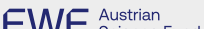
Securing Distributed Hash Tables using Proofs of Space

Christoph Günther

Krzysztof Pietrzak

CTB Workshop @ Eurocrypt 2025



This research was funded in whole or in part by the Austrian Science Fund (FWF) 10.55776/F85.

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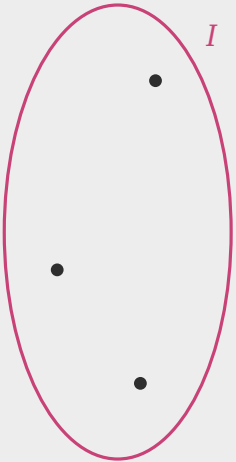

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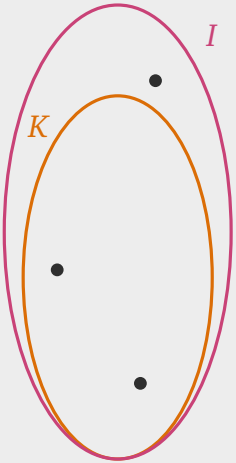

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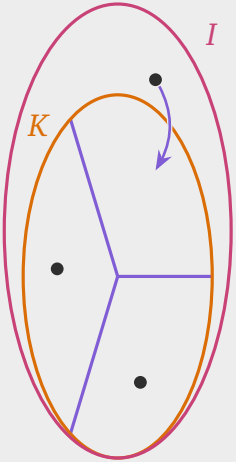

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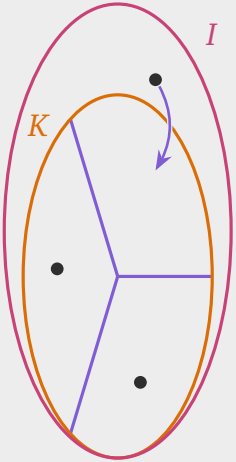
- Efficient protocol $\mathrm{lookup}\colon K \to I$



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IPFS: $\approx$ 45 000 DHT server nodes `https://probelab.io/ipfs/kpi/`, 2025-04-21

Sybil attacks

Adversary joins the network with multiple nodes using different identities

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- Eclipse attack against Ethereum's peer-to-peer network [Marcus et al., ePrint 2018/236]

Outline

1. DHT constructions & attacks

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2. Proof of work & downsides

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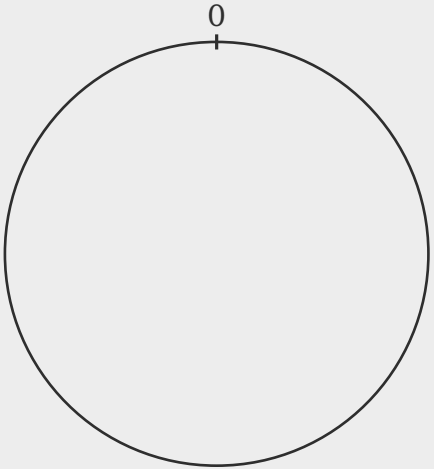
2. Proof of work & downsides
3. Proof of space (PoSp)
    - Why space is a better fit
    - Combining DHTs + PoSp
    - Theoretical analysis

Chord

- $I = K = \mathbb{Z}_N$



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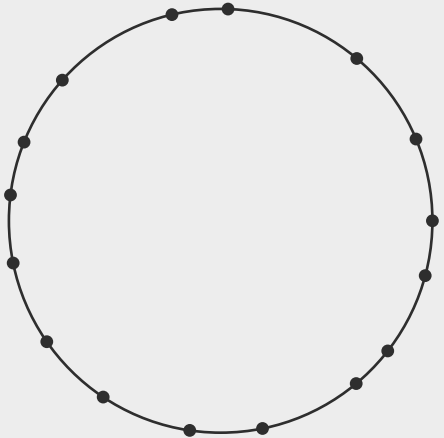

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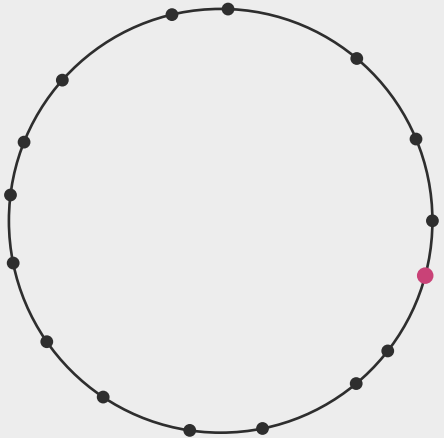

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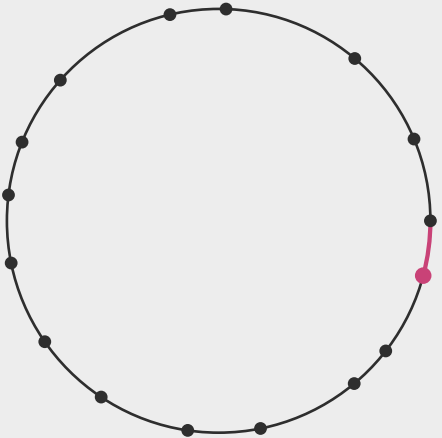

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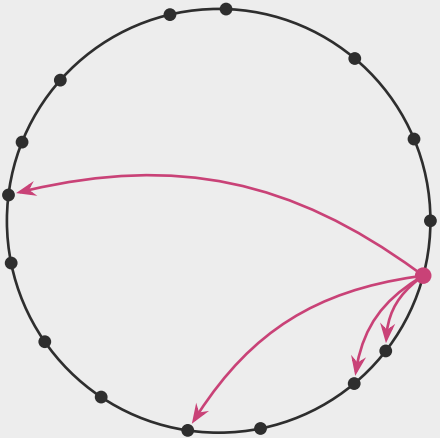

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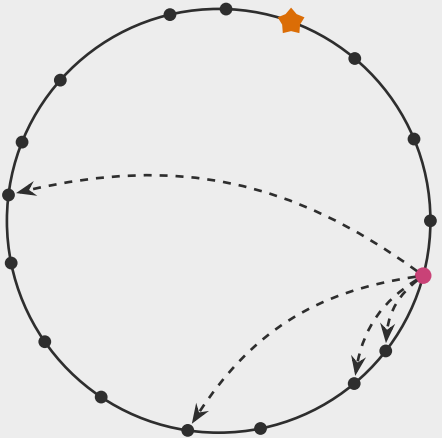

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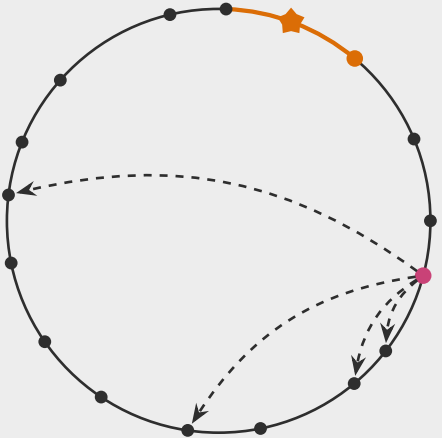

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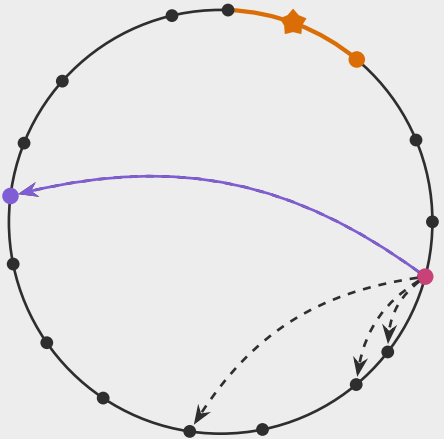

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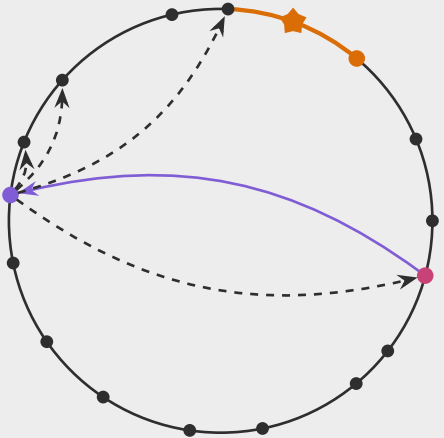

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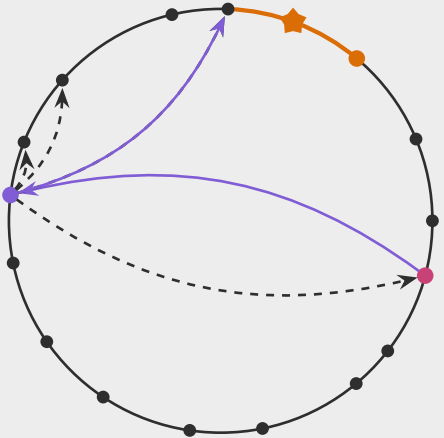

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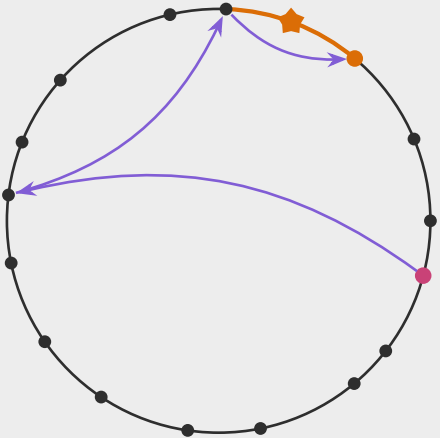
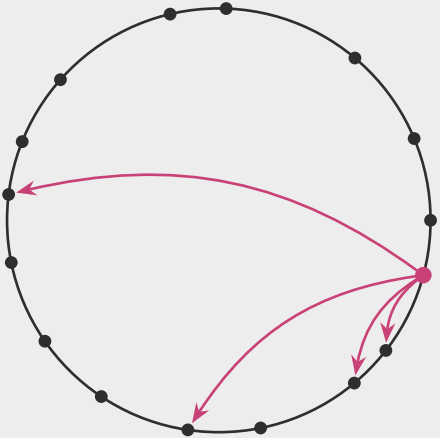


Eclipse attack



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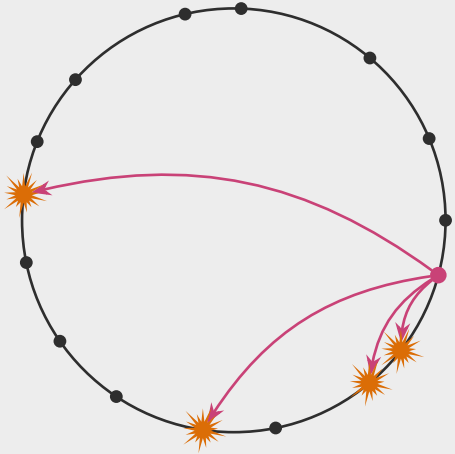

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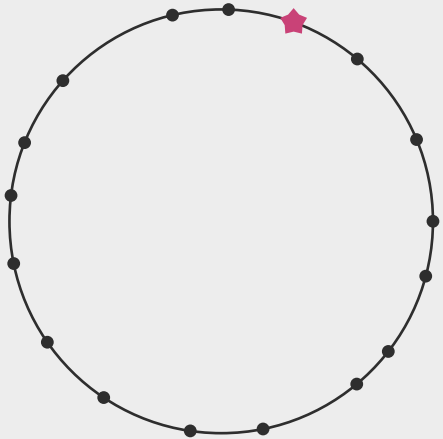

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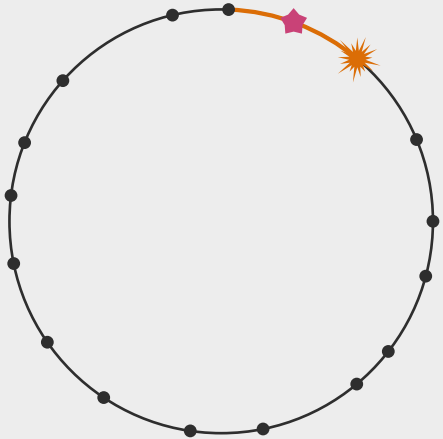

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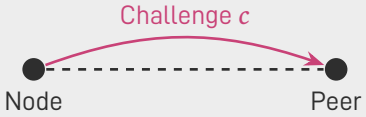

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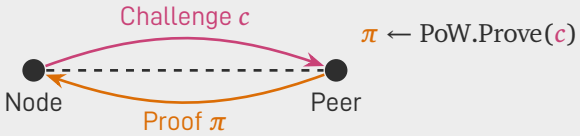

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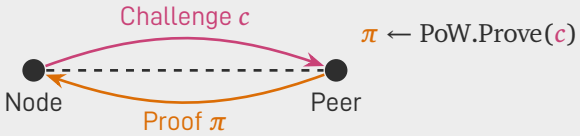

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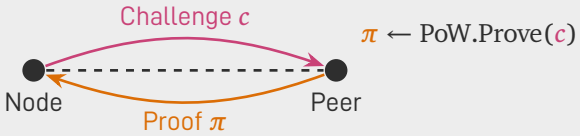

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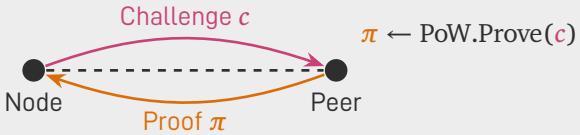

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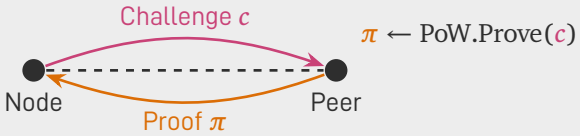

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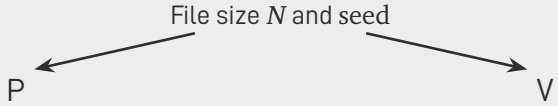
2. Energy efficient (after initial setup)

Proof of space (PoSp) à la Filecoin



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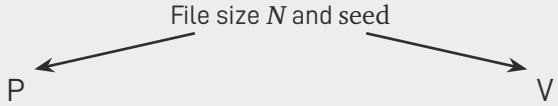

Initialization Phase

Online Phase

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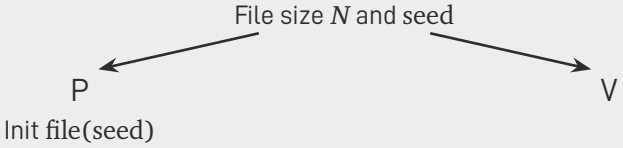

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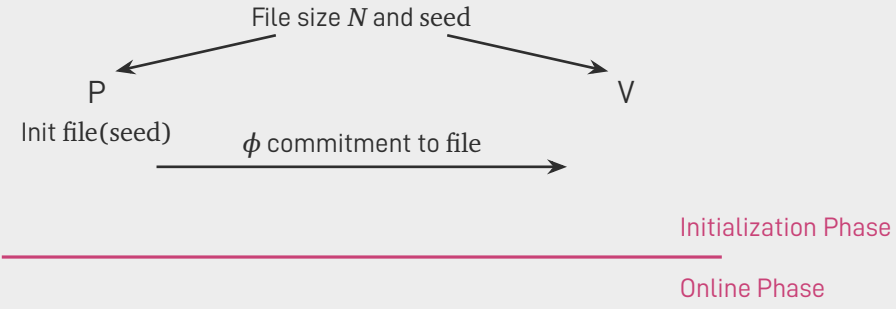

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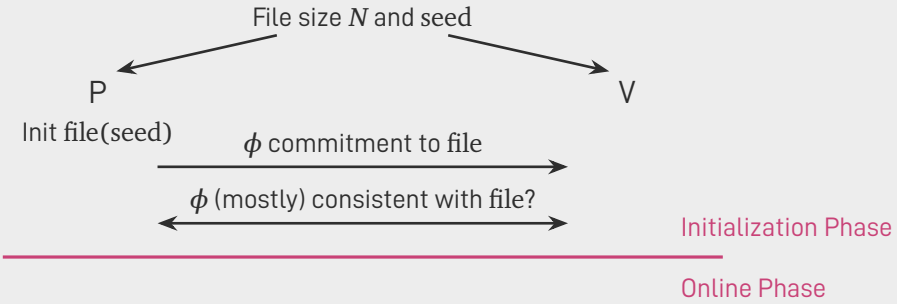

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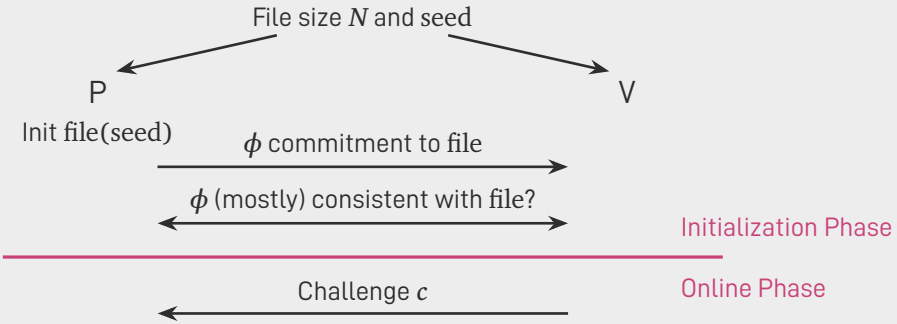

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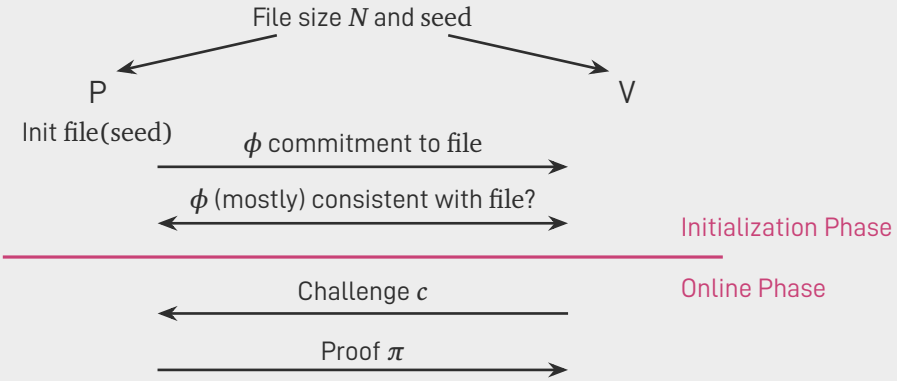

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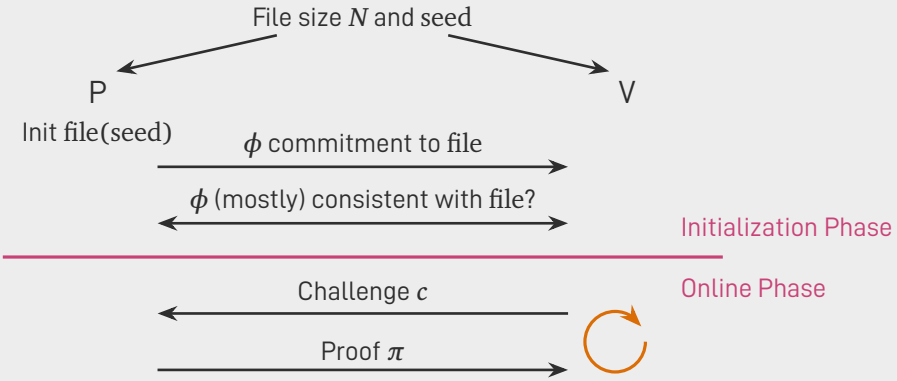

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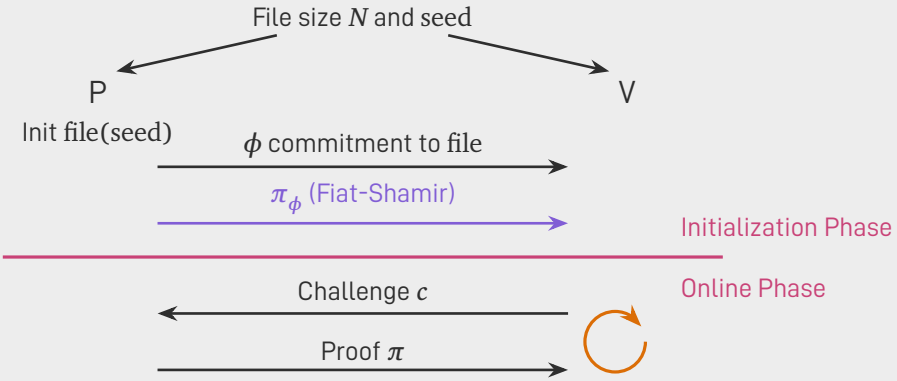

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Space-hardness: A cheating prover

storing *less than* αN bits

running in *less than* $\beta \, \text{time}(\text{Init})$

fails challenge c with probability *at least* p

Basic construction

Combines PoSp with existing DHT

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Joining the DHT

Being added as a peer

While connected

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Joining the DHT Store $(\text{file}, \phi, \pi_\phi) \leftarrow \text{PoSp.Init}(N, \text{DHT.id})$

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Being added as a peer	Send (ϕ, π_ϕ) to them
While connected	Every t seconds, receive κ PoSp challenges $c_1, \ldots, c_\kappa$
	Reply $\pi_i \leftarrow \text{PoSp.Prove}(\text{file}, \phi, c_i)$ for every $i \in [\kappa]$

Security guarantee

The number of Sybil nodes f is bounded by

$$f < \frac{S_{\text{ADV}}}{\alpha N}$$

except for exponentially small probability in λ if

- number of challenges $\kappa = \lambda / p$
- challenge interval $t < \beta \, \text{time(Init)}$

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Every Sybil costs αN space

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$\Rightarrow n$ grows linearly in the total honest space S_{HON}

Virtual nodes

Problem: Often want a bound on the *fraction* of Sybils $f/n < \gamma$

Solution: Honest node with space S participates as $\delta S/N$ distinct identities

$\Rightarrow n$ grows linearly in the total honest space S_{HON}

Security guarantee

$f/n < \gamma$ as long as $S_{\text{ADV}} < \text{const}(\alpha, \gamma, \delta) \cdot S_{\text{HON}}$

Practicality?

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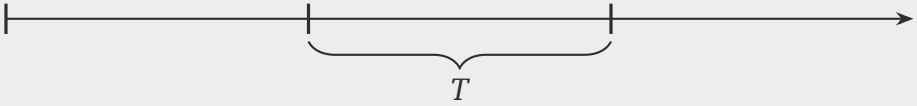
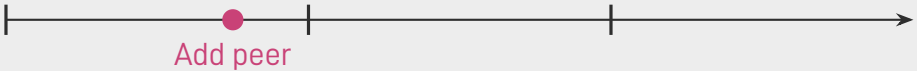
Solution: Improve protocol: Probabilistic challenges & time epochs

Improved protocol



Improved protocol



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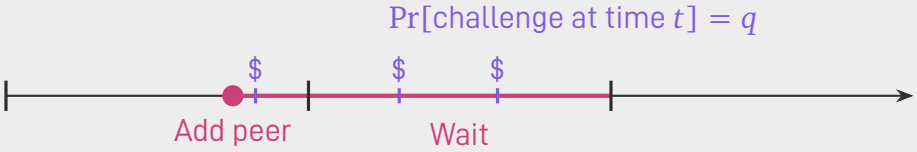

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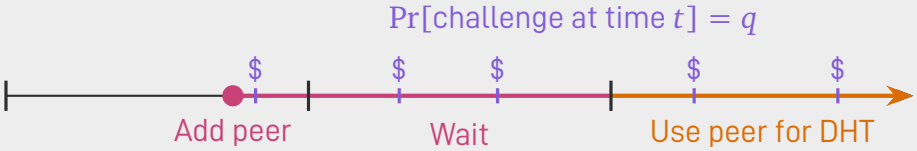

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Improvements over basic scheme

1. Fewer challenges in expectation
2. No need to boost detection probability (constant p is fine)

Contributions

- Using disk space to limit Sybils in DHTs
- Simple & practical schemes
- Theoretical analysis

Future work

- Simulations/implementation
- Don't waste space (e.g., backups)
- DHTs handling large f/n

Securing Distributed Hash Tables using Proofs of Space

C. U. Günther and K. Pietrzak

https://gnthr.eu/uploads/posp_dht_draft.pdf