many parties** have witnessed, publicly logged it
  - Protects even relying parties that can't gossip
- Can incrementally add to **existing** authorities
- CoSi protocol **scales** to large witness groups

Available: **https://github.com/dedis/cosi**

Public question/answer, discussion forum:
https://groups.google.com/forum/#!forum/cothority

Scalable Collective Timestamping

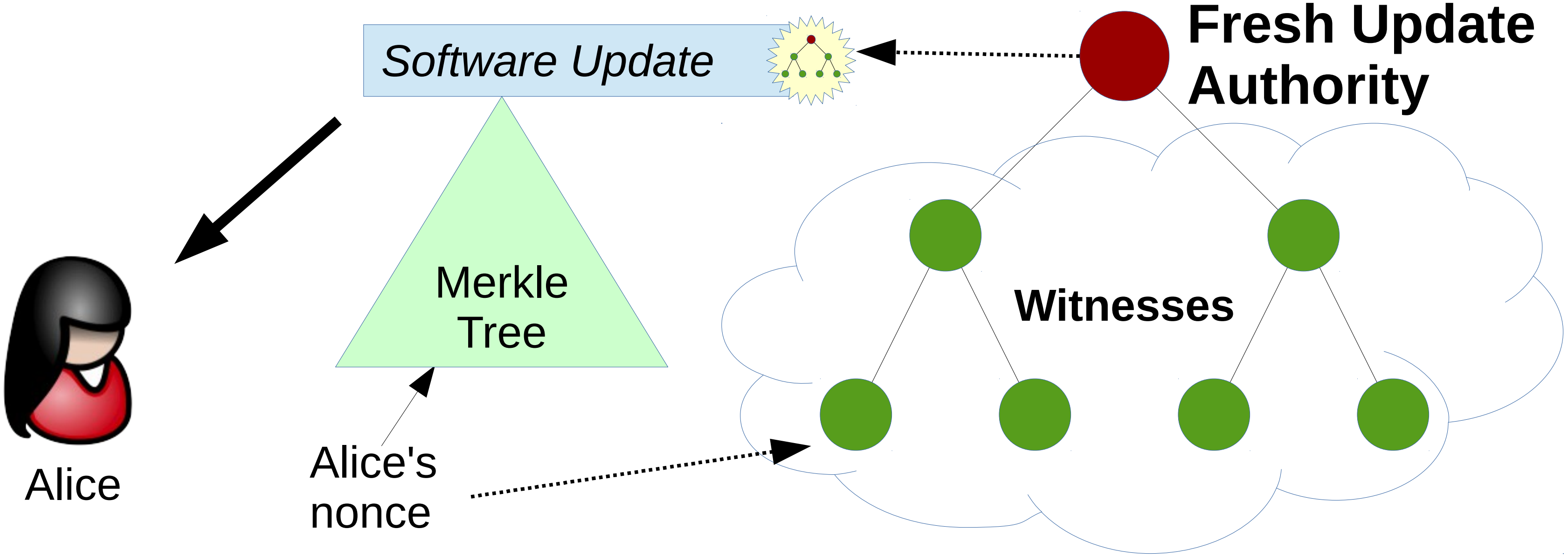
Like classic **digital timestamp** services,
only decentralized.

- Each round (e.g., 10 secs):
  1) Each server collects hashes, nonces to timestamp
  2) Each server aggregates hashes into Merkle tree
  3) Servers aggregate local trees into one global tree
  4) Servers collectively sign root of global tree
  5) Server give signed root + inclusion proof to clients
- Clients verify signature + Merkle inclusion proof

Verifiably Fresh Software Updates

Alice accepts only updates with fresh timestamp:

- Knows update can't be an outdated version: tree contains inclusion proof of *her* nonce
- Knows update can't have targeted backdoor: witness cothority ensures *many* parties saw it


Software Update
Fresh Update Authority
Merkle Tree
Witnesses
Alice
Alice's nonce