Scalable Bias-Resistant Distributed Randomness

Ewa Syta*, **Philipp Jovanovic**†, Eleftherios Kokoris Kogias†, Nicolas Gailly†,
Linus Gasser†, Ismail Khoffi‡, Michael J. Fischer§, Bryan Ford†

*Trinity College, USA
†EPFL, Switzerland
‡University of Bonn, Germany
§Yale University, USA

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Talk Outline

- Motivation
  - The need for public randomness
  - Strawman examples: Towards unbiasable randomness
- Two Randomness Protocols
  - RandHound
  - RandHerd
- Implementation and Experimental Results
- Conclusions and Demo

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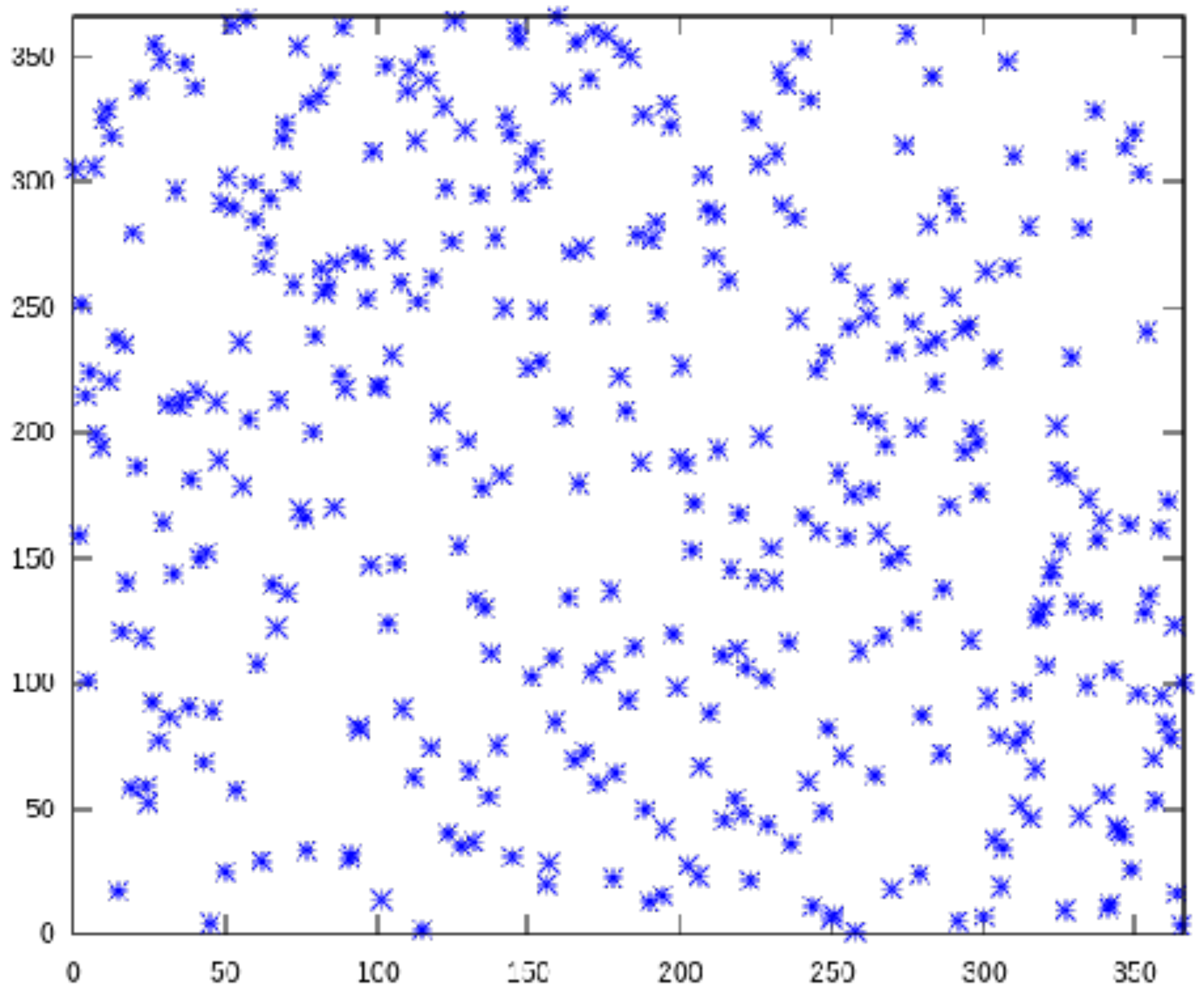
Public Randomness

- **Collectively** used
- Unpredictable ahead of time
- Not secret past a certain point in time
- Applications
  - **Random selection:** lotteries, sweepstakes, jury selection, voting and election audits
  - **Games:** shuffled decks, team assignments
  - **Protocols:** parameters, IVs, nonces, sharding
  - **Crypto:** challenges for NZKP, authentication protocols, cut-and-choose methods, "nothing up my sleeves" numbers

Failed / Rigged Randomness

Vietnam War Lotteries (1969)



'European draws have been rigged': Ex-FIFA president Sepp Blatter claims to have seen hot and cold balls used to aid cheats

Former FIFA president Sepp Blatter said he had witnessed rigged draws for European football competitions

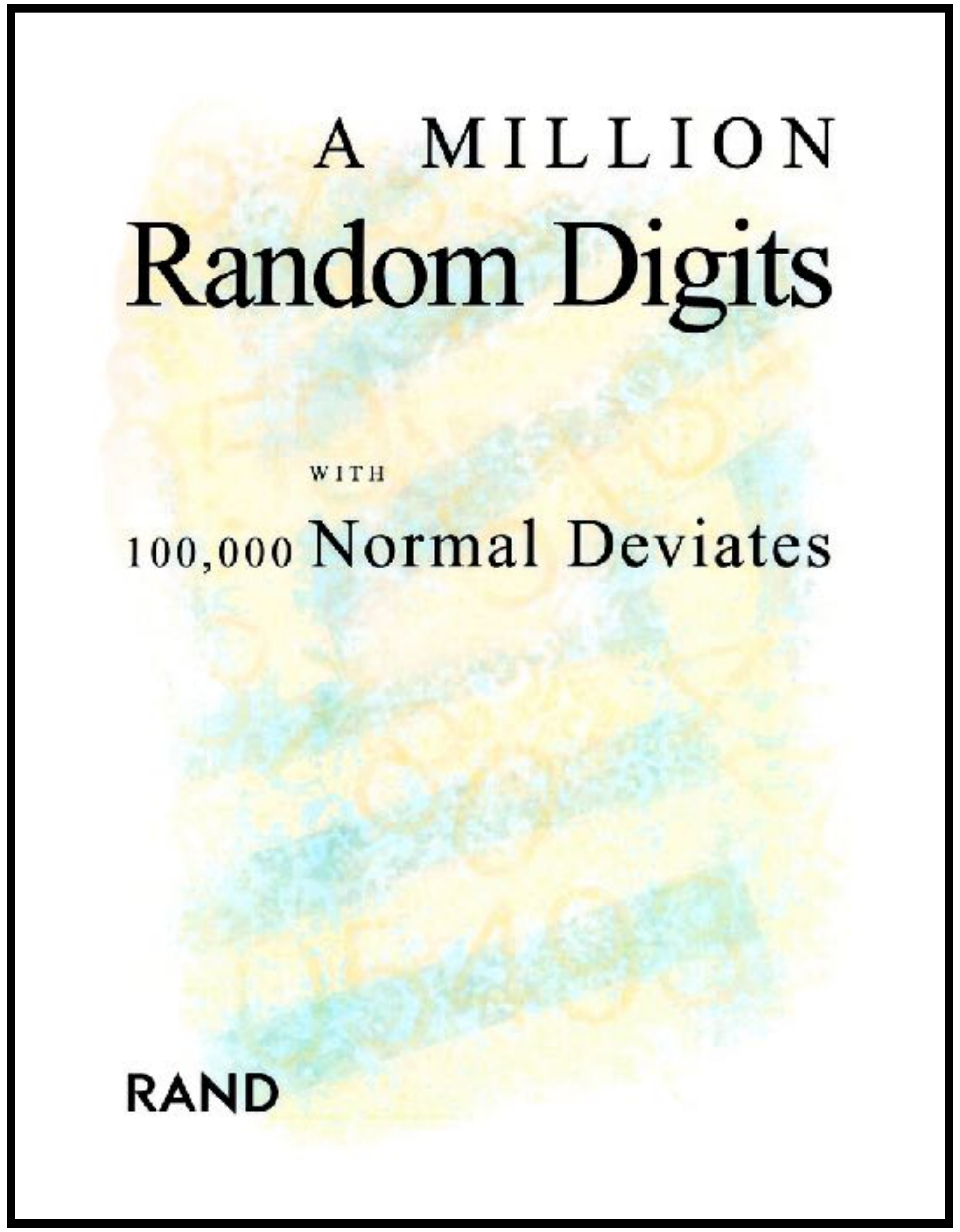
Man hacked random-number generator to rig lotteries, investigators say

New evidence shows lottery machines were rigged to produce predictable jackpot numbers on specific days of the year netting millions in winnings

'Computer whiz' rigged lottery number generator to produce predictable numbers a couple of times a year. Photograph: Brian Powers/AP

Public Randomness is not New

- 1955: Large table of random numbers published as a book by the Rand Corporation
- Today: Generating public random numbers is (still) **hard**
- Main issues: **trust** and **scale**



Goals

Decentralized, public randomness in the *(t,n)*-threshold security model

1. Availability

Successful protocol termination for up to *f=t-1* malicious nodes.

2. Unpredictability

Output not revealed prematurely.

3. Unbiasability

Output distributed uniformly at random.

4. Verifiability

Output correctness can be checked by third parties.

5. Scalability

Executable with hundreds of participants.

Assumptions: n= 3f +1, Byzantine adversary and asynchronous network with eventual message delivery

Public Randomness Approaches

- **With** Trusted Third Party
  - NIST Randomness Beacon

- **Without** TTP

Unusual assumptions

  - Bitcoin (Bonneau, 2015)
  - Slow cryptographic hash functions (Lenstra, 2015)
  - Lotteries (Baigneres, 2015)
  - Financial data (Clark, 2010)

(t,n)-threshold security model but not scalable

  - Coin-flipping (Cachin, 2015)
  - Distributed key generation (Kate, 2009)

Public Randomness is Hard

	Availability	Unpredictability	Unbiasability	Verifiability	Scalability
Strawman I	⊖	⊖	⊖	⊖	⊖
Strawman II	⊖	✓	⊖	⊖	⊖
Strawman III	✓	✓	✓	⊖	⊖

Strawman I

- **Idea:** Combine random inputs of all participants.
- **Problem:** Last node controls output.

Strawman II

- **Idea:** Commit-then-reveal random inputs.
- **Problem:** Dishonest nodes can choose not to reveal.

Strawman III

- **Idea:** Secret-share random inputs.
- **Problem:** Dishonest nodes can send bad shares.

Public Randomness is Hard

	Availability	Unpredictability	Unbiasability	Verifiability	Scalability
Strawman I	⛔	⛔	⛔	⛔	⛔
Strawman II	⛔	✔	⛔	⛔	⛔
Strawman III	✔	✔	✔	⛔	⛔
RandShare	✔	✔	✔	⛔	⛔

RandShare

- **Idea:** Strawman III + *verifiable secret sharing* (Feldman, 1987)
- **Problems:**
  - Not publicly verifiable
  - Not scalable: $O(n^3)$ communication / computation complexity

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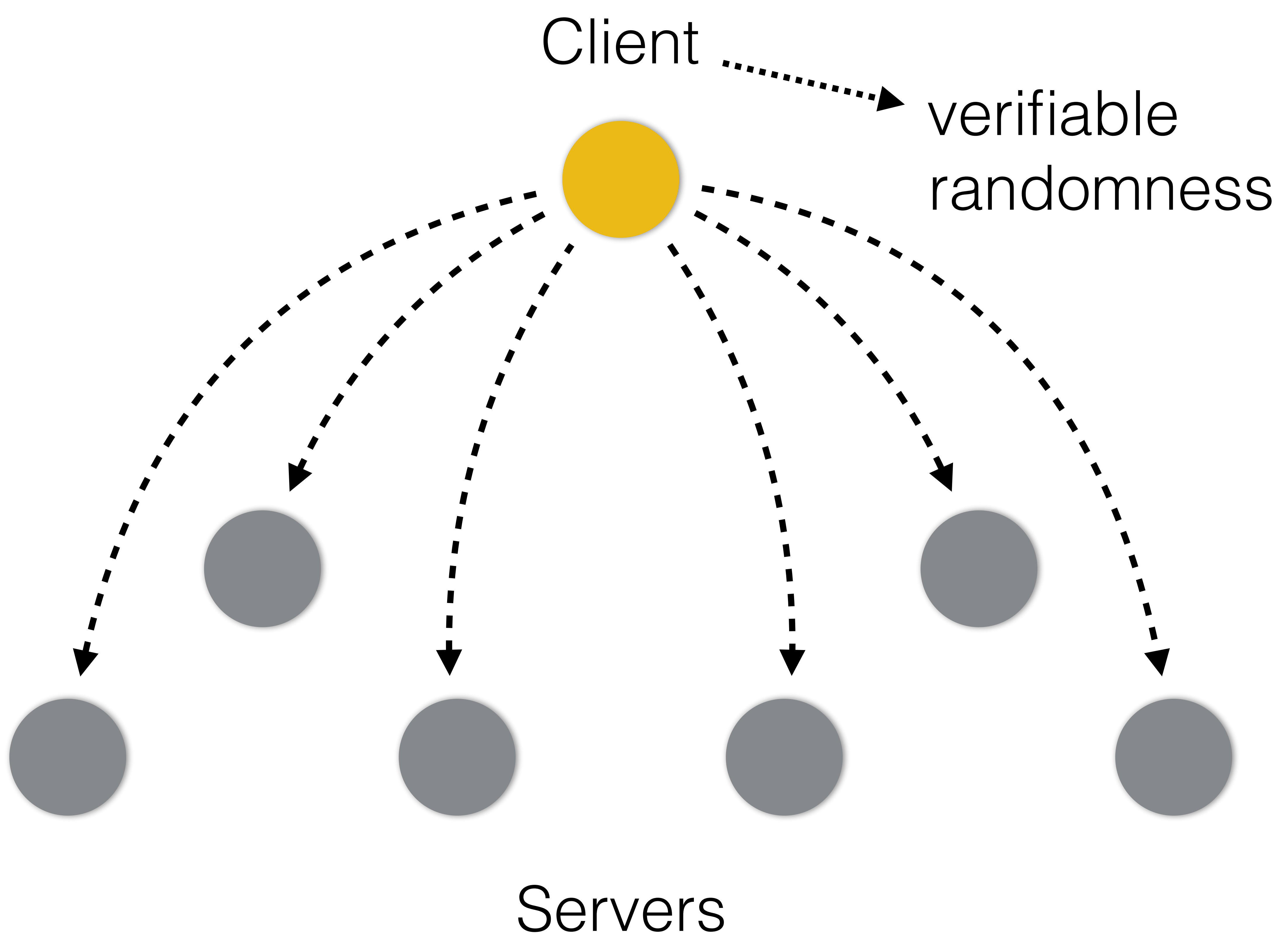
RandHound

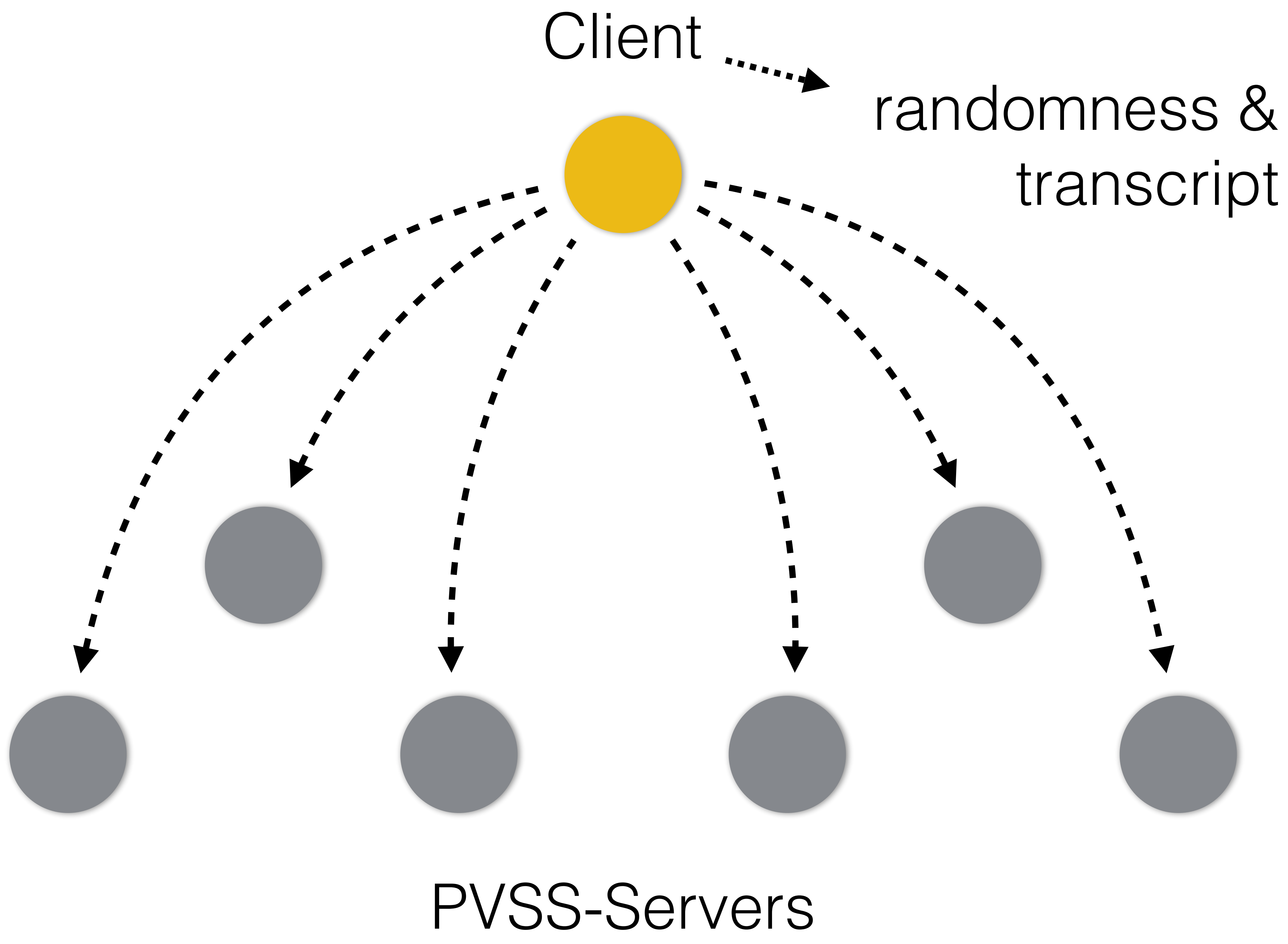
- Goals
  - Verifiability: By third parties
  - Scalability: Performance better than $O(n^3)$
- Client/server randomness scavenging protocol
  - Untrusted client uses a large set of nearly-stateless servers
  - On demand (via configuration file)
  - One-shot approach
  - Example: lottery authority



RandHound

Achieving Public Verifiability

- Publicly-VSS (Schoenmakers, 1999)
  - Shares are encrypted and publicly verifiable through zero-knowledge proofs
  - No communication between servers
- Collective signing (Syta, 2016)
  - Client publicly commits to their choices
- Create protocol transcript from all sent/received (signed) messages



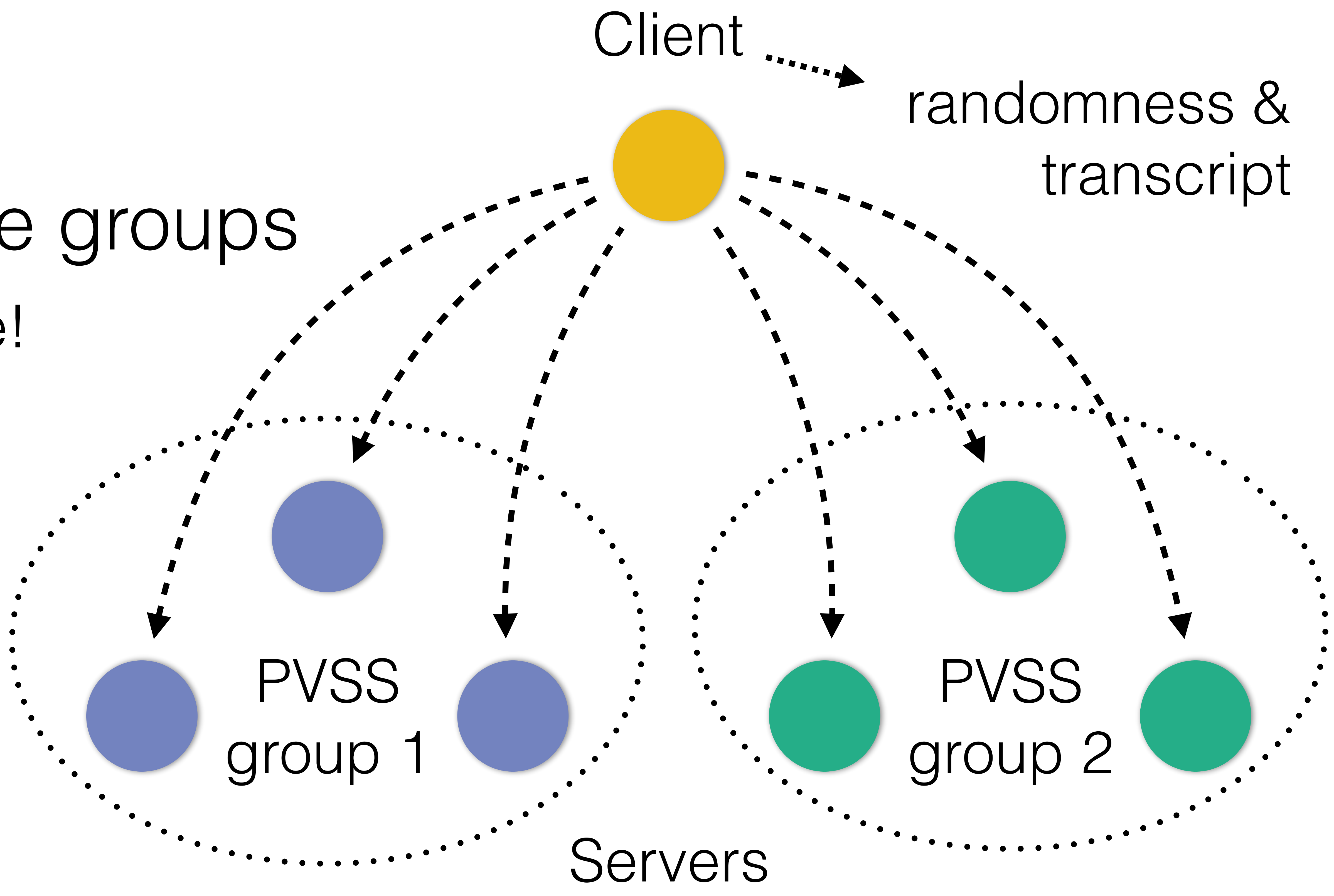
RandHound

Achieving Scalability

- Shard participants into constant size groups
  - Secret sharing with everyone too expensive!
  - Run secret sharing (only) inside groups
  - Collective randomness: combination of all group outputs

Chicken-and-Egg problem?

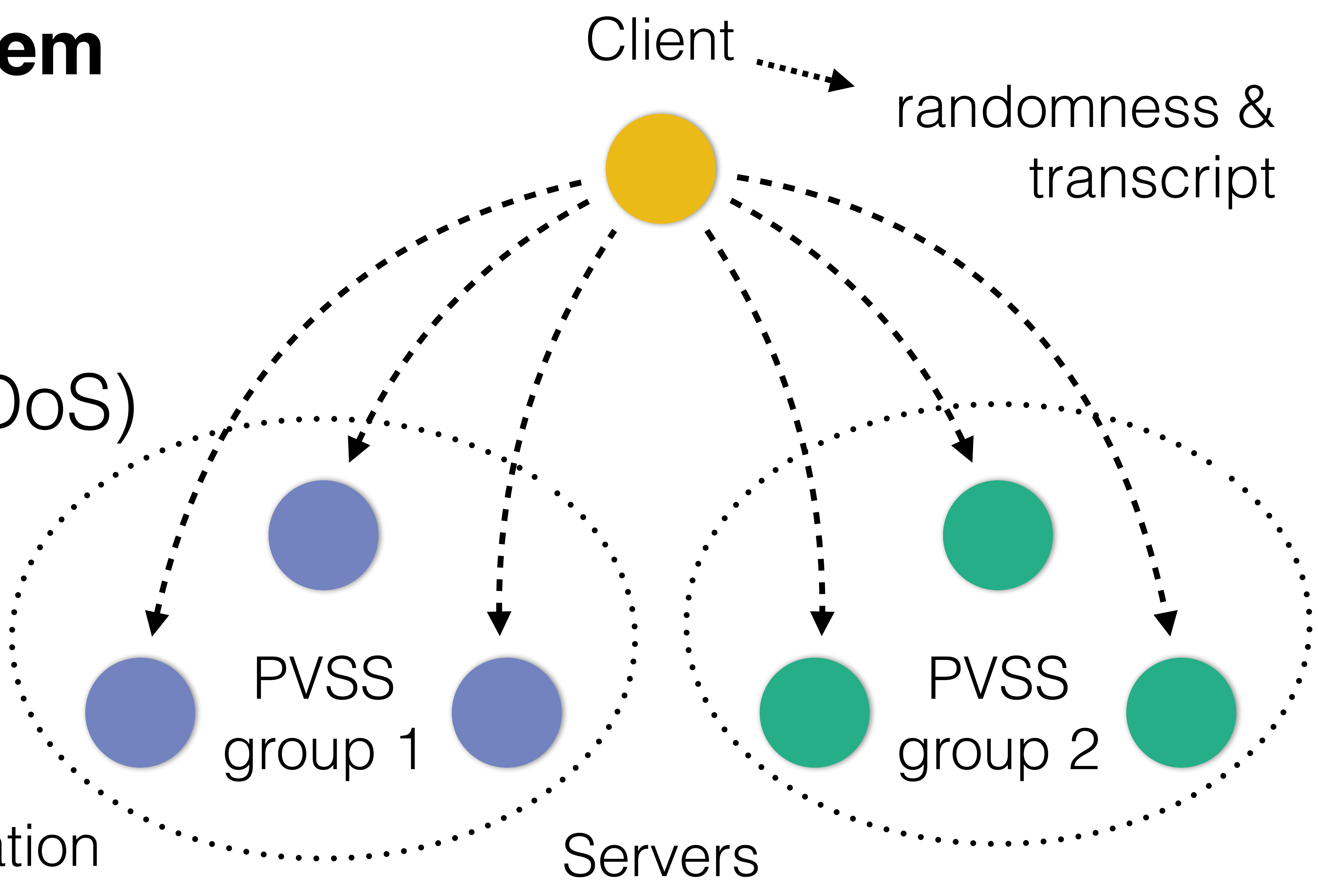
- How to securely assign participants to groups?



RandHound

Solving the Chicken-and-Egg Problem

- Client selects server grouping
- Availability might be affected (self-DoS)
- Security properties through
  - *Pigeonhole principle:* at least one group is not controlled by the adversary
  - *Collective signing:* prevents client equivocation by fixing the secrets that contribute to randomness



Public Randomness is (not so) Hard

	Availability	Unpredictability	Unbiasability	Verifiability	Scalability
Strawman I	⛔	⛔	⛔	⛔	⛔
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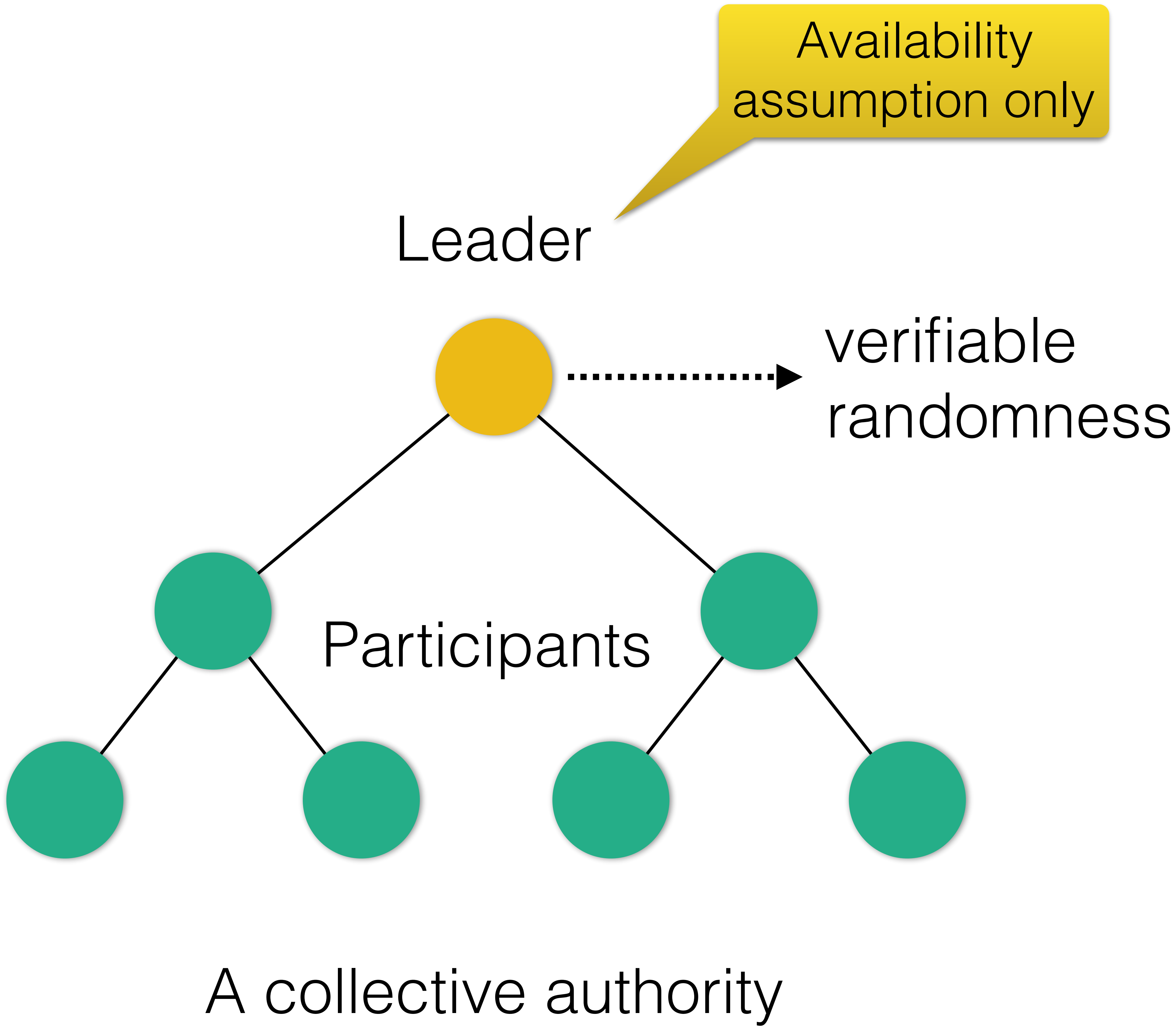
Strawman III	✓	✓	✓	⛔	⛔
RandShare	✓	✓	✓	⛔	⛔
RandHound	✓	✓	✓	✓	✓

Communication / computation complexity: $O(c^2n)$

RandHerd

- Goals
  - Continuous, leader-coordinated randomness generation
  - Small randomness proof size (a single Schnorr signature)
  - Better performance than O(n)
- Decentralized randomness beacon
  - Built as a collective authority or *cothority*
  - Randomness on demand, at frequent intervals, or both

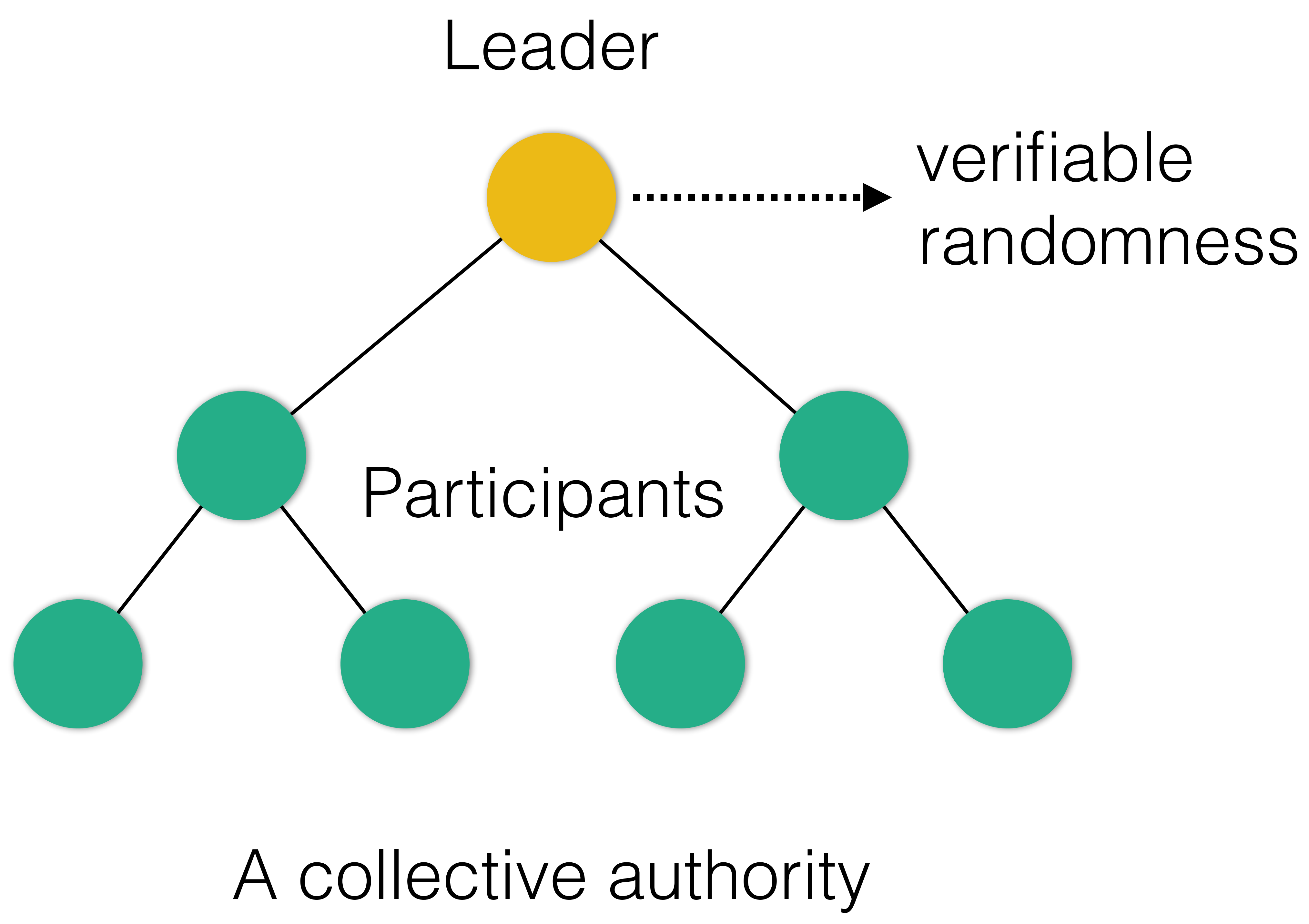


RandHerd

Achieving RandHerd's Goals

- Idea
  - Collective randomness = collective Schnorr signature
  - Benefits: Small proofs, O(log n) complexity
  - Problem: Failing nodes influence output

- Solution
  - Arrange nodes into *(t,n)*-threshold Schnorr signing (Stinson, 2001) groups (failure resistance)
  - Collective randomness = aggregate group signatures
  - Approach: Setup + round function



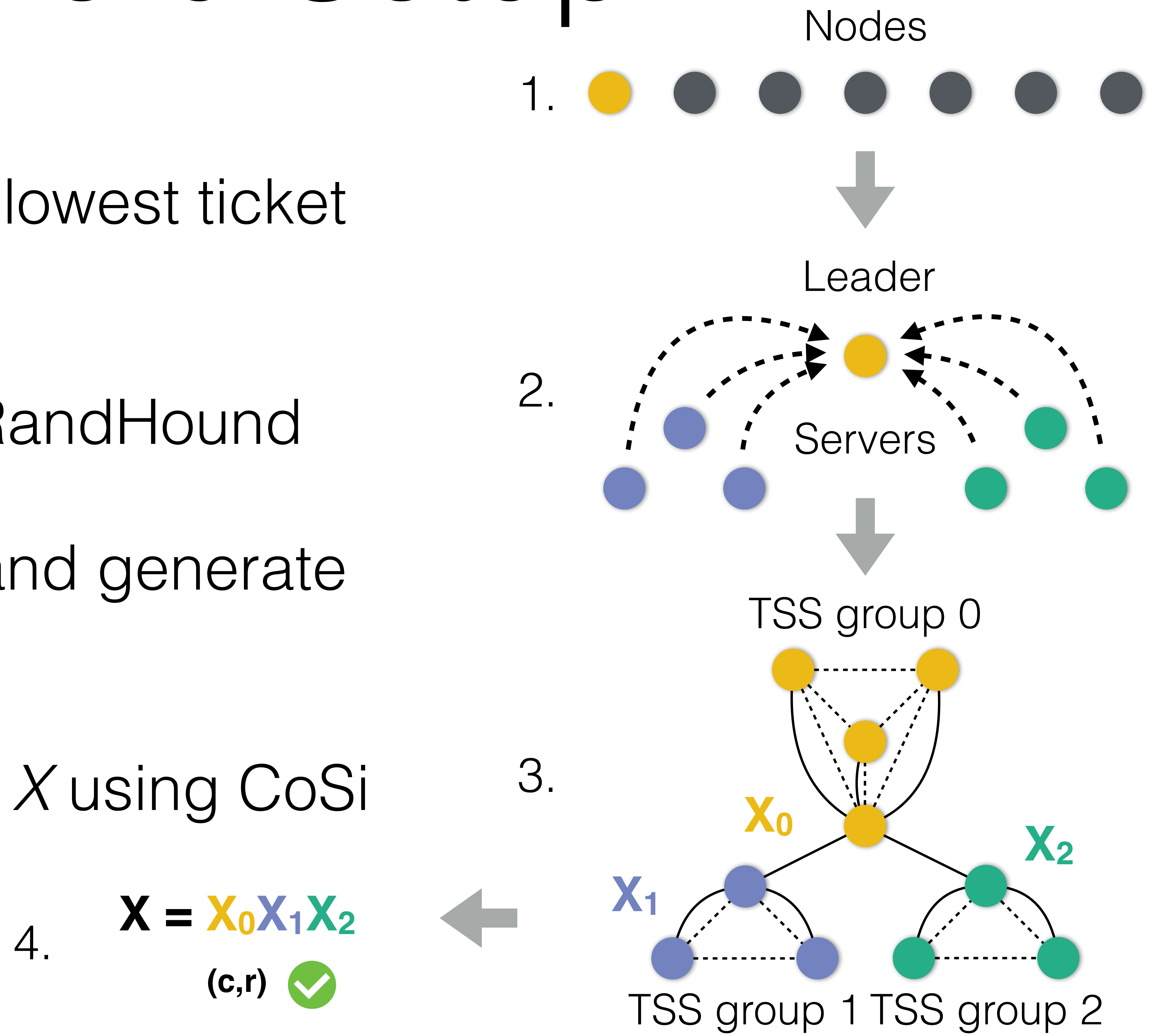
RandHerd Setup

1. Elect a temporary leader via lowest ticket
   t_i = VRF(*config*, *key*$_i$)

2. Obtain randomness Z from RandHound

3. Create TSS groups using Z and generate group keys X_i

4. Certify aggregate public key X using CoSi



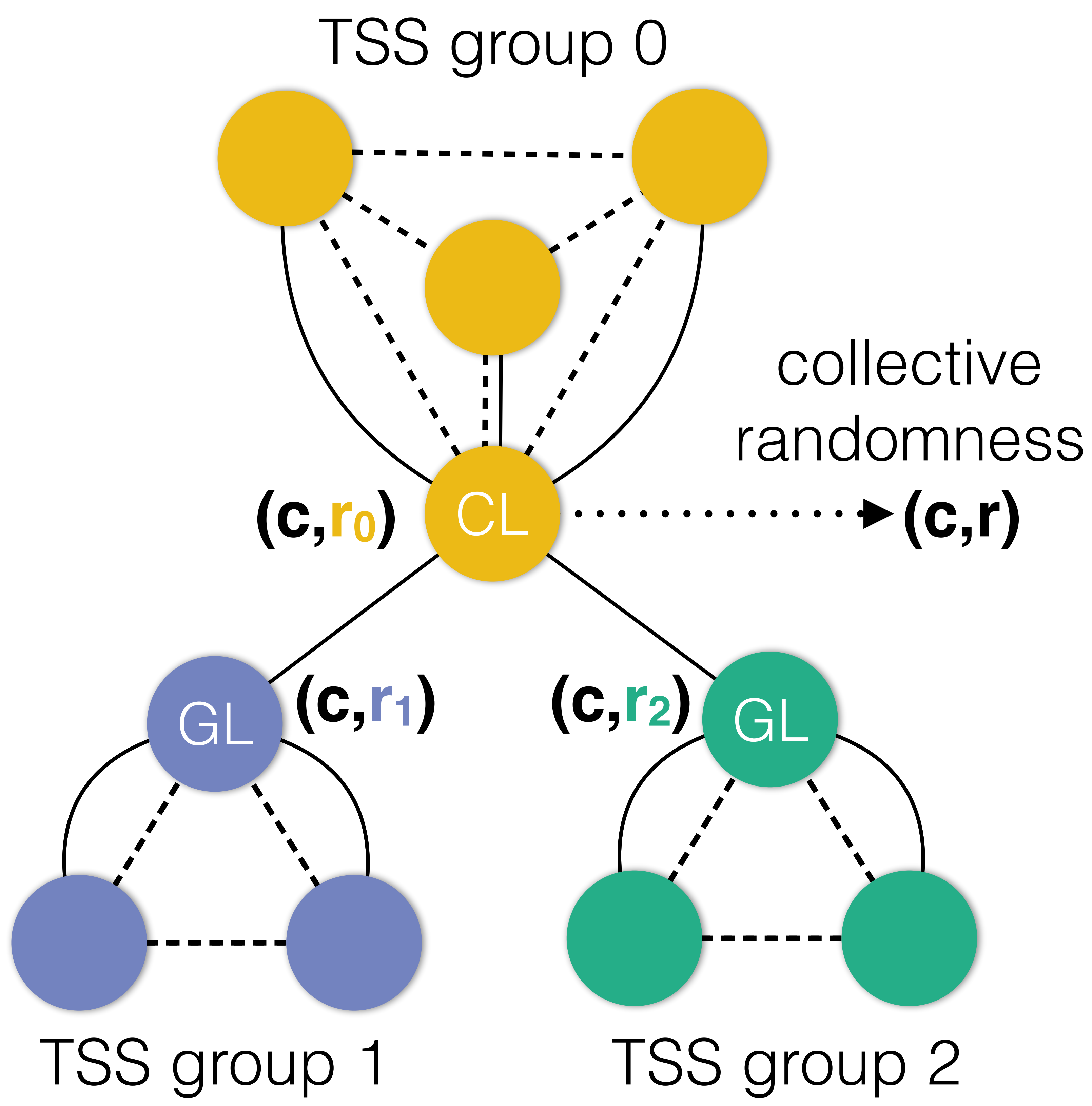
RandHerd Round

Generation

1. Cothority Leader (CL) broadcasts timestamp ***v***

2. TSS-CoSi
    a. Produce group Schnorr signatures $\mathbf{(c,r_0)}$ $\mathbf{(c,r_1)}$ $\mathbf{(c,r_2)}$ on ***v***
    b. Aggregate into collective Schnorr signature $\mathbf{(c,r = r_0+r_1+r_2)}$
    c. Publish **(c,r)** as collective randomness

Verification of **(c,r)** on **v** using the collective public key $\mathbf{X = X_0X_1X_2}$



Public Randomness is (not so) Hard

	Availability	Unpredictability	Unbiasability	Verifiability	Scalability
Strawman I	⛔	⛔	⛔	⛔	⛔
Strawman II	⛔	✅	⛔	⛔	⛔
Strawman III	✅	✅	✔️	⛔	⛔
RandShare	✅	✅	✅	⛔	⛔
RandHound	✅	✅	✅	✅	✔️
RandHerd	✅	✅	✅	✅	✅

Communication / computation complexity: $O(c^2 \log(n))$

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Implementation & Experiments

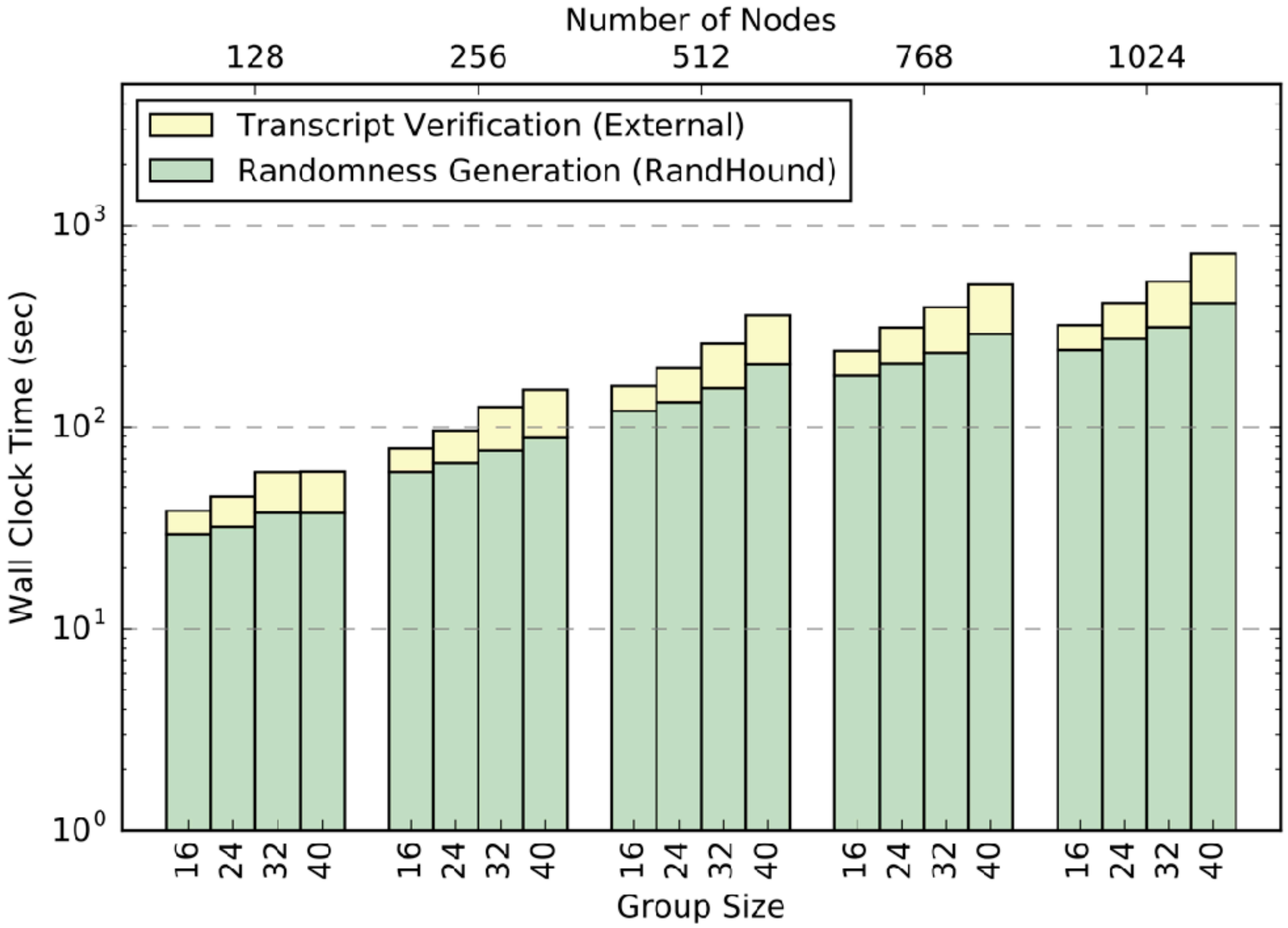
Implementation

- Go versions of DLEQ-proofs, PVSS, TSS, CoSi-TSS, RandHound, RandHerd
- Based on DEDIS code
  - Crypto library
  - Network library
  - Cothority framework
- https://github.com/dedis

DeterLab Setup

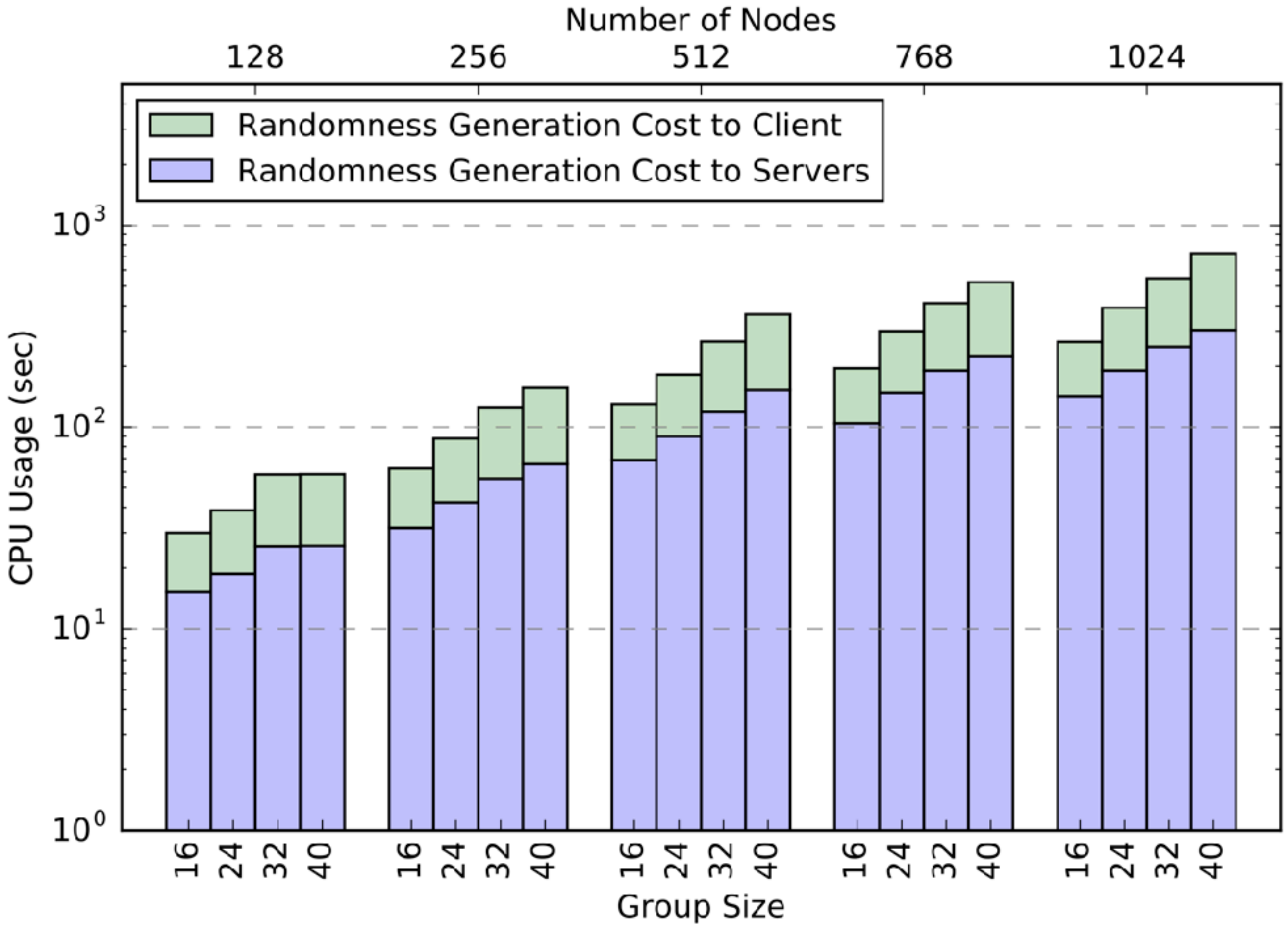
- 32 physical machines
  - Intel Xeon E5-2650 v4 (24 cores @ 2.2 GHz)
  - 64 GB RAM
  - 10 Gbps network link
- Network restrictions
  - 100 Mbps bandwidth
  - 200 ms round-trip latency

Experimental Results – RandHound



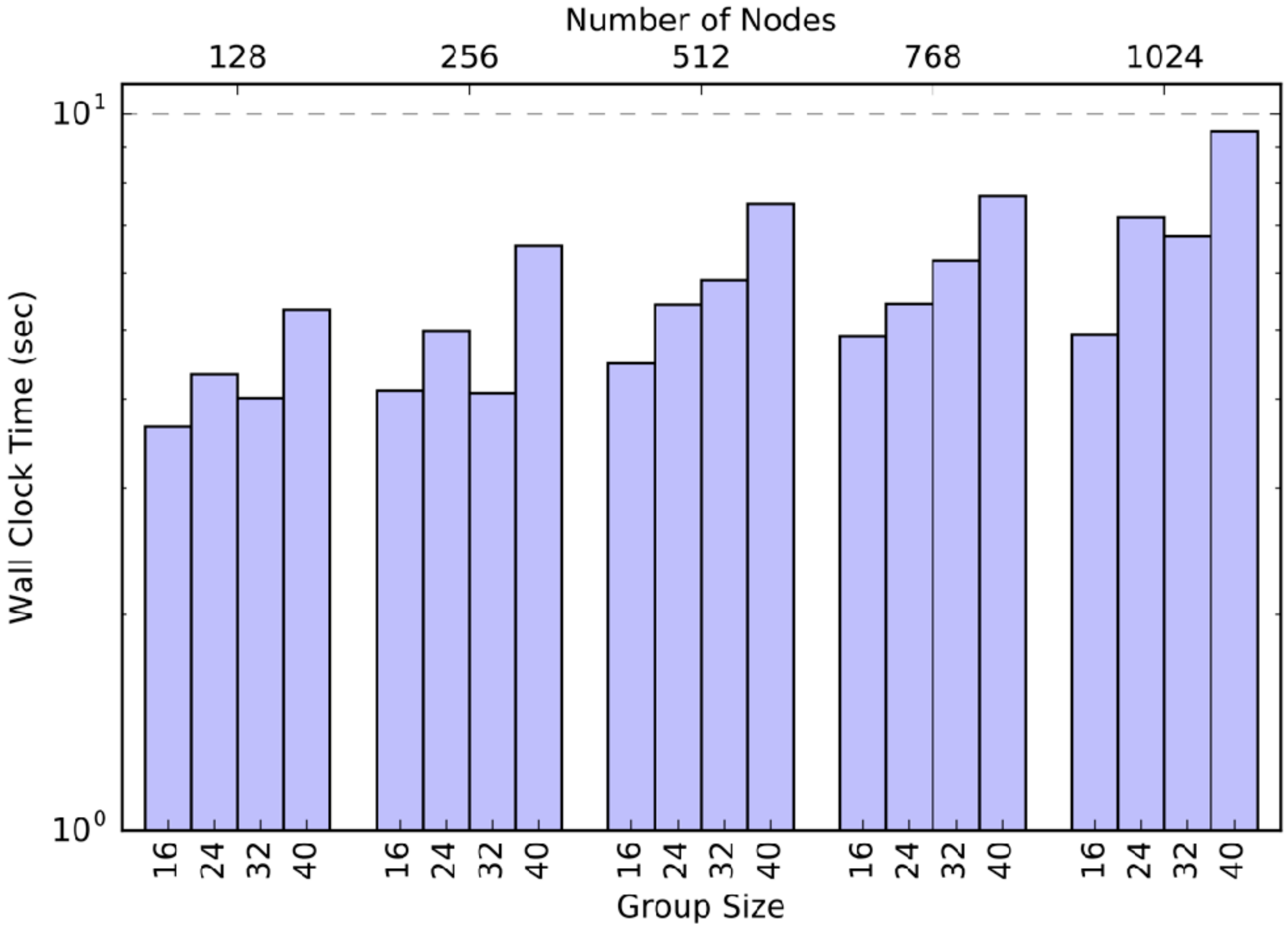
Take-away: Gen. / ver. time for 1 RandHound run is 290 sec / 160 sec with 1024 nodes, group size 32.

Experimental Results – RandHound



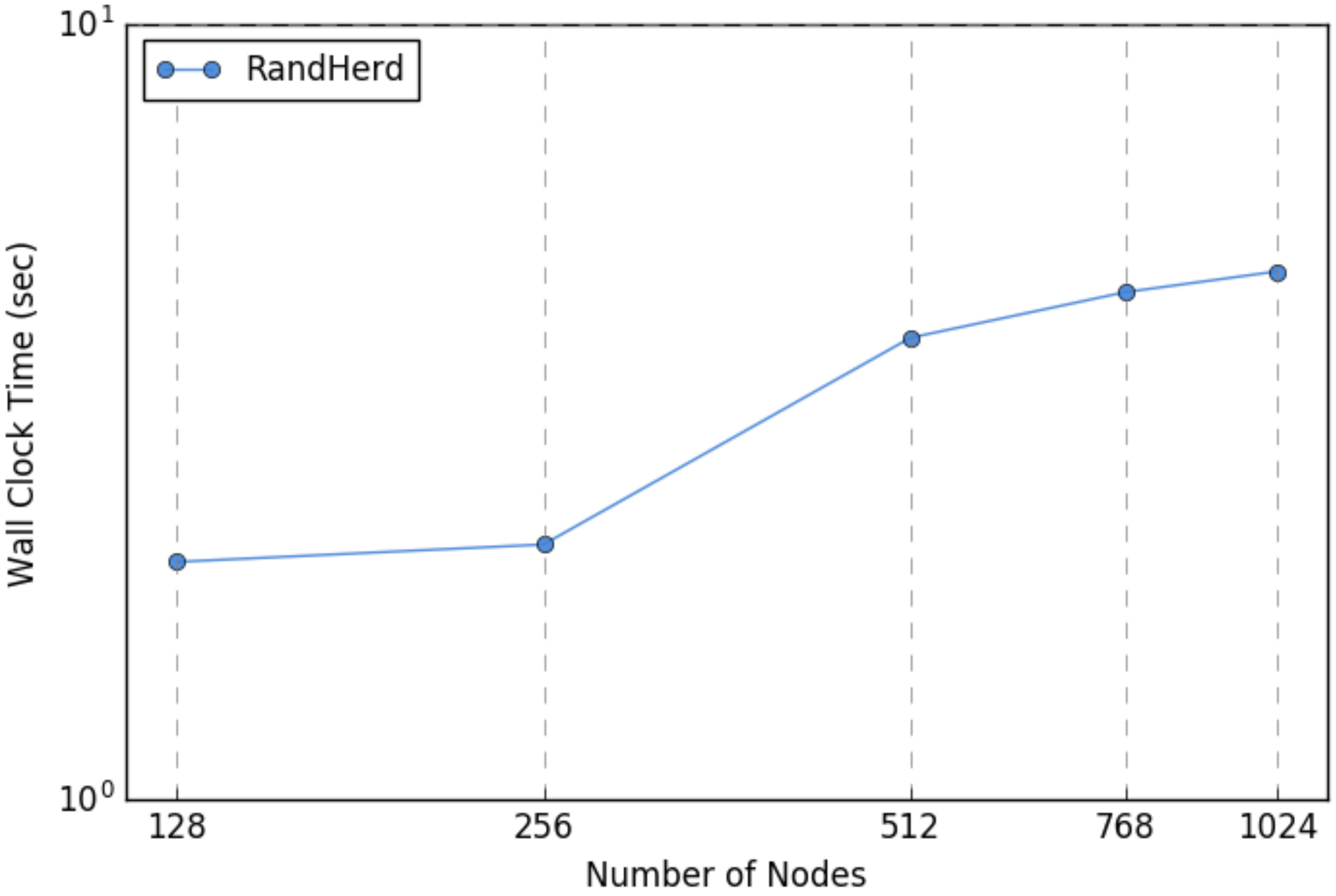
Take-away: Total cost for 1 RandHound run is 10 CPU min (EC2: < $0.02) with 1024 nodes, group size 32.

Experimental Results – RandHerd



Take-away: Gen. time for 1 RandHerd run with is 6 sec, after setup (10 mins) with 1024 nodes, group size 32.

Experimental Results – RandHerd



Take-away: For a constant group size RandHerd has O(log n) randomness generation complexity.

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Conclusion

- Generation of public randomness: **trust** and **scale** issues
- Our solution: two protocols in the *(t,n)*-threshold security model

	Availability	Unpredictability	Unbiasability	Verifiability	Scalability	Complexity
RandHound	✓	✓	✓	✓	✓	O(n)
RandHerd	✓	✓	✓	✓	✓	O(log(n))

- Code: https://github.com/dedis/cothority

Demo

pulsar.dedis.ch

Thank you!

Questions?

Ewa Syta
ewa.syta@trincoll.edu

Philipp Jovanovic
philipp.jovanovic@epfl.ch