Concentrated Stopping Set Design for Coded Merkle Tree: Improving Security Against Data Availability Attacks in Blockchain Systems

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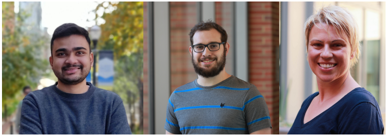
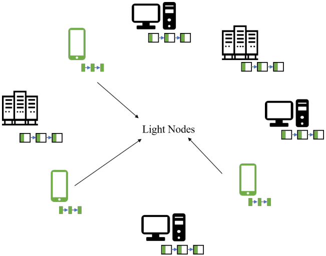
ITW 2020



UCLA Samueli School of Engineering

Data Availability (DA) Attacks in Blockchains



Light Nodes:

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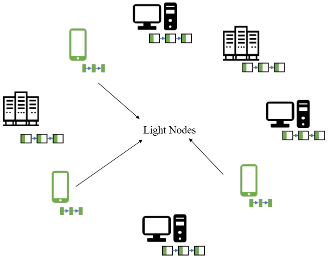

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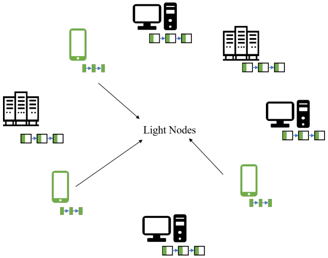

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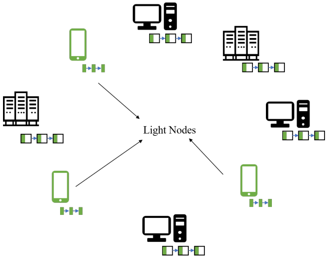

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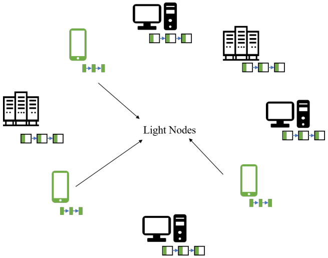

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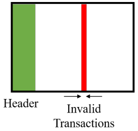

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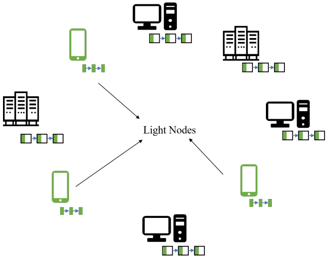

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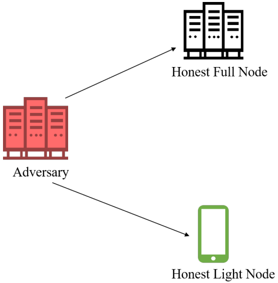

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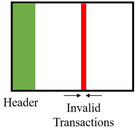

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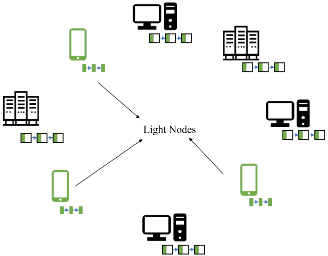

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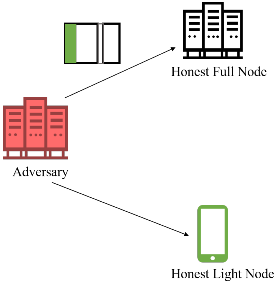

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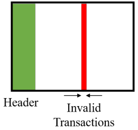

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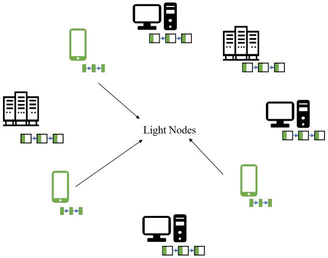

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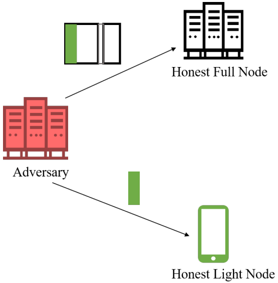

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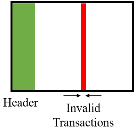

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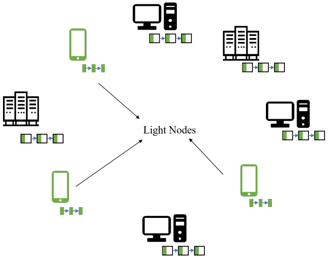

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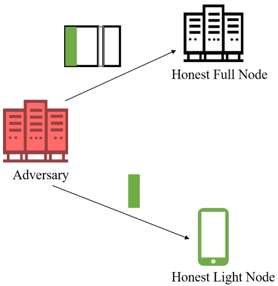

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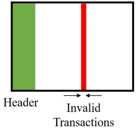

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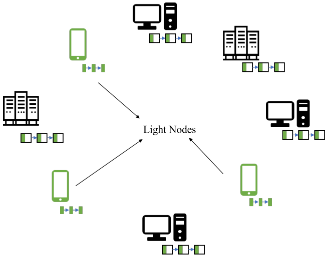

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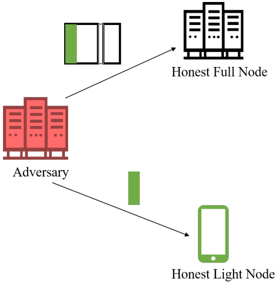

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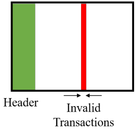
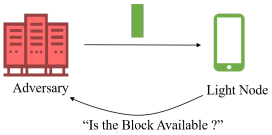


- Full nodes: cannot send fraud proof
- Light nodes: accept the invalid header

Ensure Data Availability: Light Node Sampling



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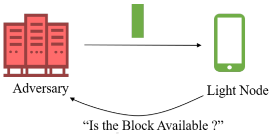

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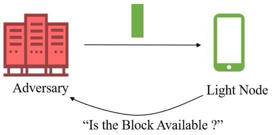

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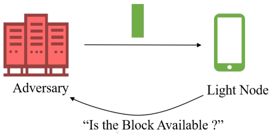

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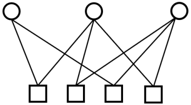

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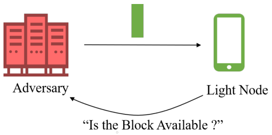

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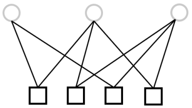

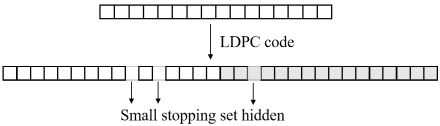

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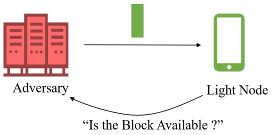

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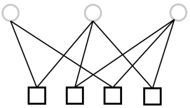

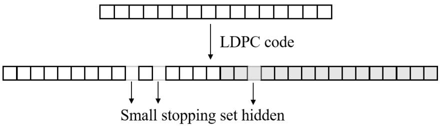

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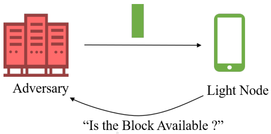

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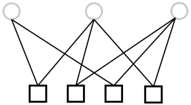

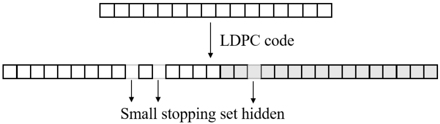

Probability of failure (2 samples):

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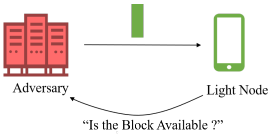

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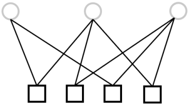

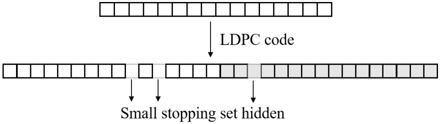

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Our work: Design of specialized LDPC codes with a coupled sampling strategy to achieve a significantly lower probability of failure.

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In this work, we considered an adversary which randomly hides a stopping set of a particular size.

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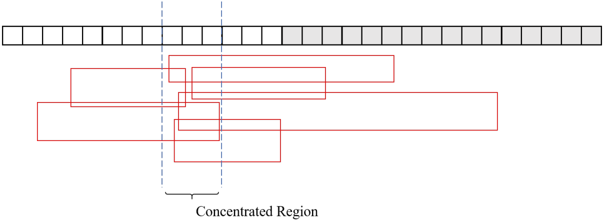

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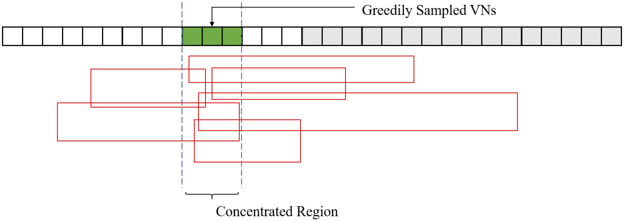

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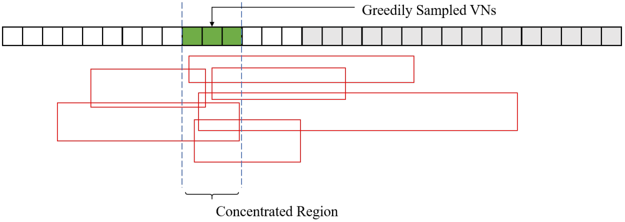

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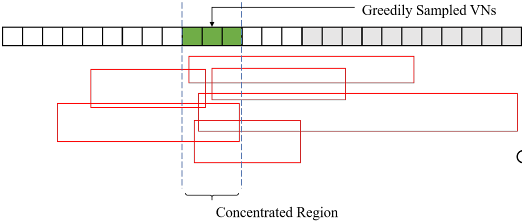

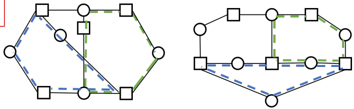

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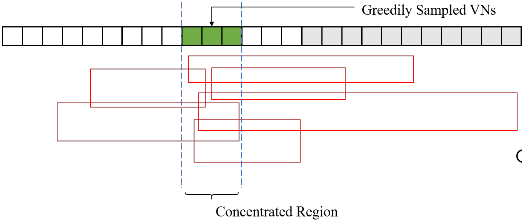

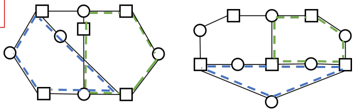

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- Concentrating cycles $\Longrightarrow$ Concentrating stopping sets

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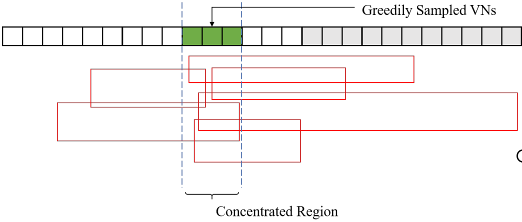

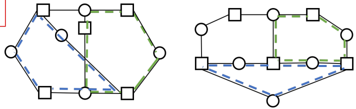

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- We concentrate cycles by modifying the Progressive Edge Growth (PEG) algorithm

Entropy to Concentrate Cycles: EC-PEG Algorithm

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EC (Entropy Constrained)-PEG Algorithm

For each VN v_j

Expand Tanner Graph in a BFS fashion

If $\exists$ CNs not connected to v_j

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For distribution $p = (p_1, p_2, \ldots, p_n)$, Entropy $\mathcal{H}(p) = \sum_{i=1}^{n} p_i \log \frac{1}{p_i}$

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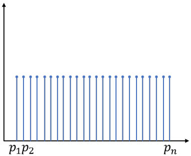

High Entropy

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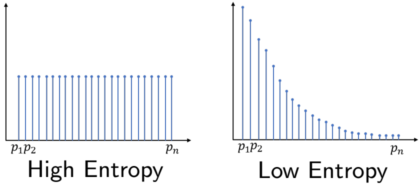

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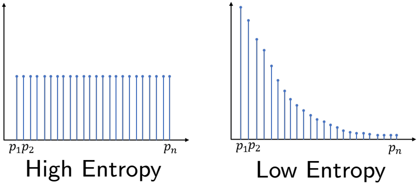

EC (Entropy Constrained)-PEG Algorithm

For each VN v_j

Expand Tanner Graph in a BFS fashion

If $\exists$ CNs not connected to v_j

- select a CN with min degree not connected to v_j

Else *New cycles created*

- Find CNs most distant to v_j
- Select CN that concentrates the cycle distribution

We want the cycle distributions to be concentrated

Entropy to Concentrate Cycles: EC-PEG Algorithm

For distribution $p = (p_1, p_2, \ldots, p_n)$, Entropy $\mathcal{H}(p) = \sum_{i=1}^{n} p_i \log \frac{1}{p_i}$

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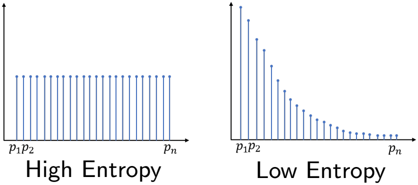

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We want the cycle distributions to be concentrated

$\rightarrow$ Select CNs such that the entropy of the cycle distribution is minimized

Entropy to Concentrate Cycles: EC-PEG Algorithm

For distribution $p = (p_1, p_2, \ldots, p_n)$, Entropy $\mathcal{H}(p) = \sum_{i=1}^{n} p_i \log \frac{1}{p_i}$

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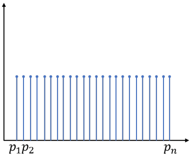
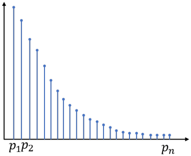


High Entropy



Low Entropy

EC (Entropy Constrained)-PEG Algorithm

For each VN v_j

Expand Tanner Graph in a BFS fashion

If $\exists$ CNs not connected to v_j

- select a CN with min degree not connected to v_j

Else *New cycles created*

- Find CNs most distant to v_j
- Select CN that results in minimum entropy of resultant cycle distribution

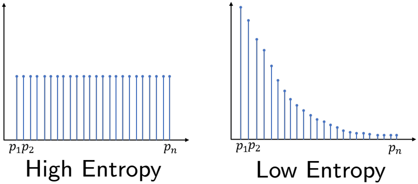
We want the cycle distributions to be concentrated

$\rightarrow$ Select CNs such that the entropy of the cycle distribution is minimized

Entropy to Concentrate Cycles: EC-PEG Algorithm

For distribution $p = (p_1, p_2, \ldots, p_n)$, Entropy $\mathcal{H}(p) = \sum_{i=1}^{n} p_i \log \frac{1}{p_i}$

- Uniform distributions have high entropy
- Concentrated distributions have low entropy



EC (Entropy Constrained)-PEG Algorithm

For each VN v_j

Expand Tanner Graph in a BFS fashion

If $\exists$ CNs not connected to v_j

- select a CN with min degree not connected to v_j

Else *New cycles created*

- Find CNs most distant to v_j
- Select CN that results in minimum entropy of resultant cycle distribution
- Update cycle distribution

We want the cycle distributions to be concentrated

$\rightarrow$ Select CNs such that the entropy of the cycle distribution is minimized

Sampling Strategy

- Greedy Sampling: greedily sample VNs that are part of a large number of cycles
- Random Sampling (with replacement): sample each variable node with equal probability

Simulation Results

Probability of failure for a stopping set of size μ

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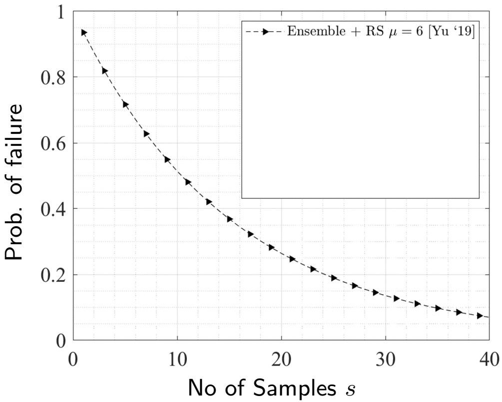
Probability of failure for a stopping set of size μ

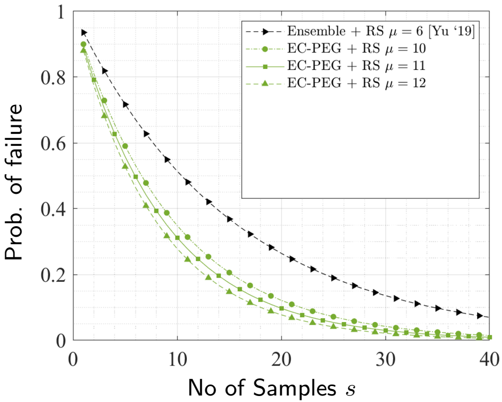
RS: Random Sampling



Simulation Results

Probability of failure for a stopping set of size μ

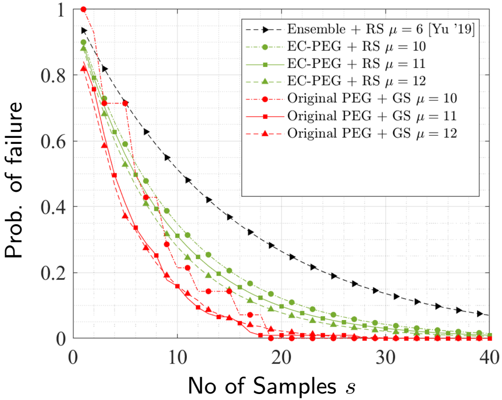
RS: Random Sampling



Simulation Results

Probability of failure for a stopping set of size μ

RS: Random Sampling
GS: Greedy Sampling



Simulation Results

Probability of failure for a stopping set of size μ

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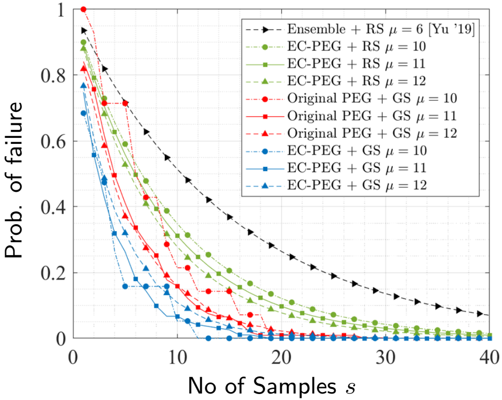

Simulation Results

Probability of failure for a stopping set of size μ

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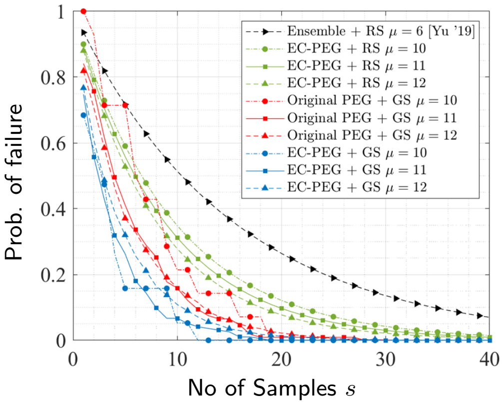

- Concentrated LDPC codes with Greedy sampling improve the probability of failure

References

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