Eos: Efficient Private Delegation of zkSNARK provers

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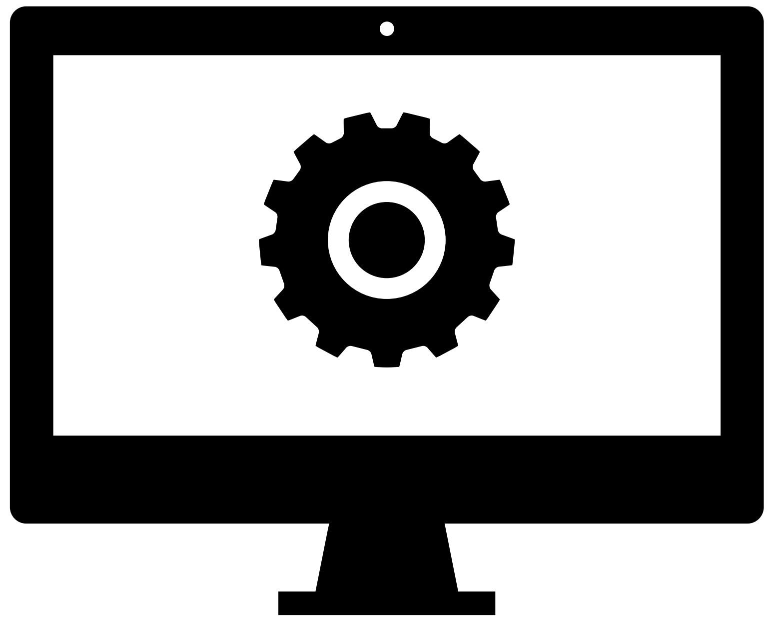
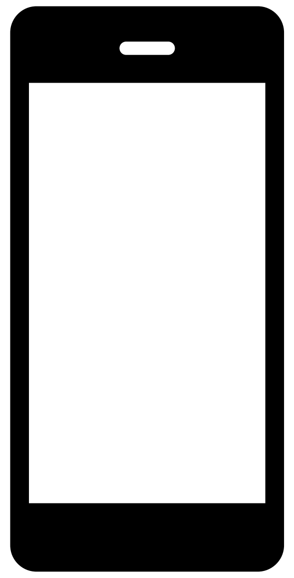
zkSNARKs [Mic94, Groth10, GGPR13, Groth16… …, GWC19, CHMMVW20, …]

Goal: Prove that a private value satisfies some property



Prover



Verifier

zkSNARKs [Mic94, Groth10, GGPR13, Groth16… …, GWC19, CHMMVW20, …]

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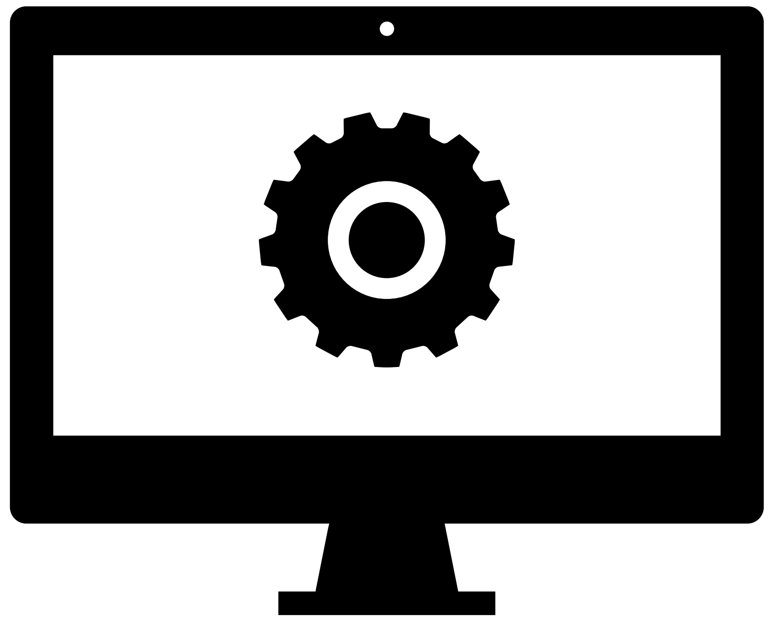
I know **w** s.t. SHA256(**w**) = **x**

public hash: **x**



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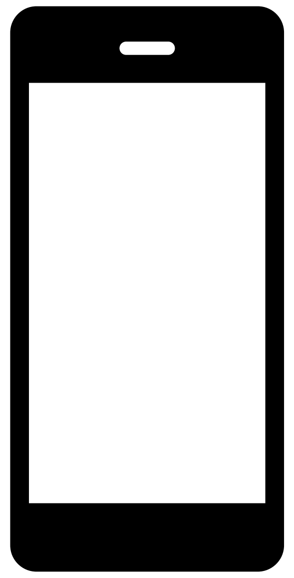

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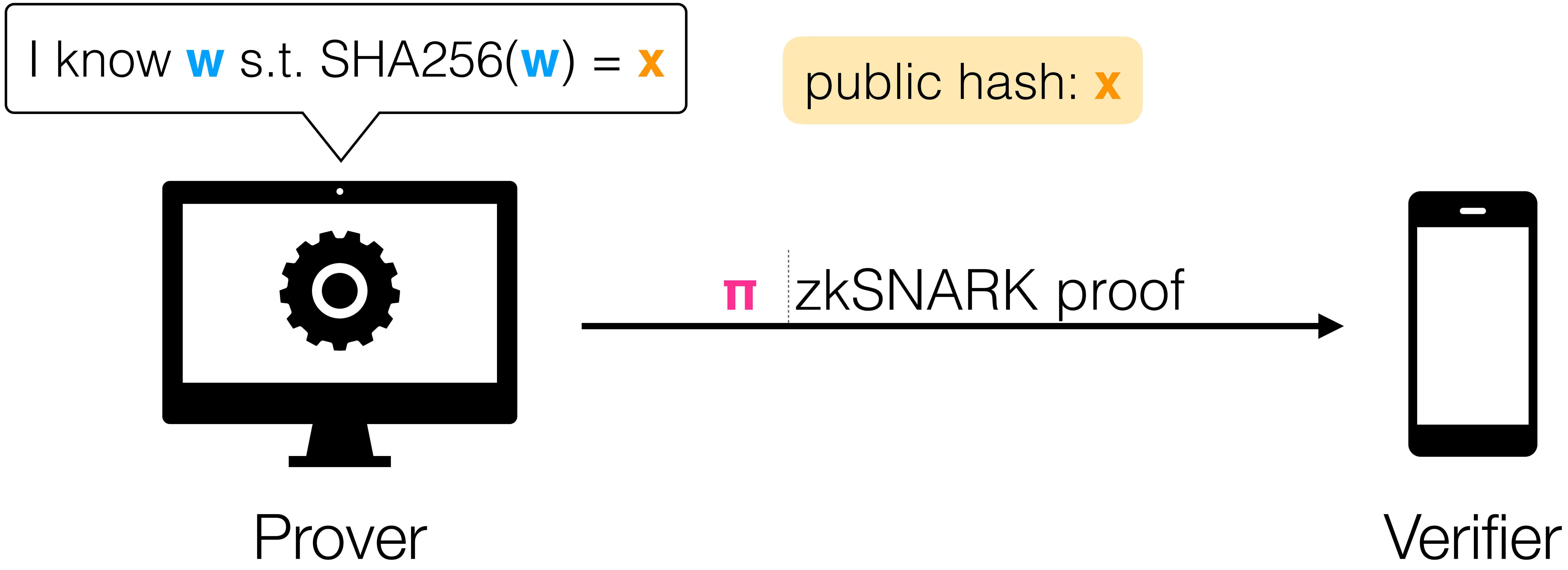

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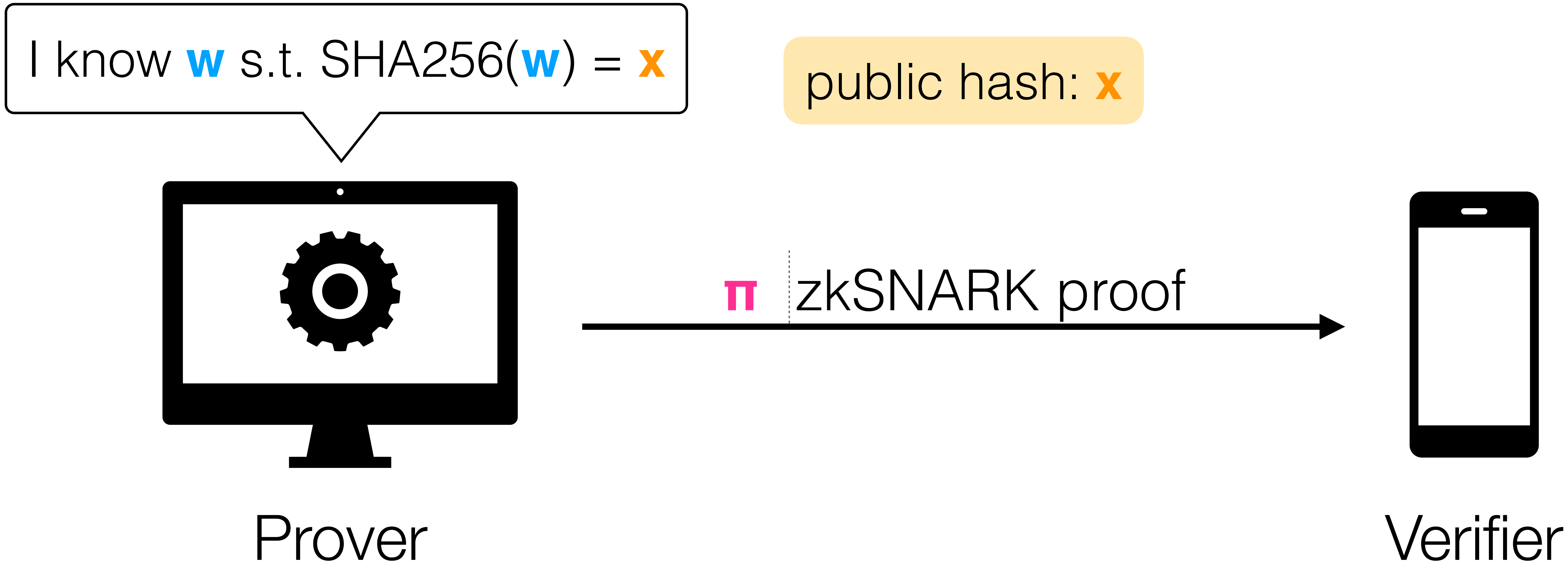
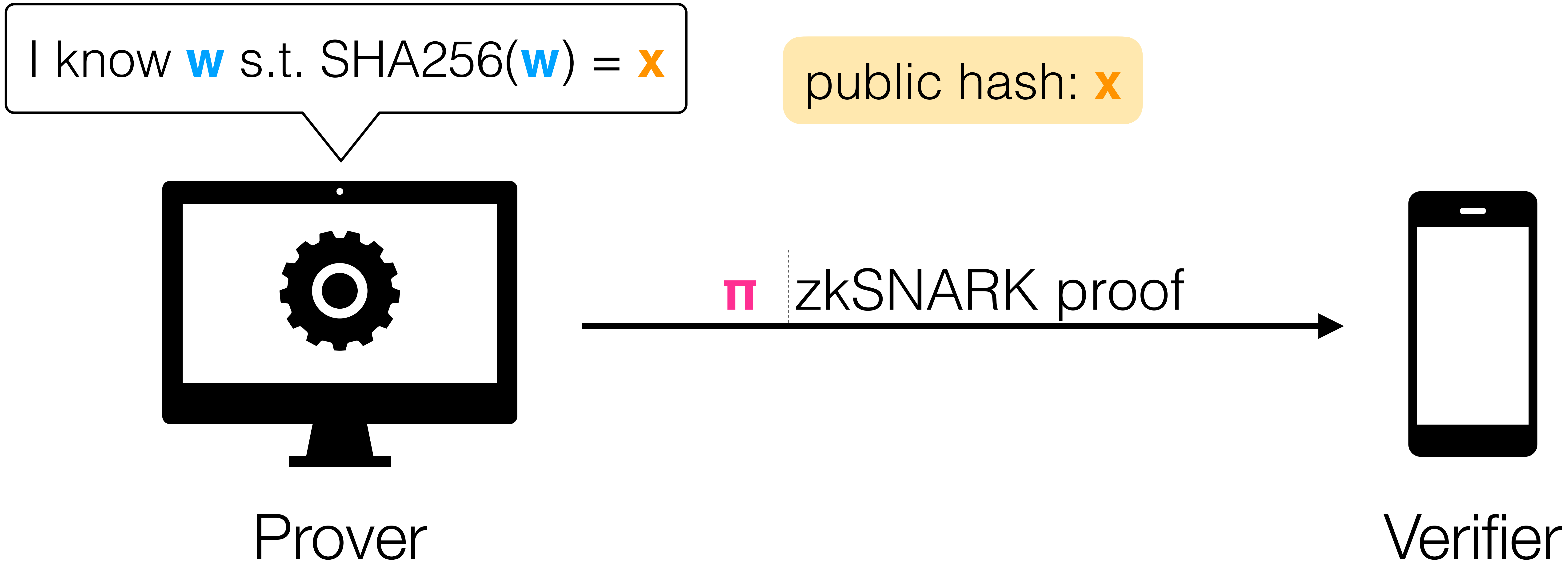


Zero Knowledge: Verifier learns nothing about **w** except that SHA256(**w**) = **x**

Problem: Proving is *really* slow



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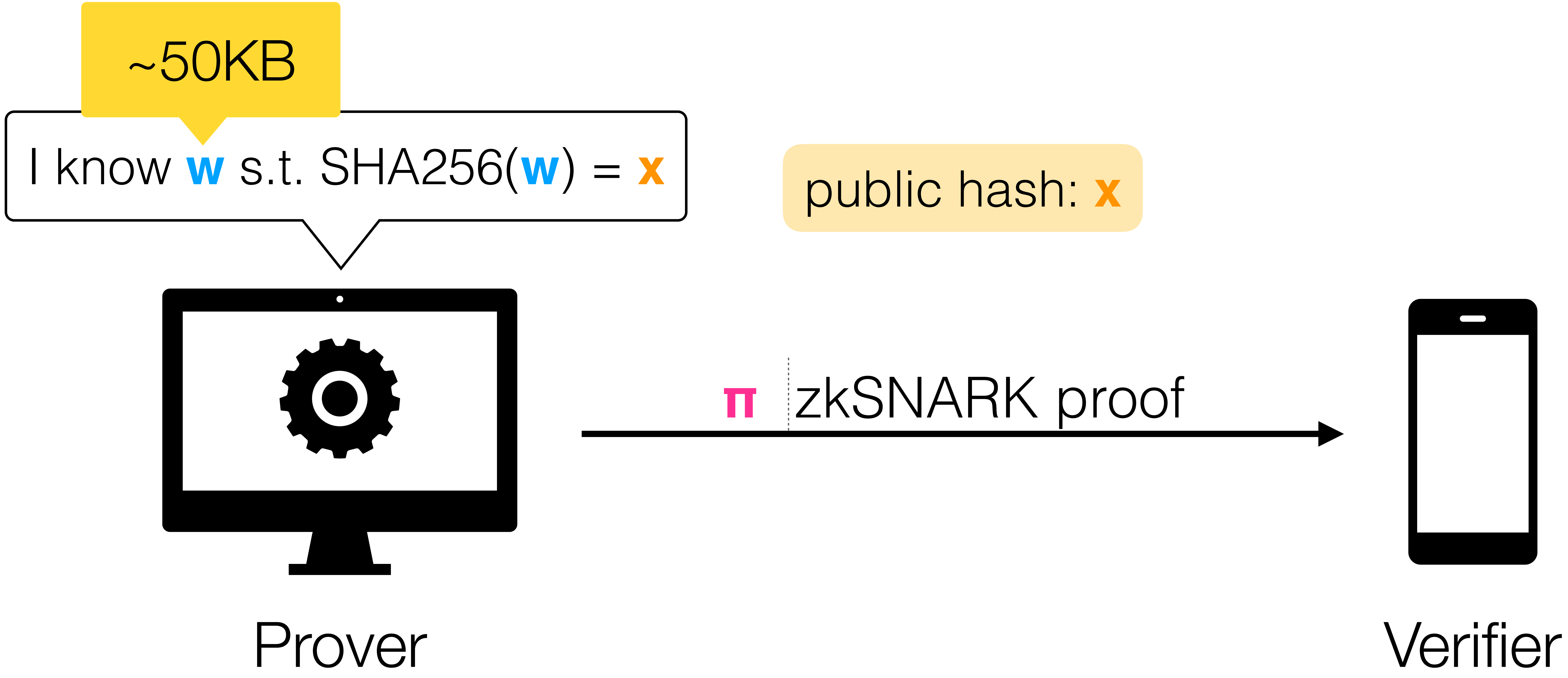

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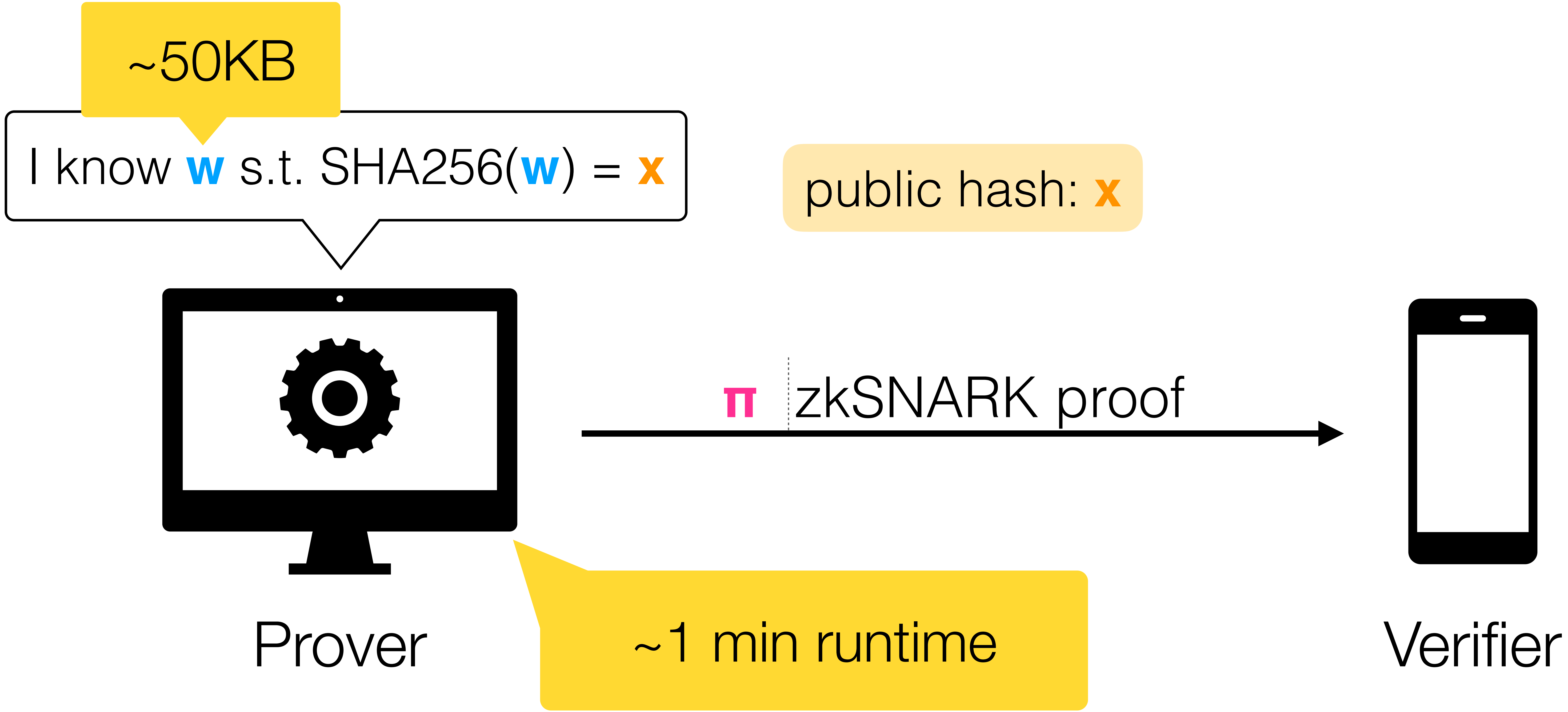

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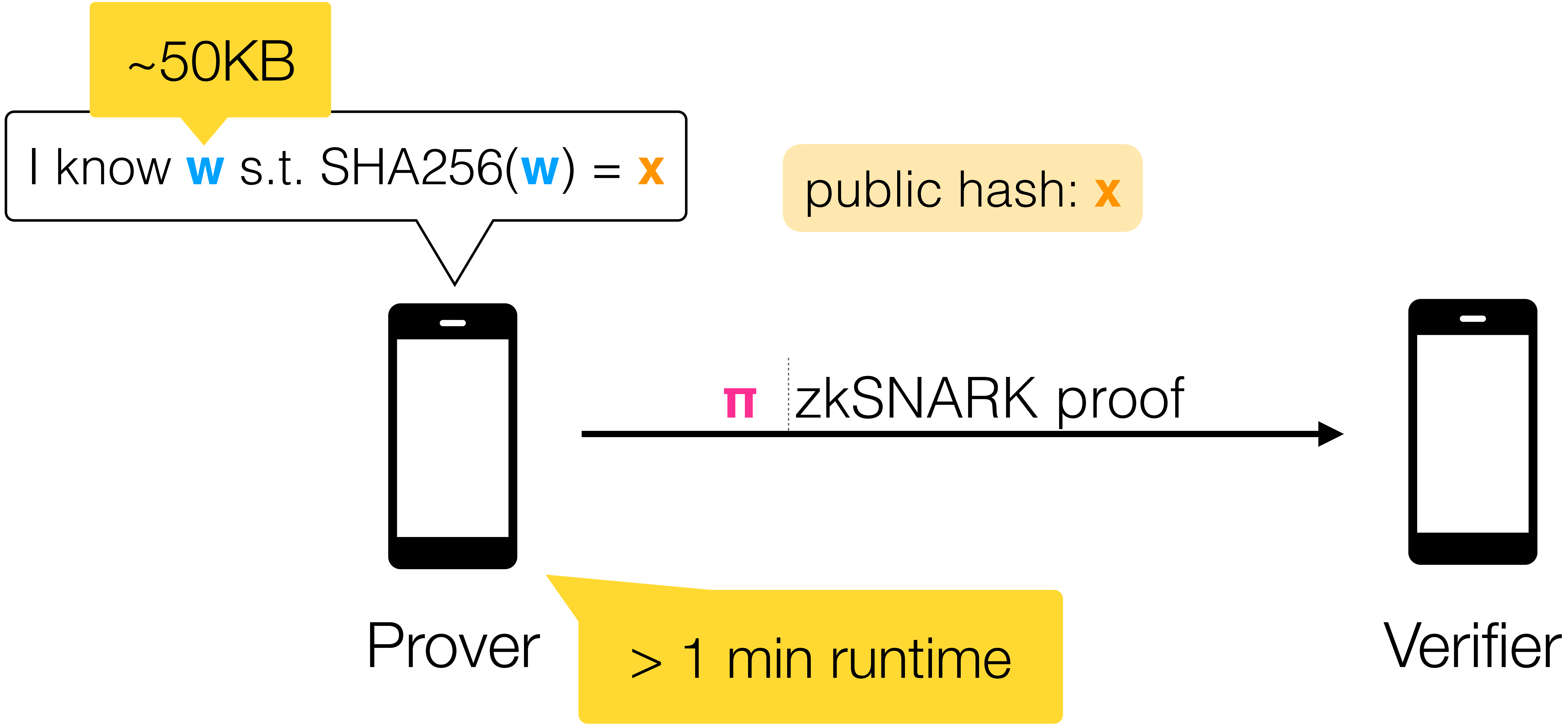
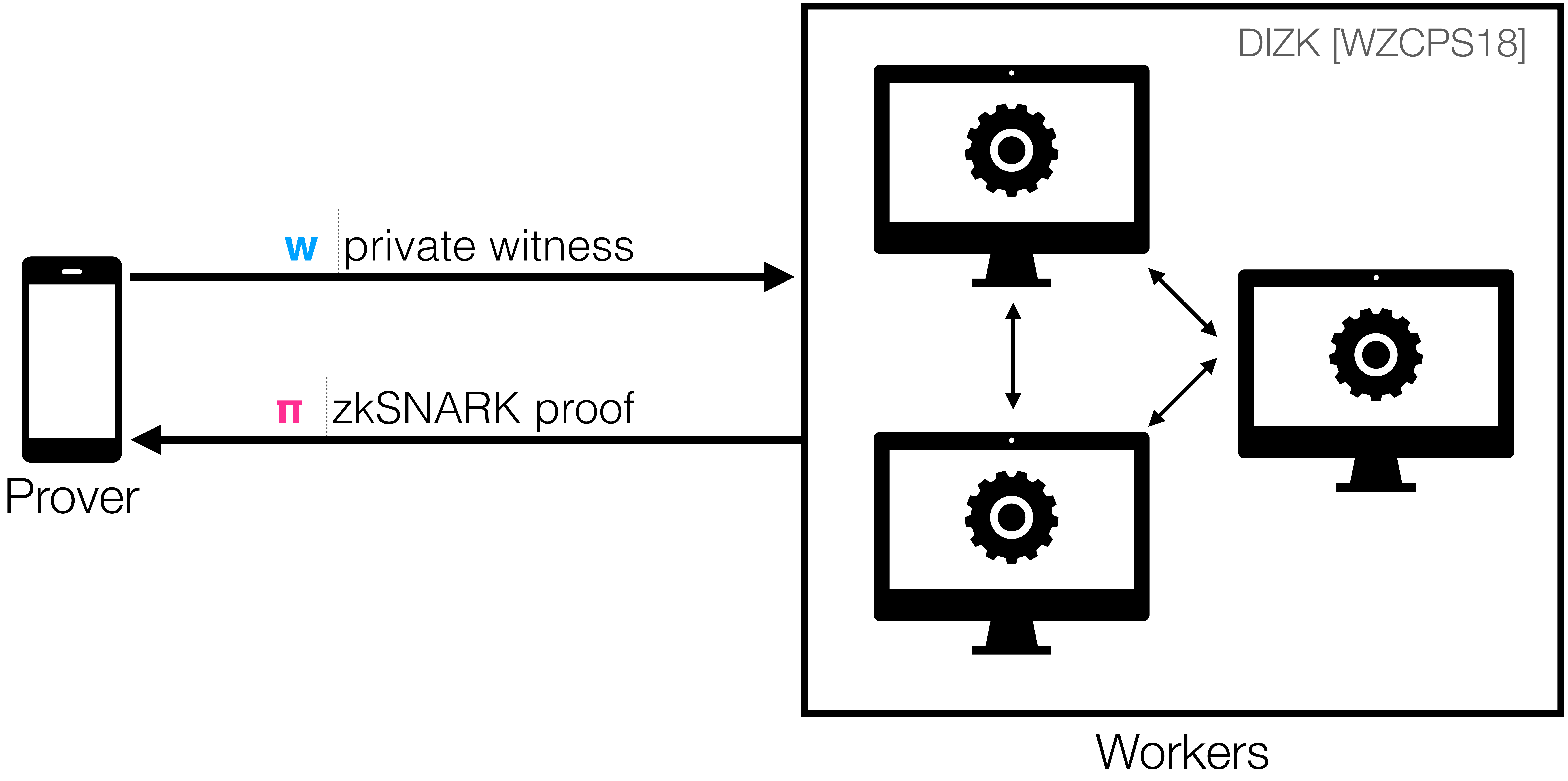


Potential Solution: Delegate Proving!



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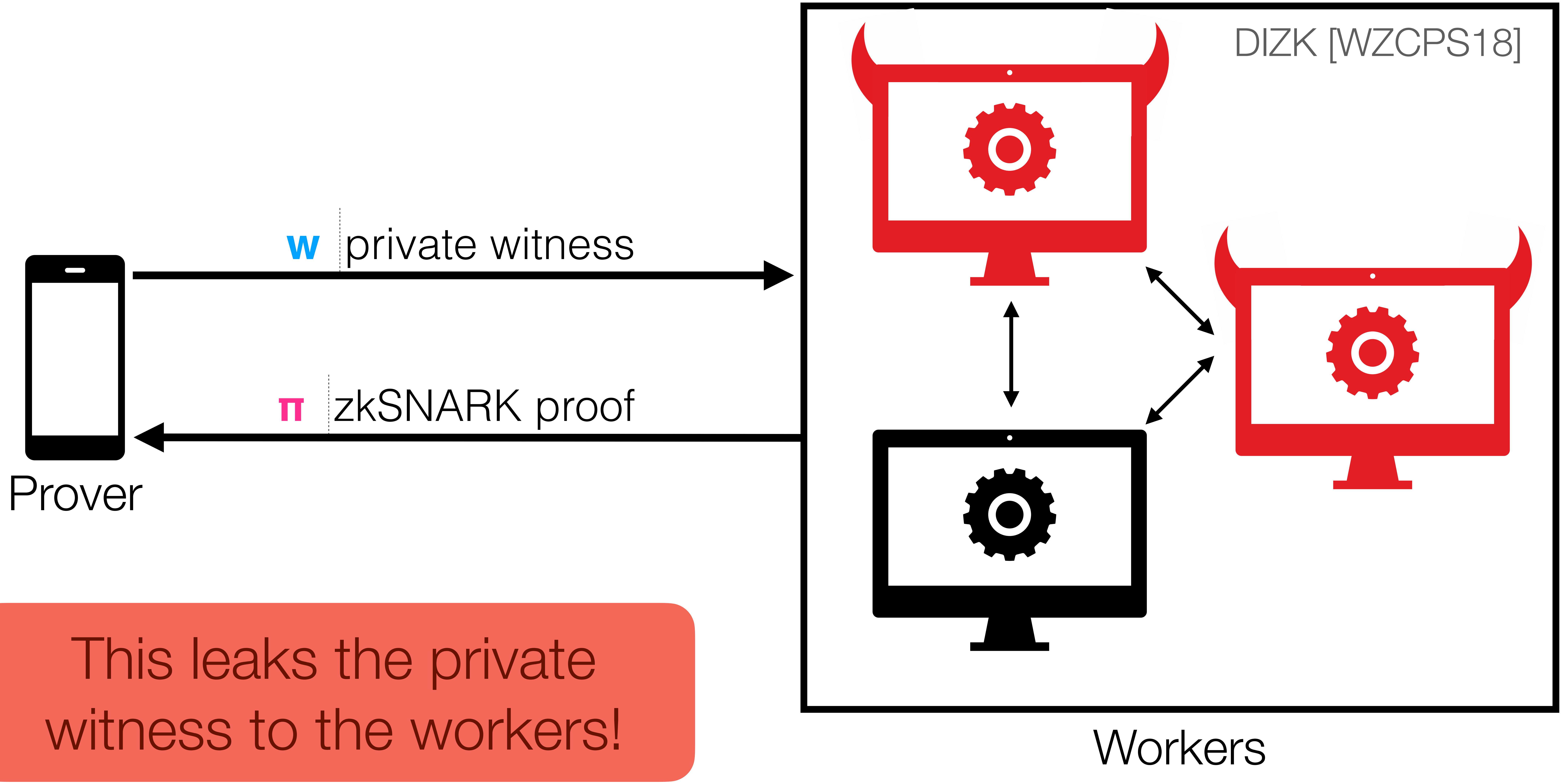
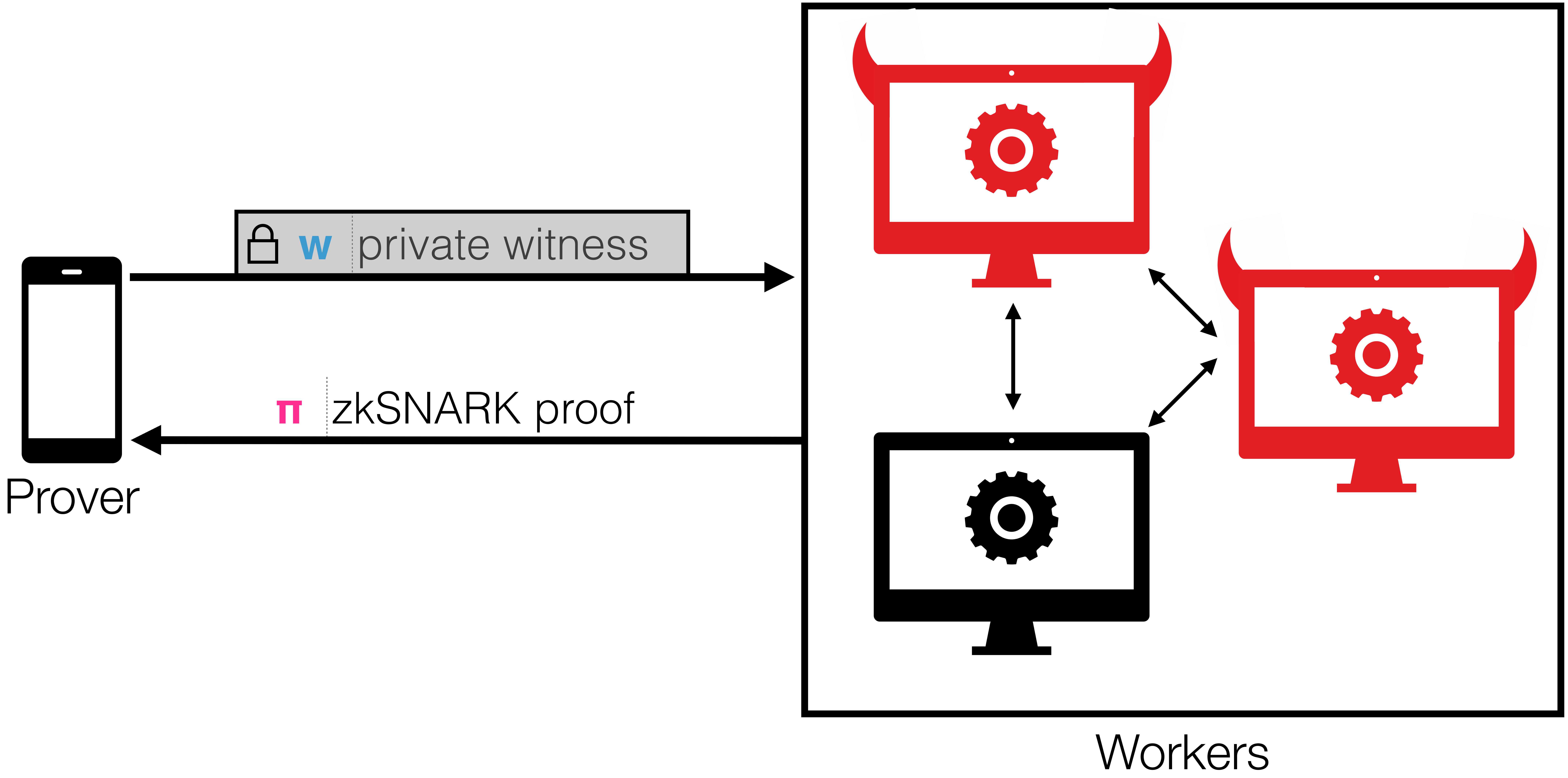


This leaks the private witness to the workers!

Goal: Delegate Proving with Privacy



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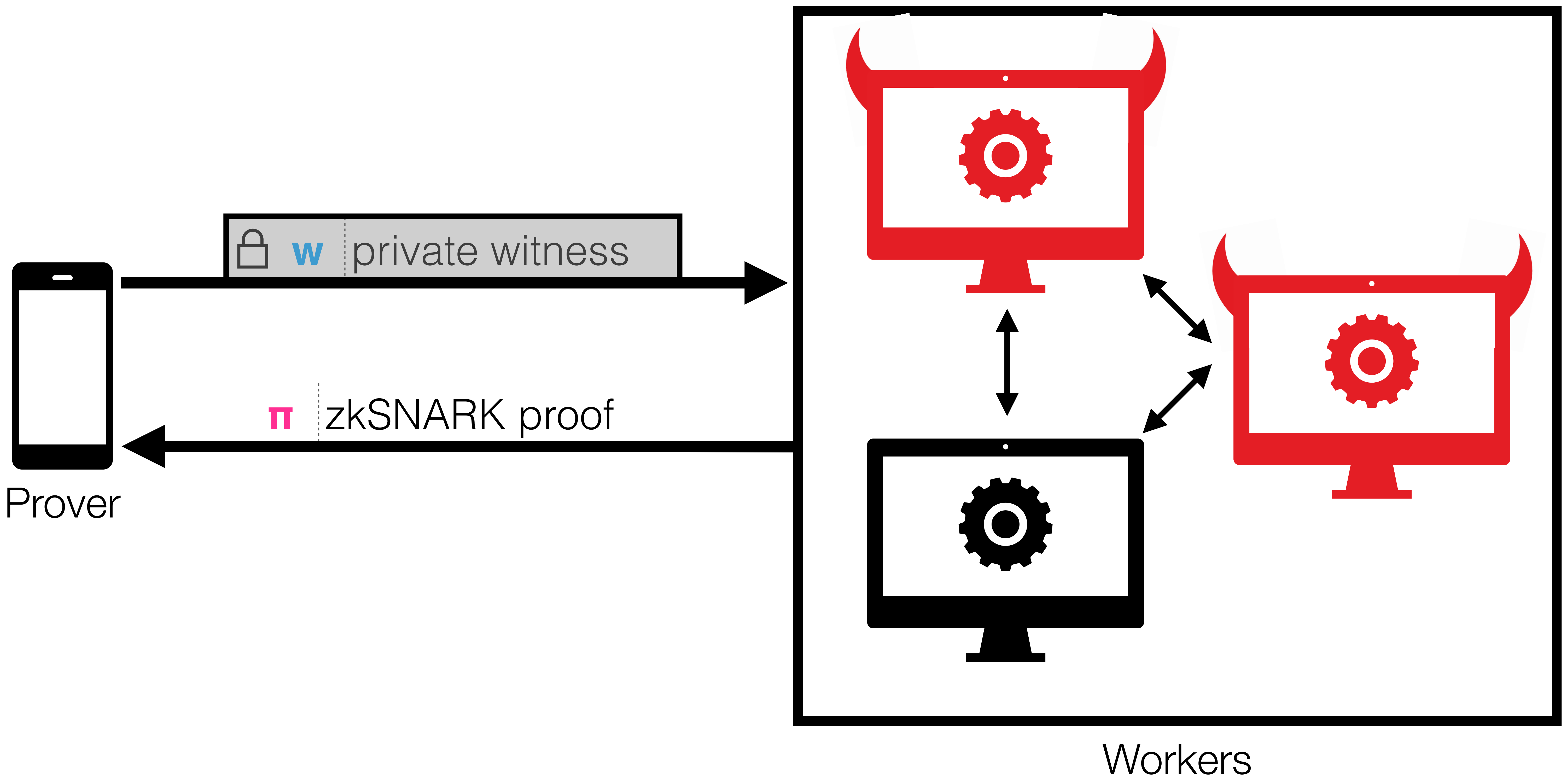

Goal 1: Efficiency — Delegation should be faster than local proving

Goal 2: Privacy — The witness should remain hidden from the workers if at least one worker is honest

Our results

Eos

Private delegation of ‘algebraic’ zkSNARK provers* in the presence of N-1 malicious workers.

*[MBKM19, GWC19, CHMMVW20, CFFQR21, BGH19]

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Private delegation of 'algebraic' zkSNARK provers* in the presence of N-1 malicious workers.

*[MBKM19, GWC19, CHMMVW20, CFFQR21, BGH19]

Compared to local proving, running Eos on a mobile phone is:

1) **26x** faster
2) Uses **256x** less memory

Contributions

- Efficient circuits for zkSNARK provers
- Prover-assisted MPC
- Lightweight techniques for malicious security
- Systems optimizations

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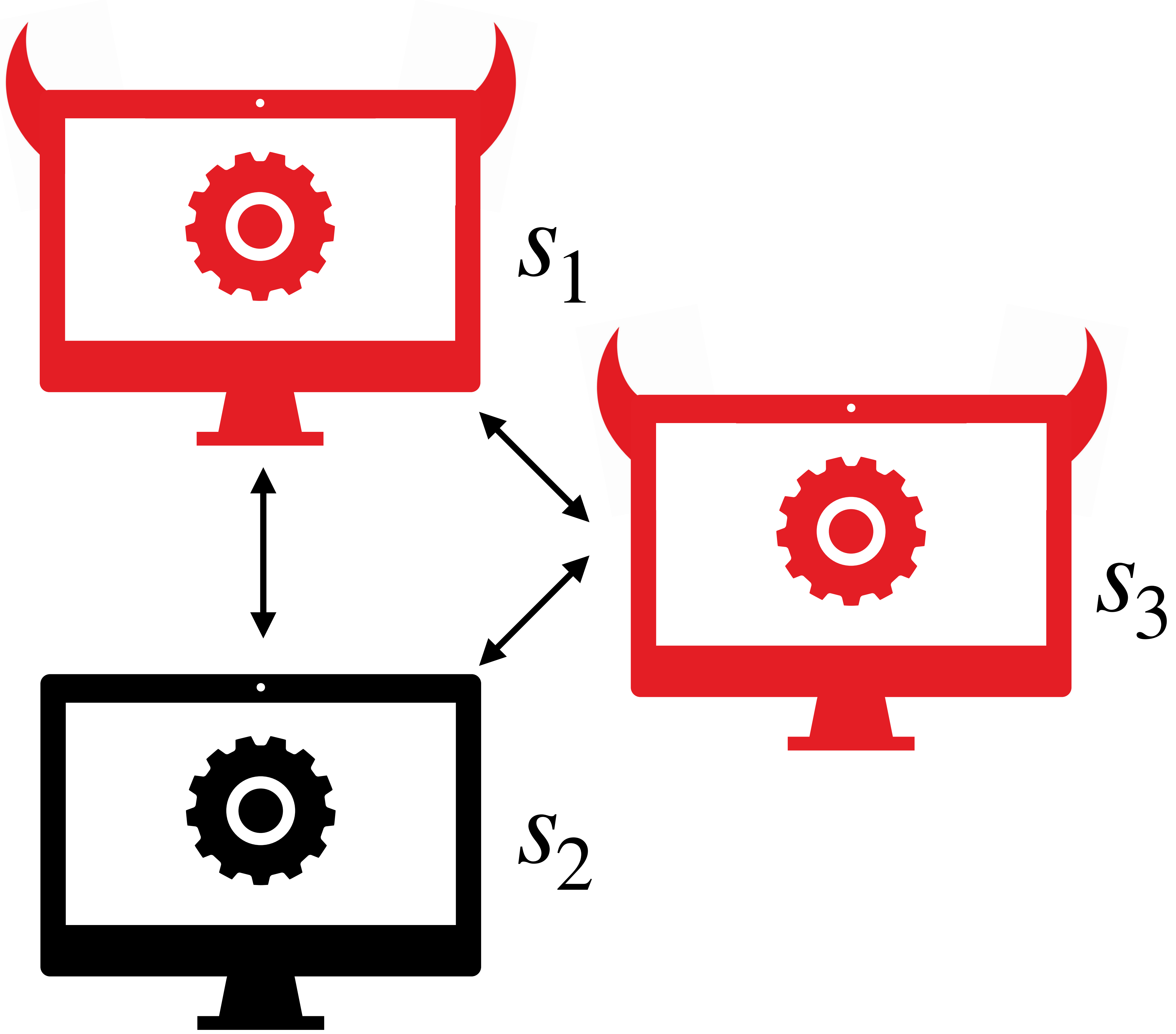
- **Prover-assisted MPC**
- **Lightweight techniques for malicious security**
- Systems optimizations

Starting point: MPC

Allows multiple parties to compute a function F over their private inputs

N-1 Malicious Security:
Privacy + correctness holds if at least one party is honest



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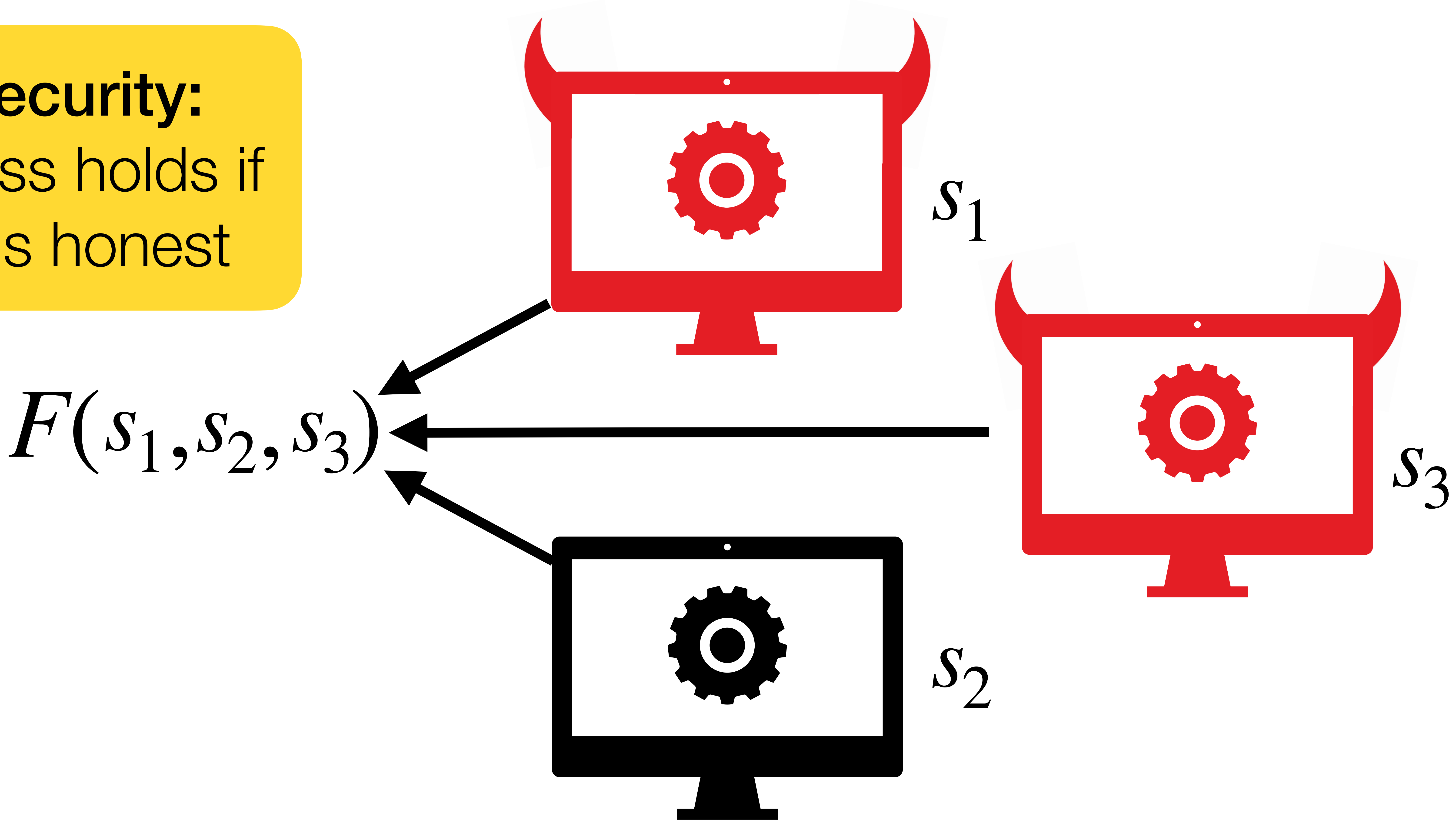

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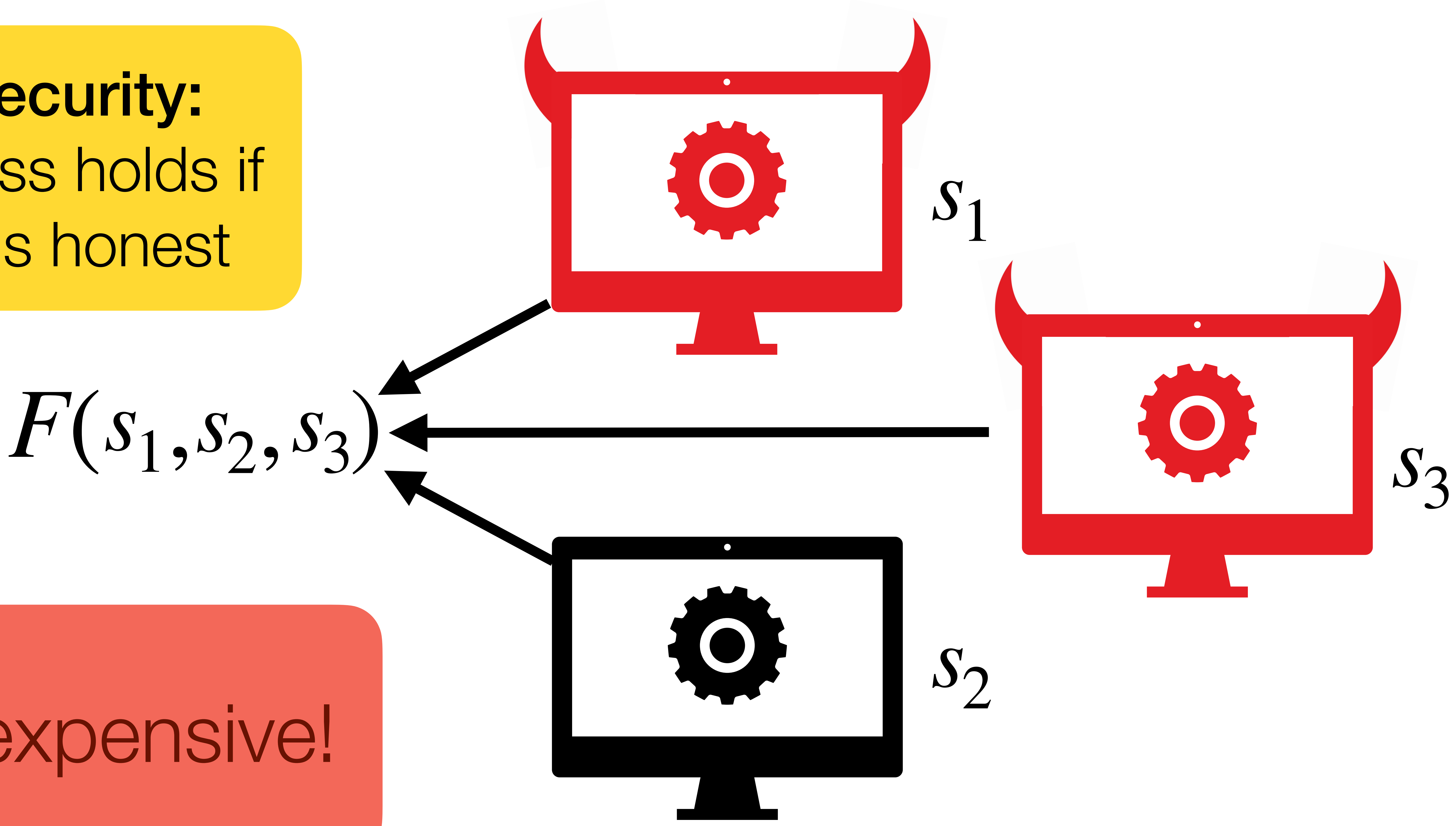


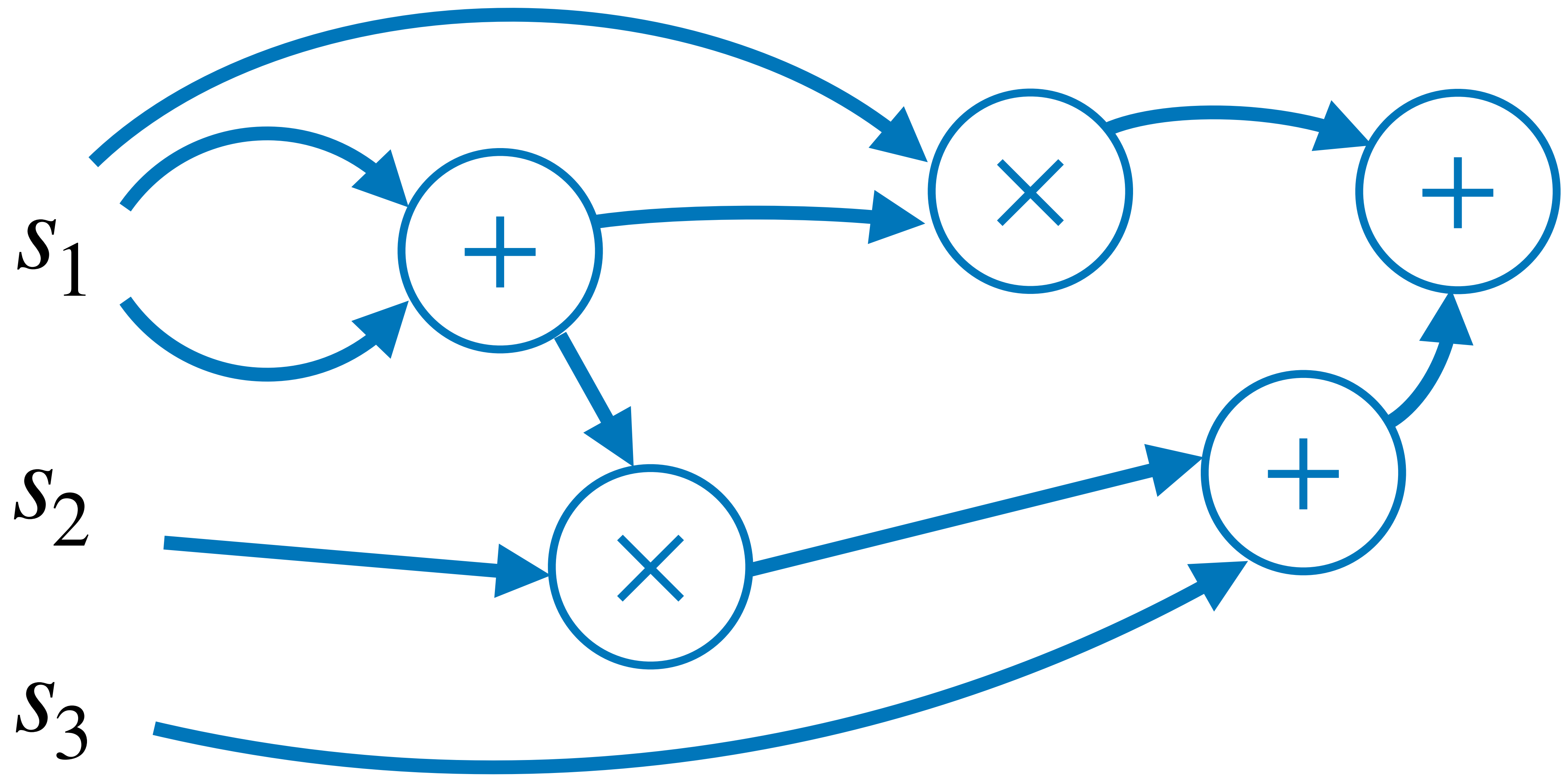
Generic MPC is expensive!

Efficient Circuits for zkSNARK Provers

MPC Protocol [SPDZ]

1) Express function as an arithmetic circuit

2) All parties execute circuit gate-by-gate



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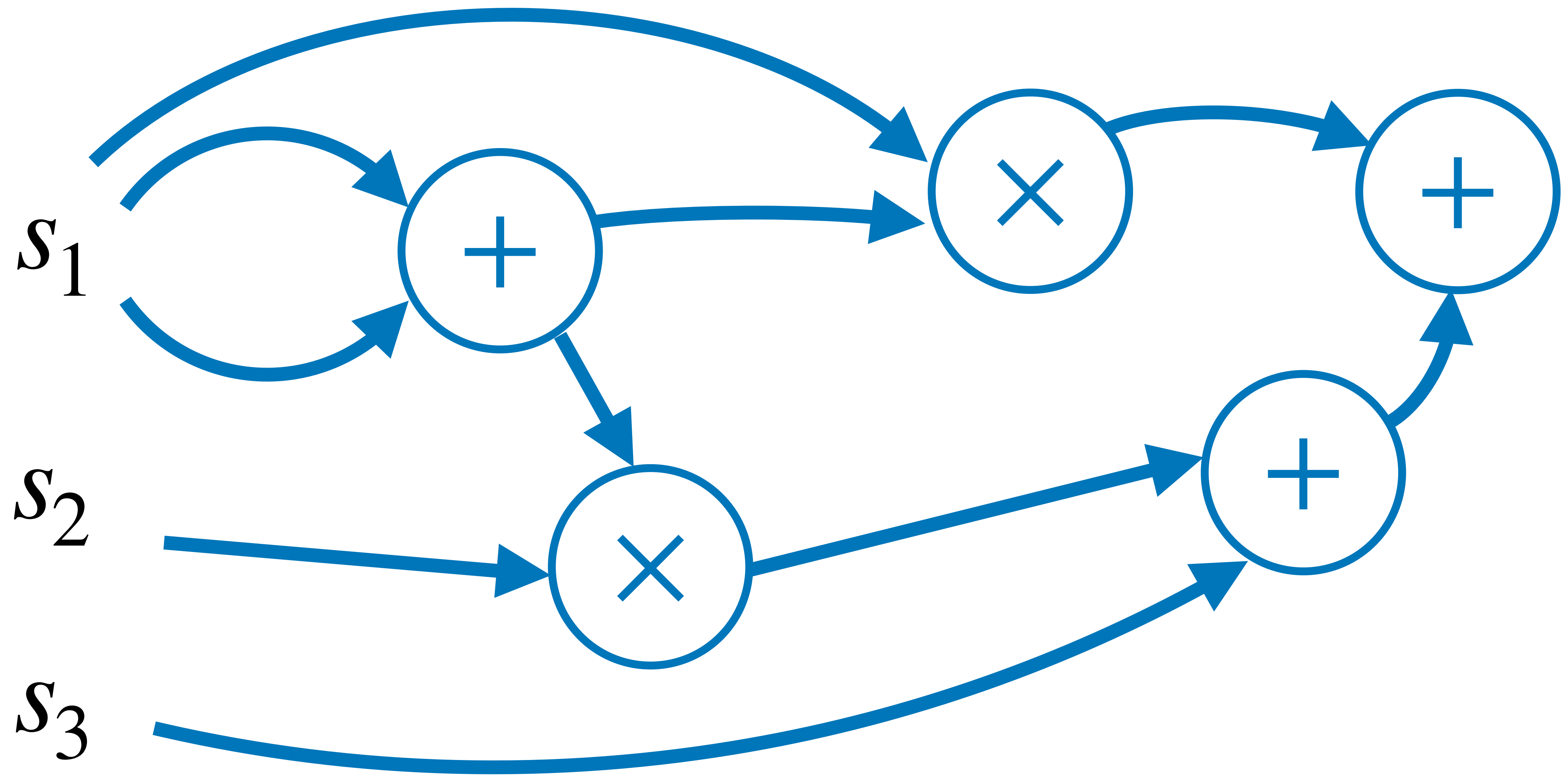

Circuit for zkSNARK prover is large! Need to support polynomial arithmetic, group operations, and random oracle calls

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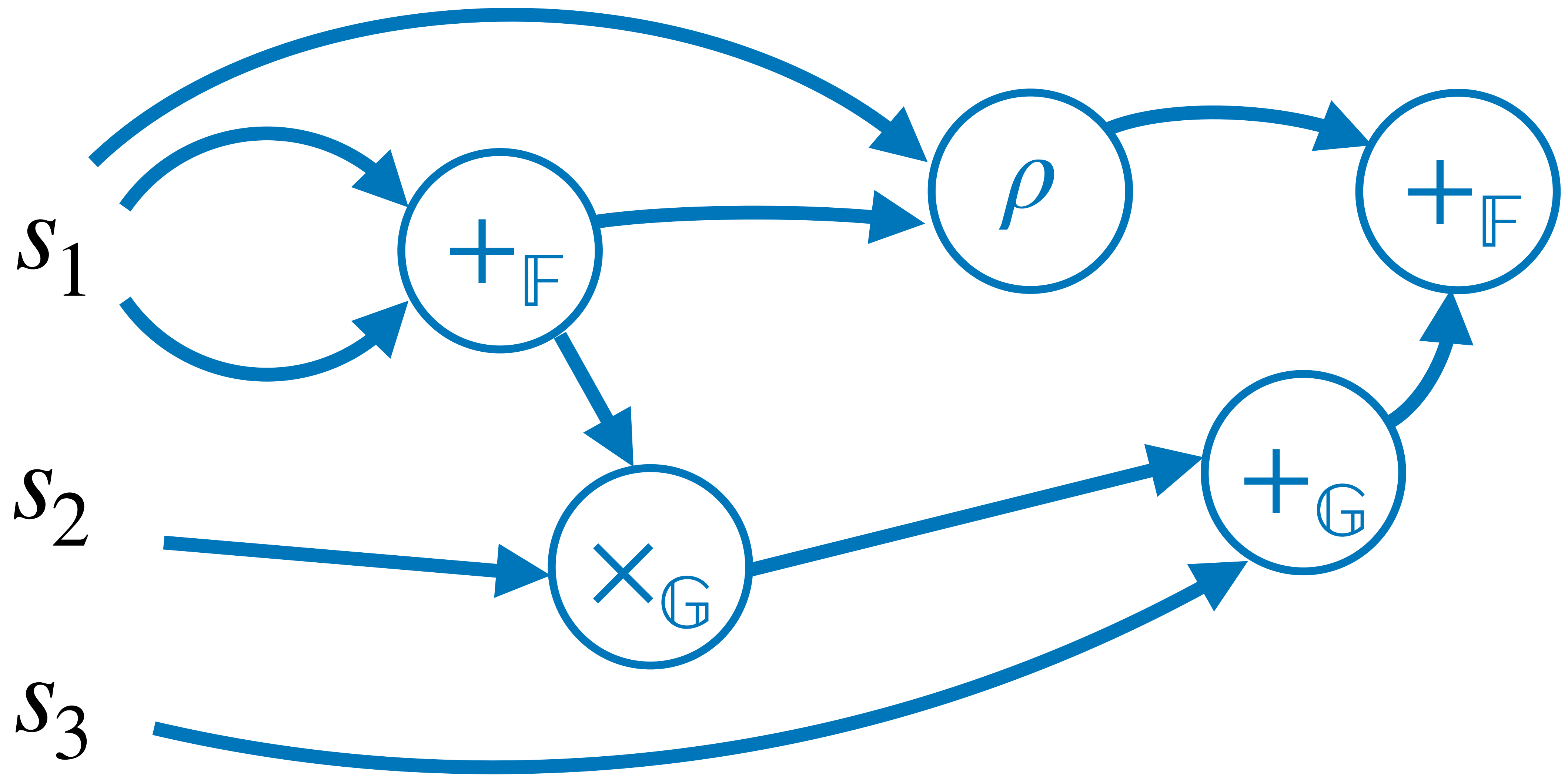
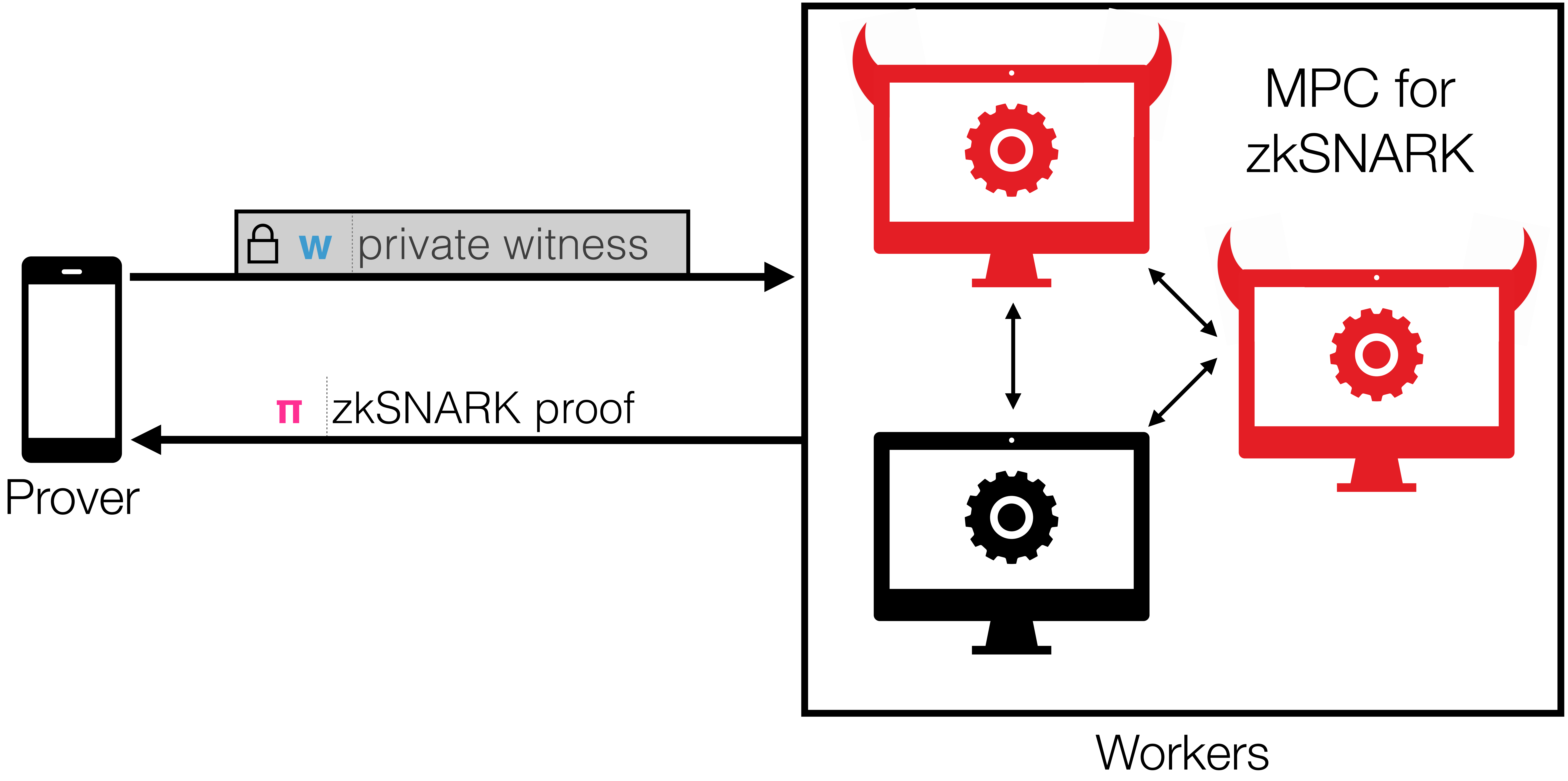


Idea: Extend the circuit model [SA19, OB22]!

- Add gates for $\mathbb{G}$-ops and random oracle calls
- New, efficient subcircuits for polynomial arithmetic

Using the Asymmetric Threat Model



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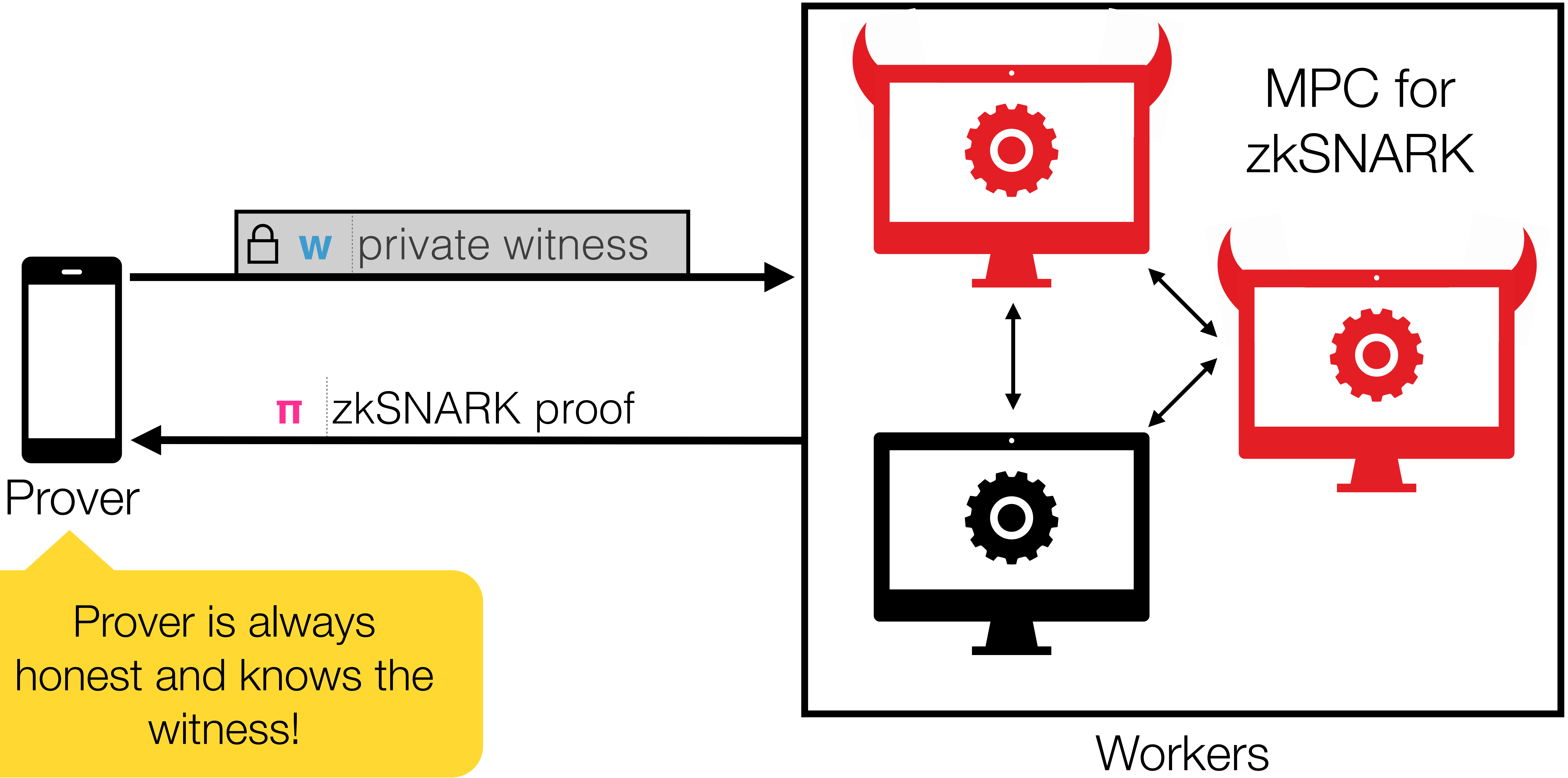
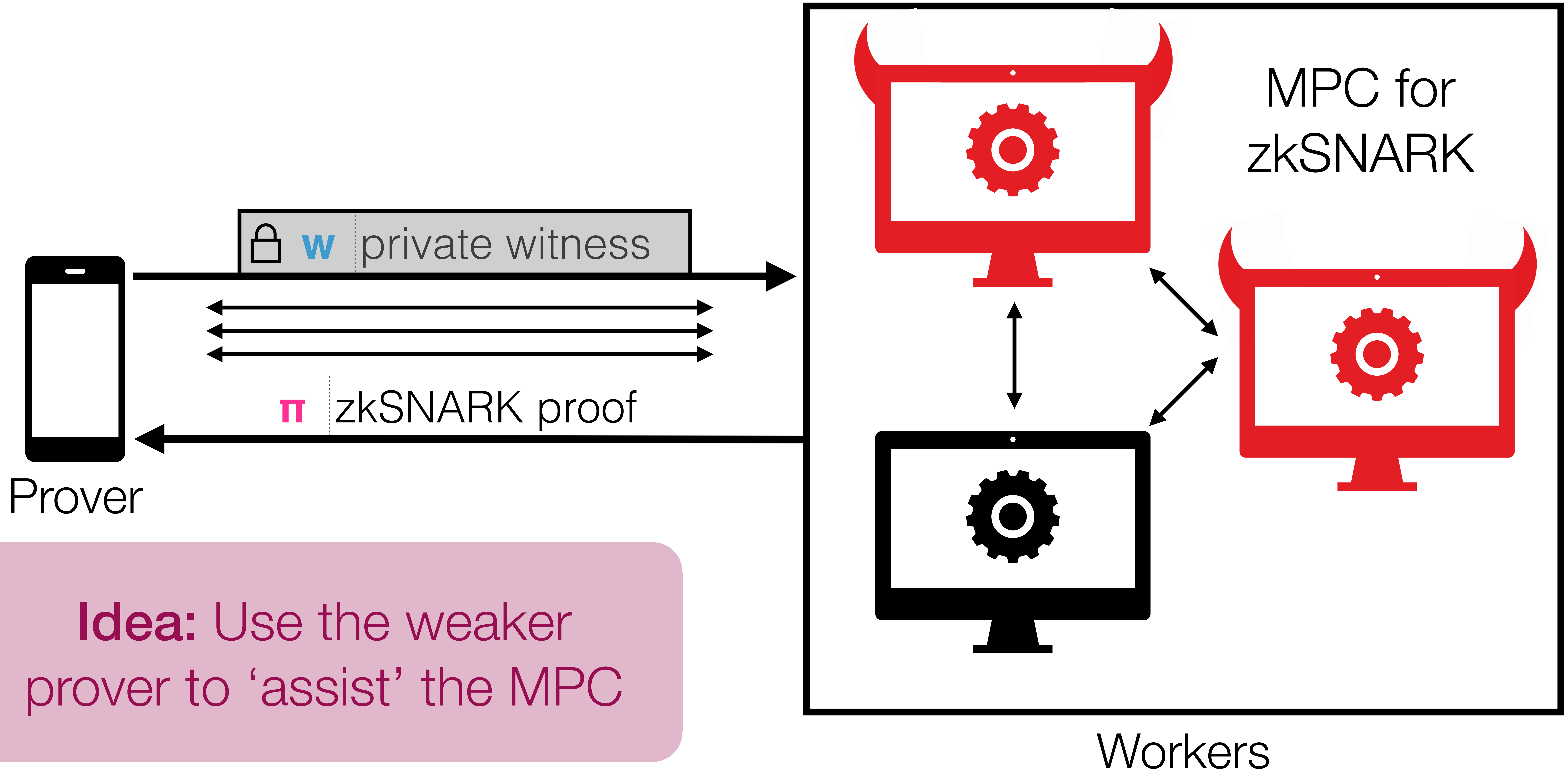


Prover is always honest and knows the witness!

Using the Asymmetric Threat Model



Idea: Use the weaker prover to 'assist' the MPC

Prover-assisted MPC

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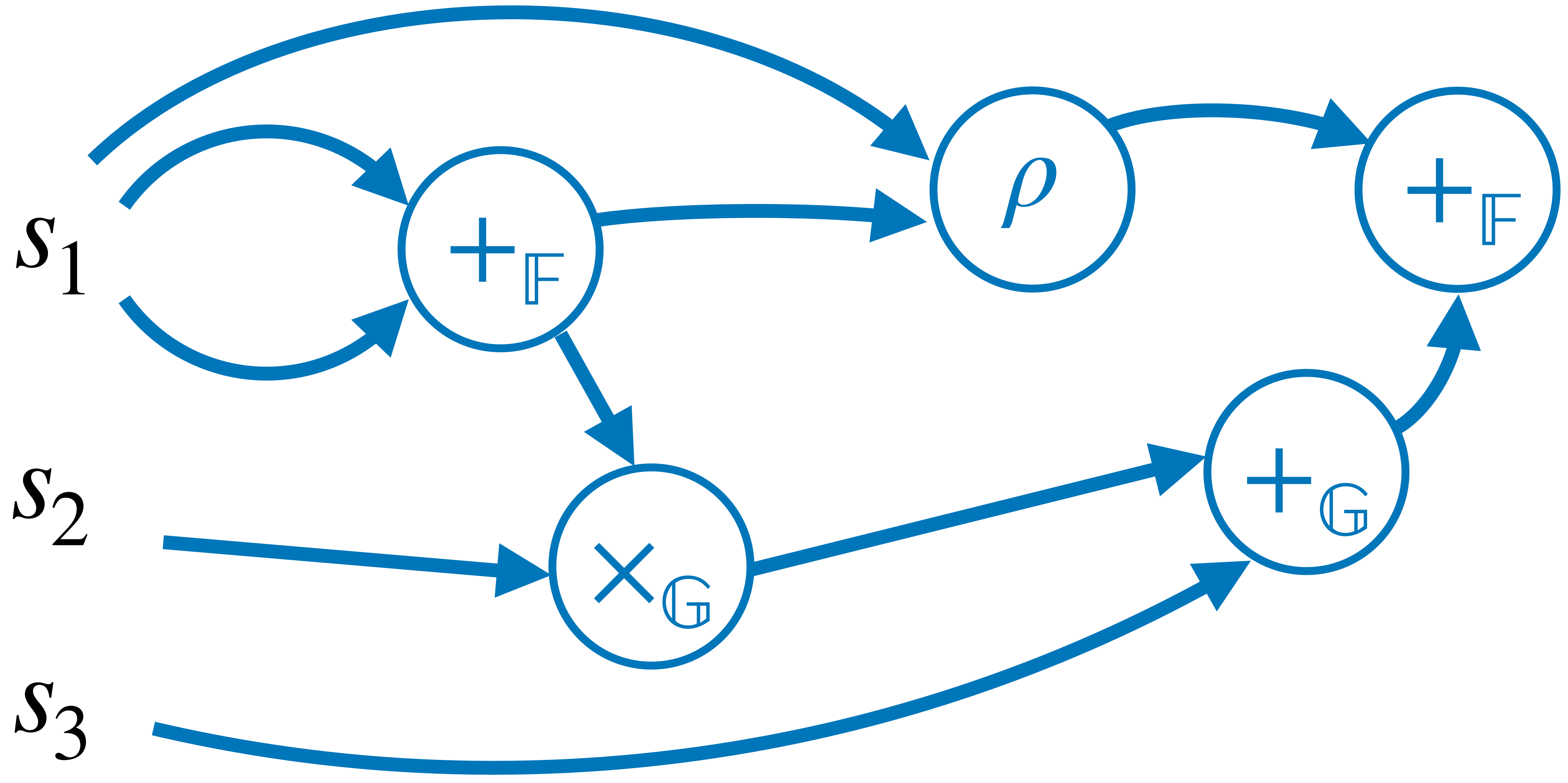

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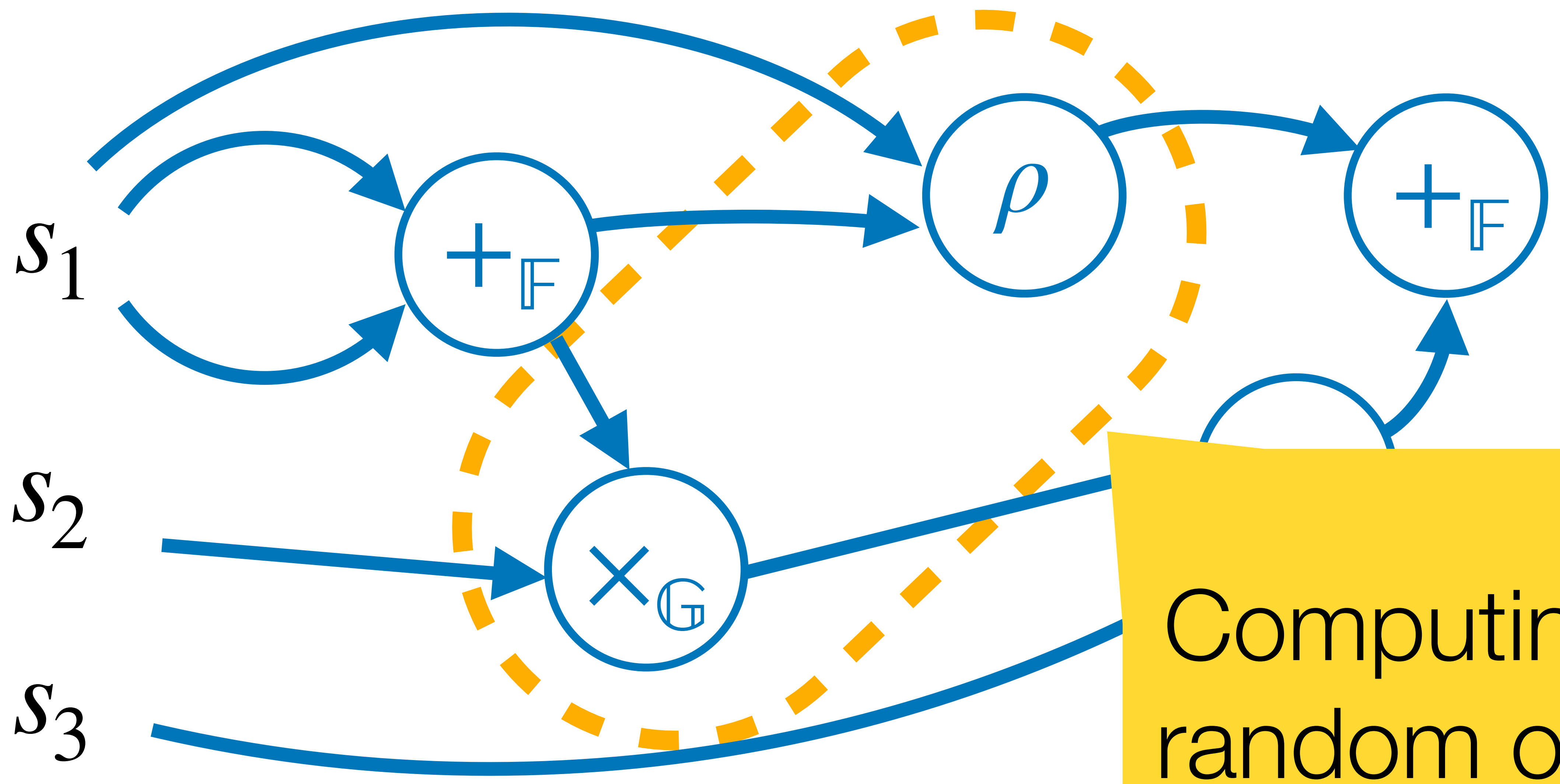

Computing multiplications and random oracles is expensive in MPC but cheap in plaintext

Prover-assisted MPC

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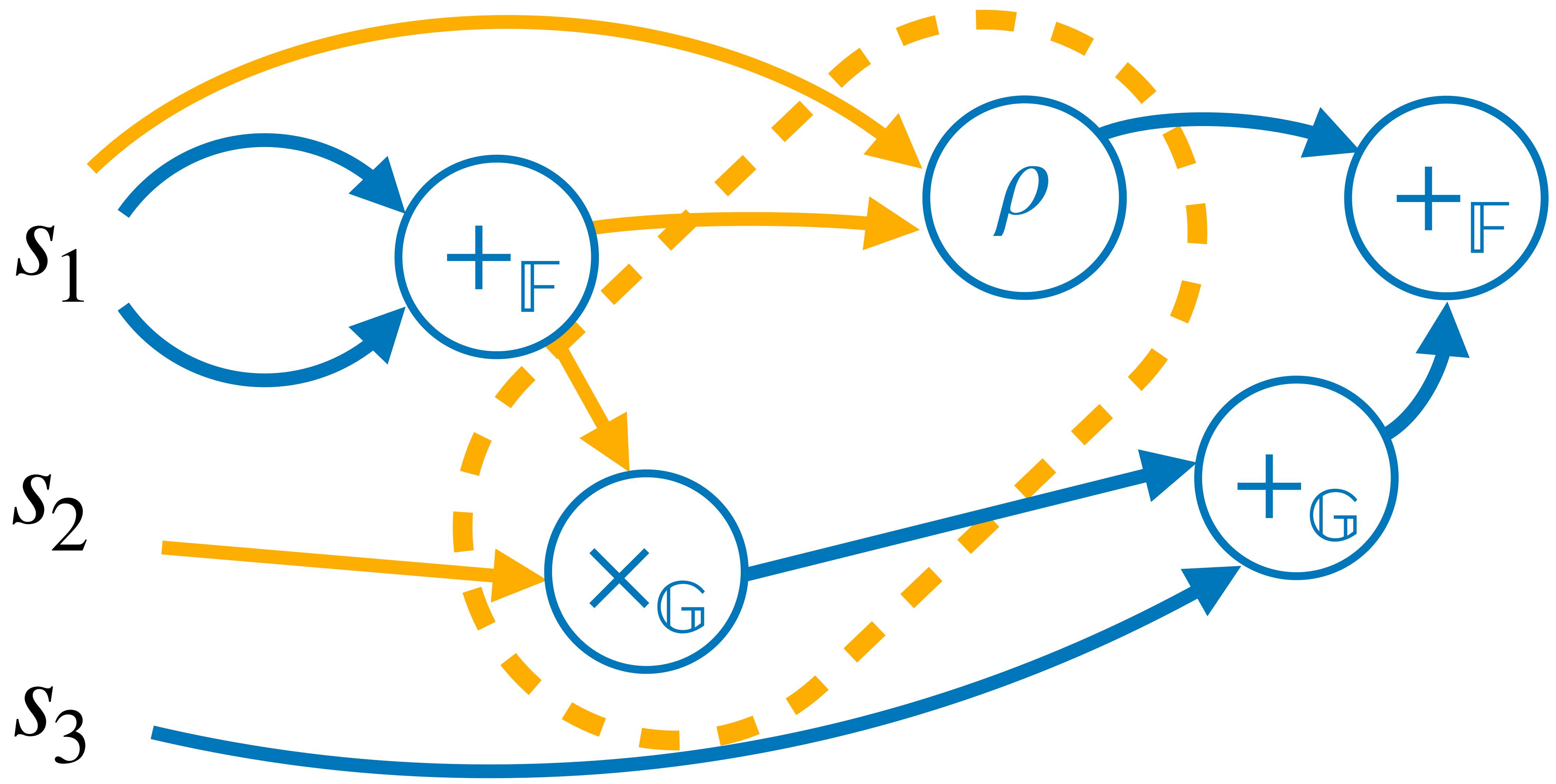

- Workers share subcircuit input wires with prover

Prover-assisted MPC

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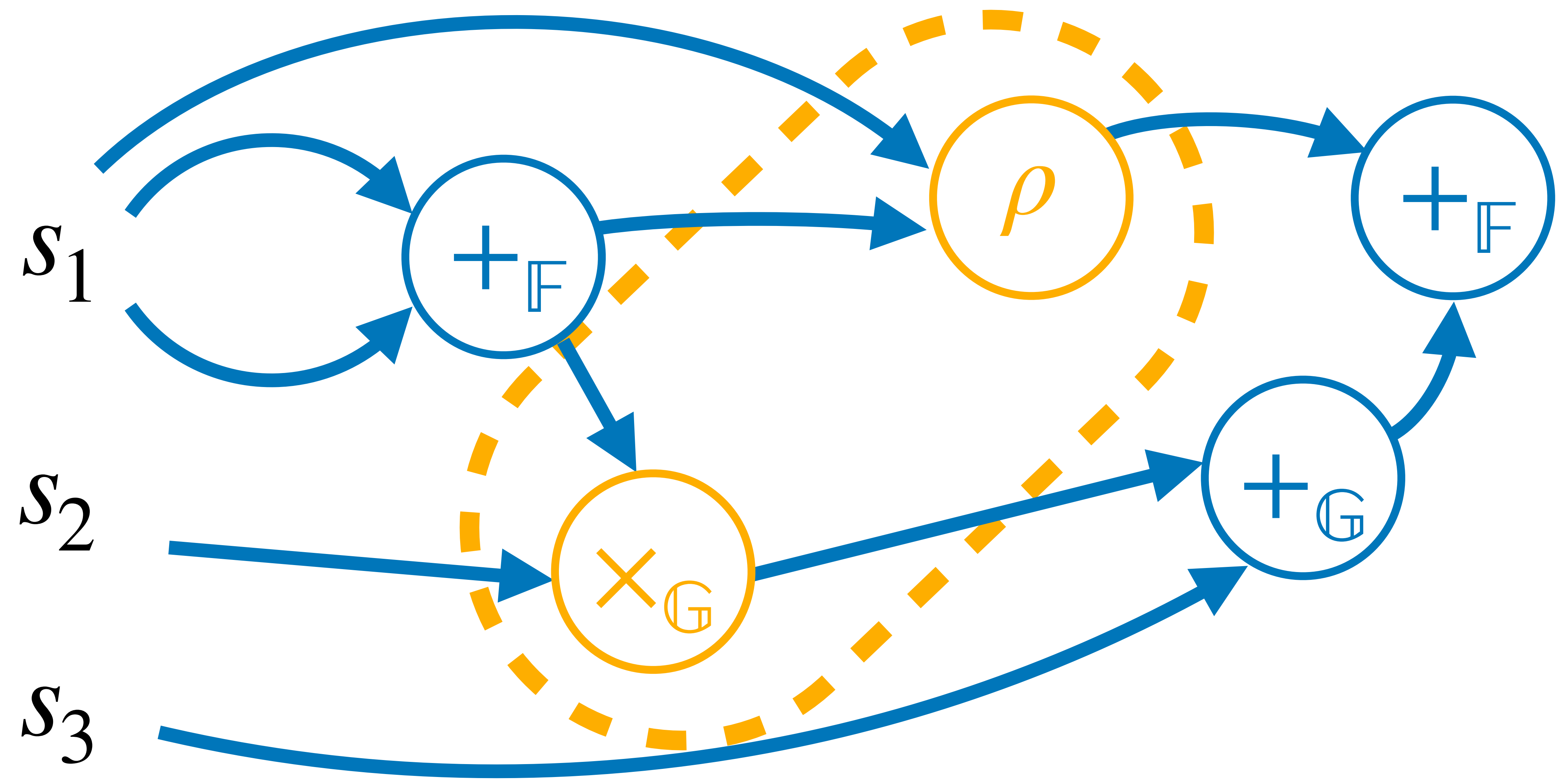

- Workers share subcircuit input wires with prover
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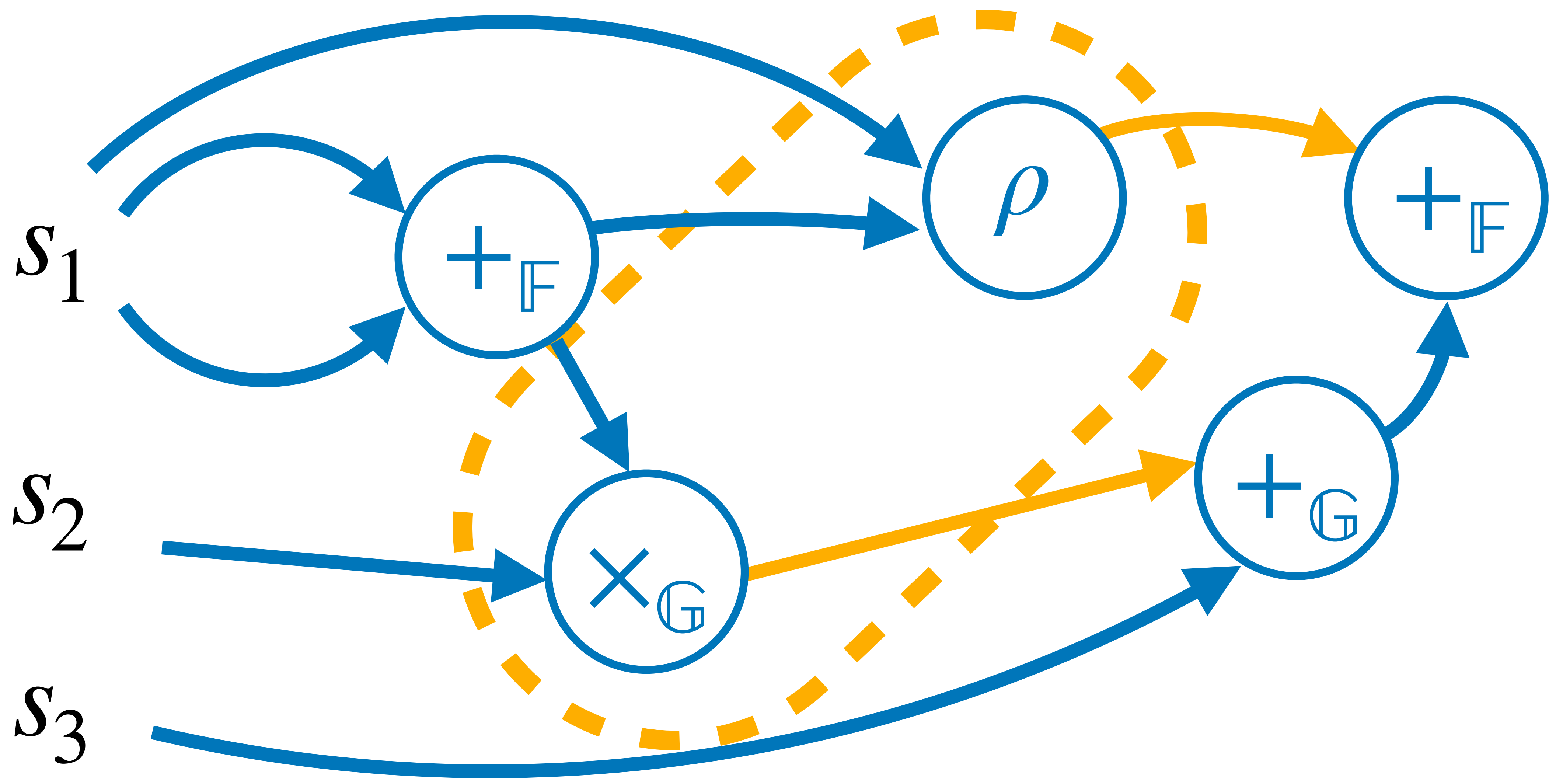
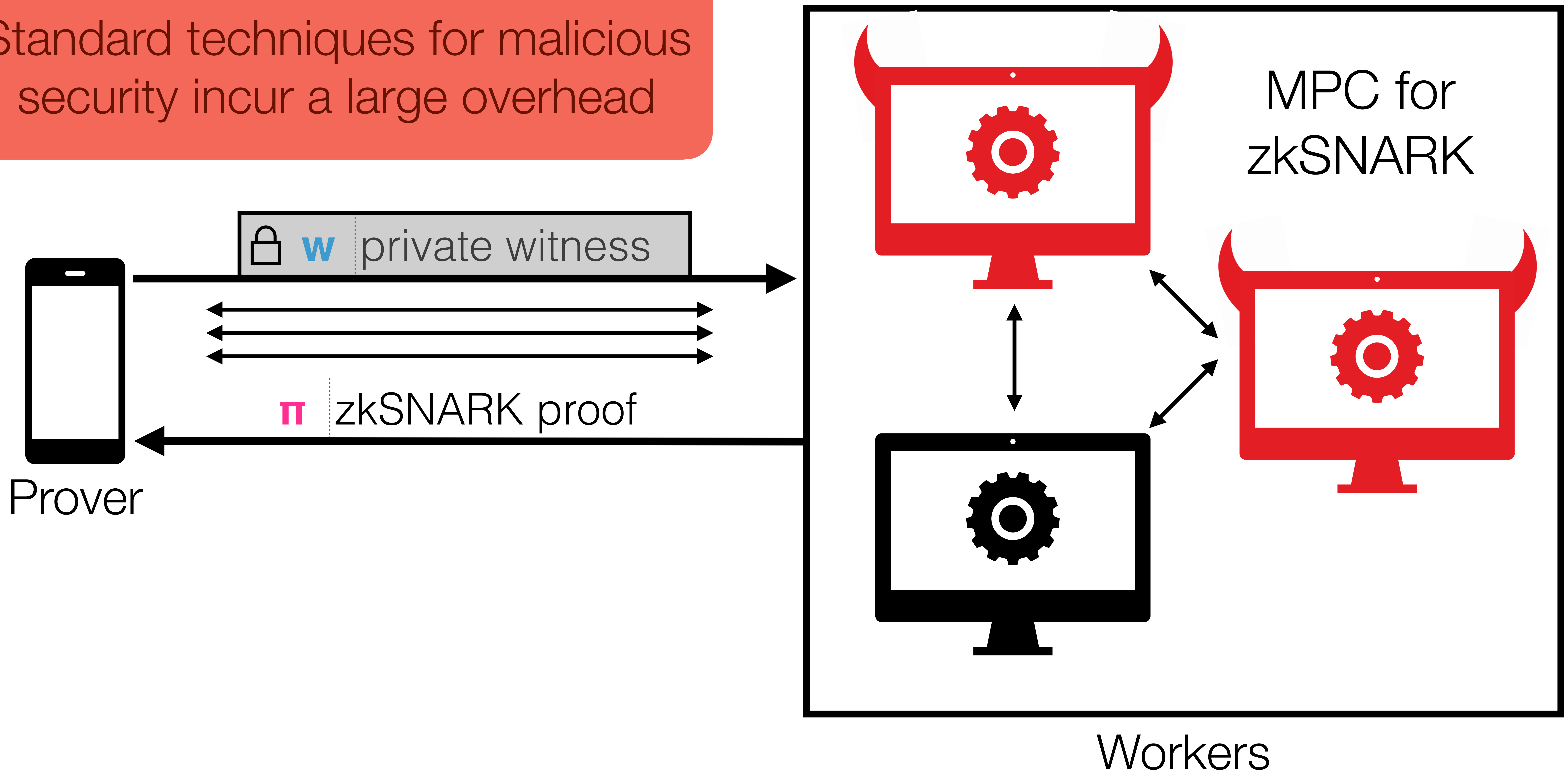


- Workers share subcircuit input wires with prover
- Prover executes the subcircuit in plaintext
- Prover sends subcircuit output wires to workers

Achieving Malicious Security

Standard techniques for malicious security incur a large overhead



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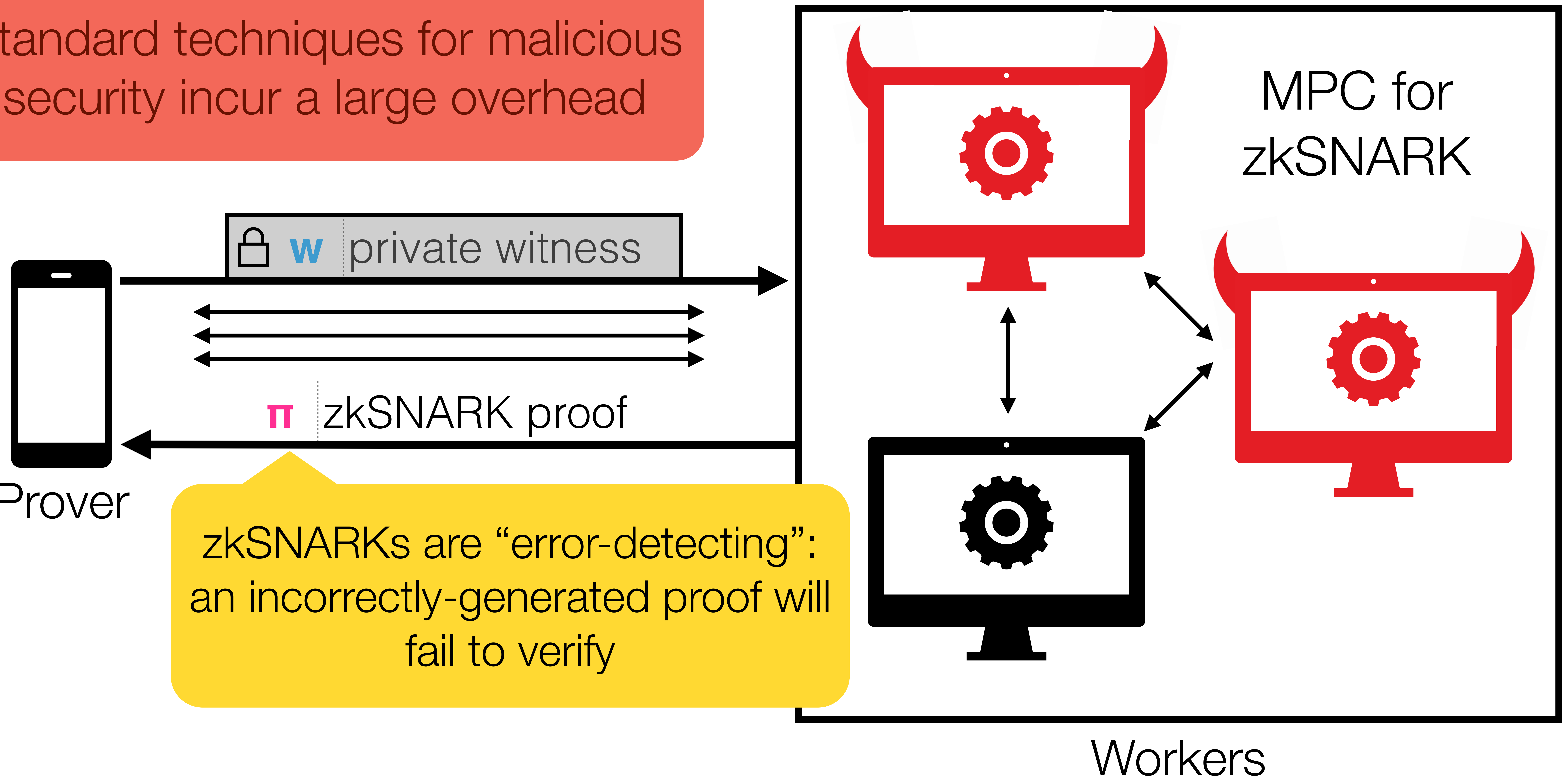

zkSNARKs are "error-detecting": an incorrectly-generated proof will fail to verify

Achieving Malicious Security

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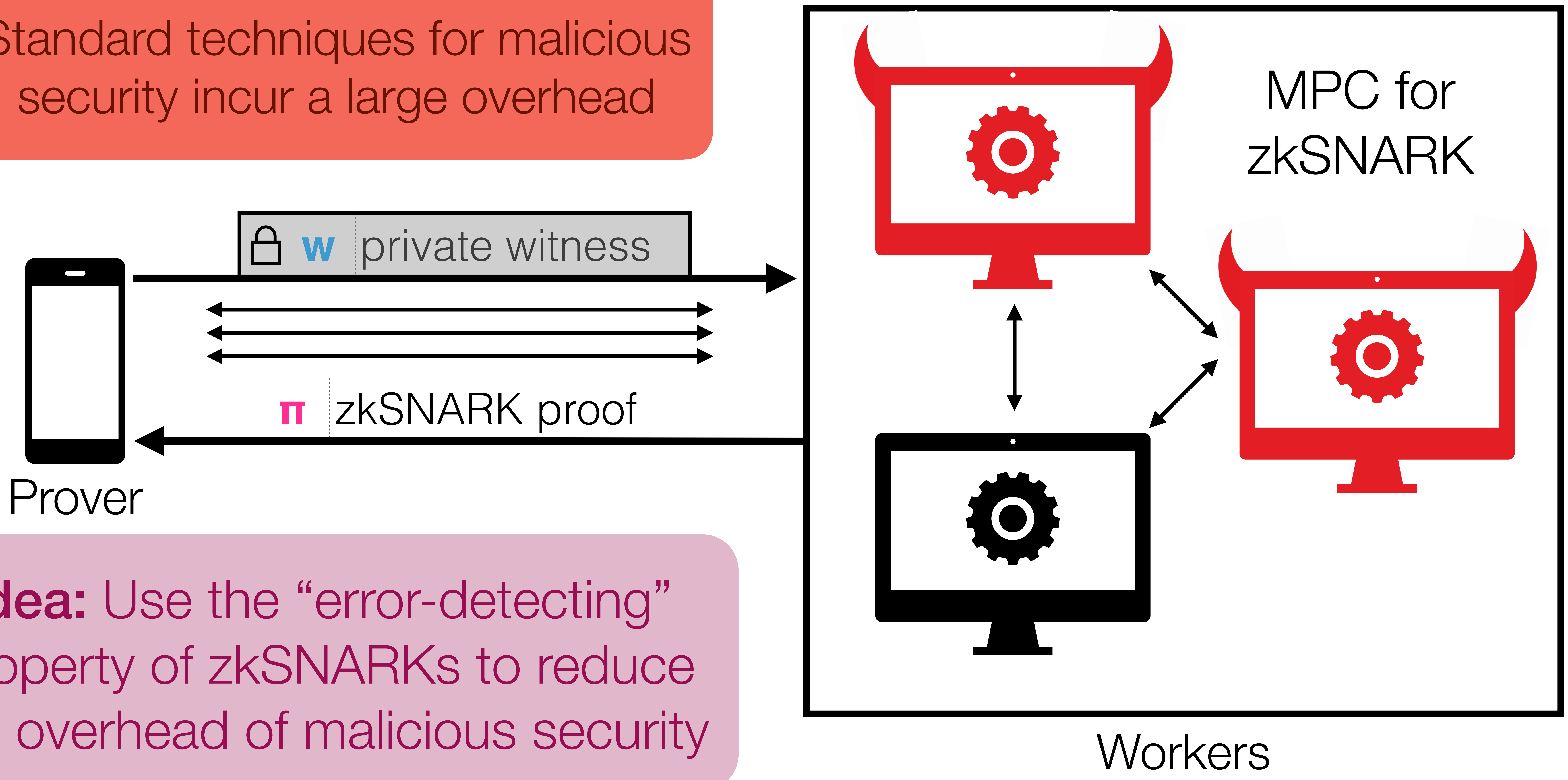
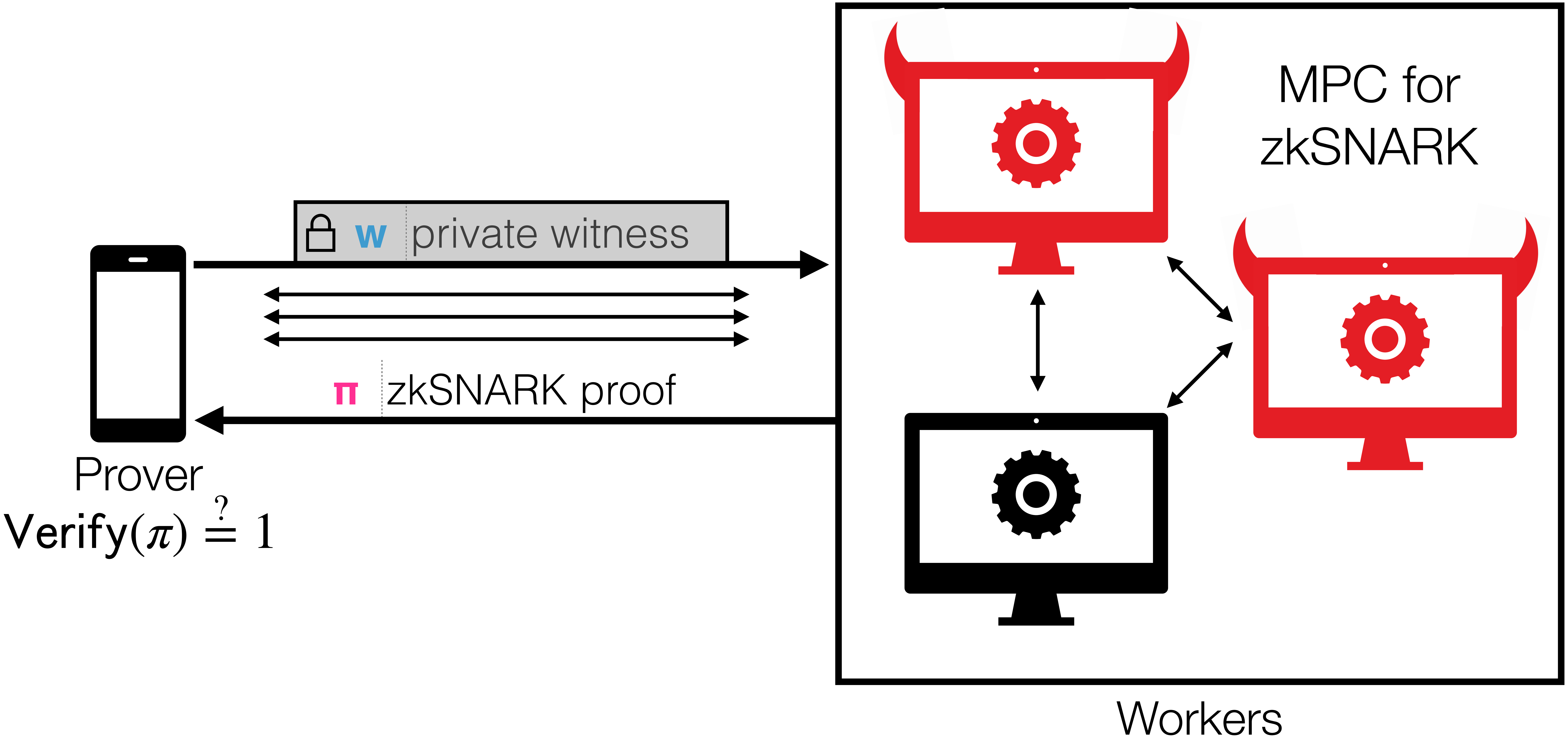


Idea: Use the "error-detecting" property of zkSNARKs to reduce the overhead of malicious security

Achieving Malicious Security



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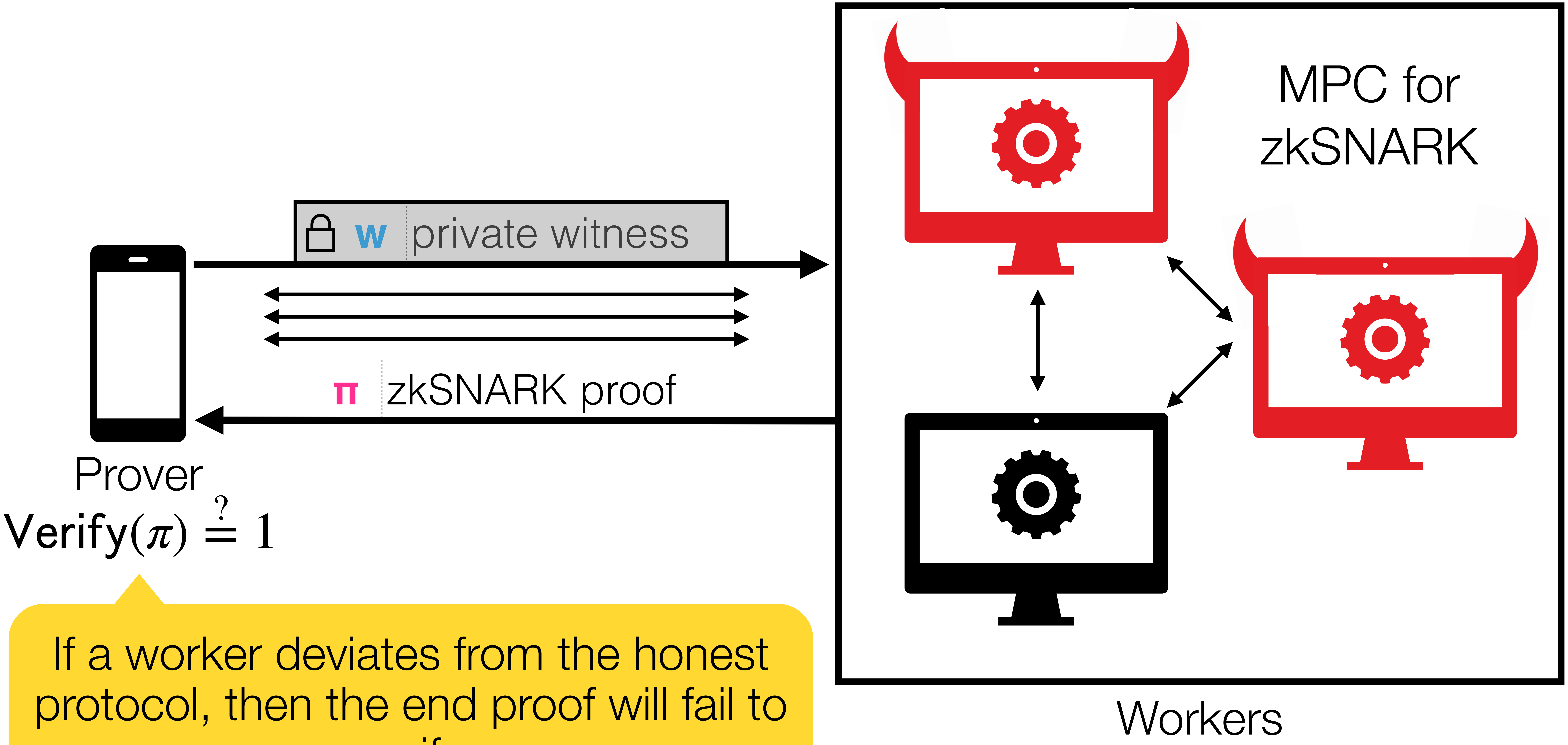
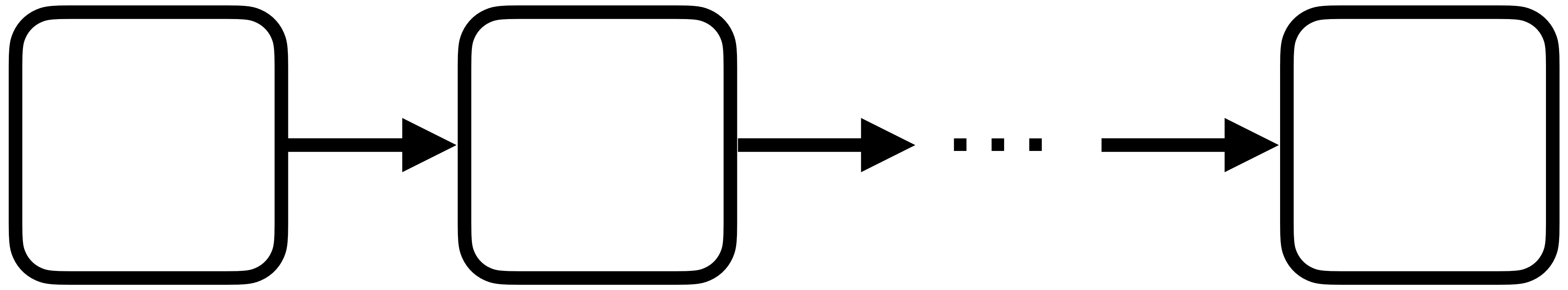
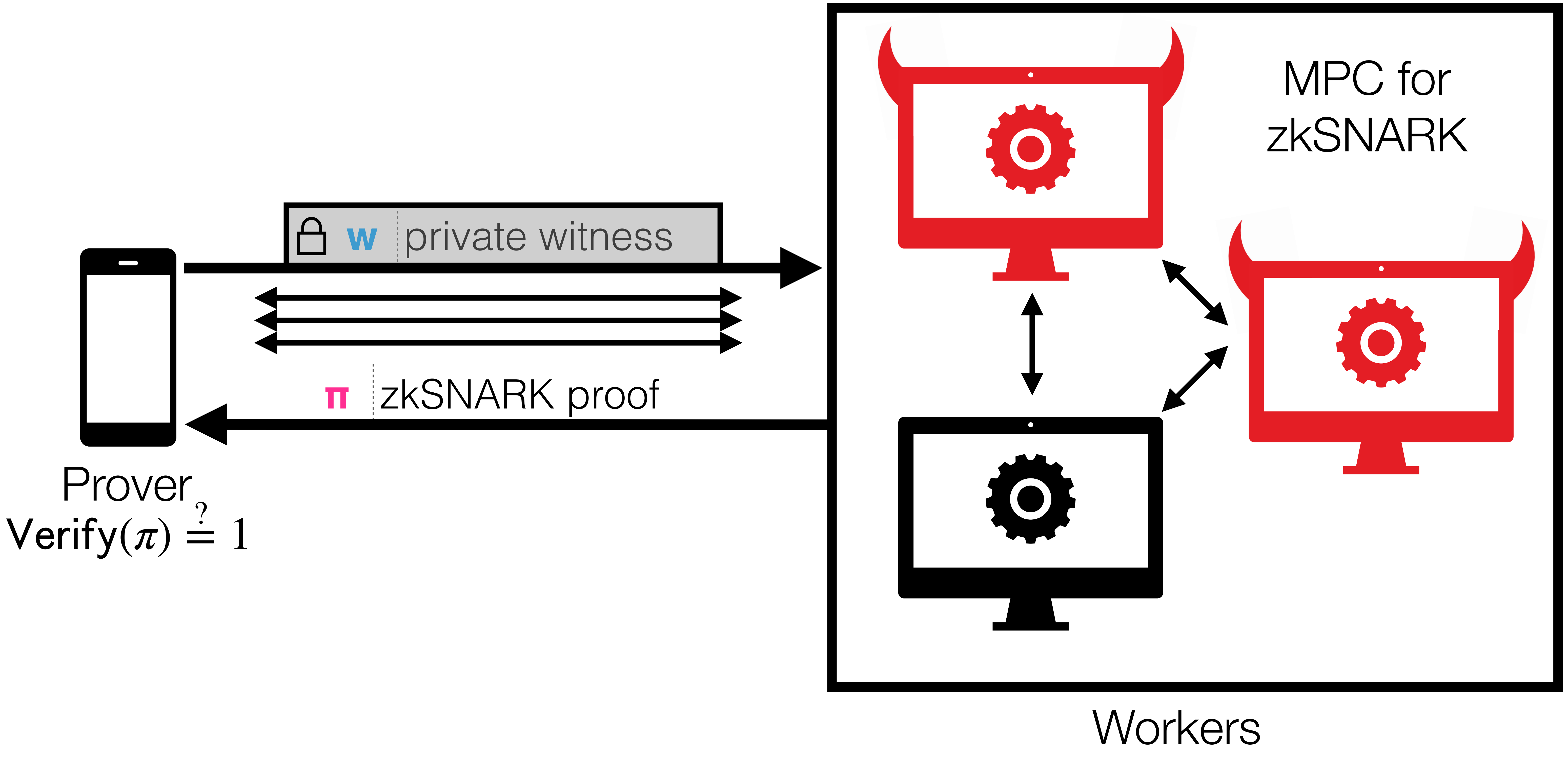


Verify(π) $\stackrel{?}{=}$ 1

If a worker deviates from the honest protocol, then the end proof will fail to verify

Achieving Malicious Security





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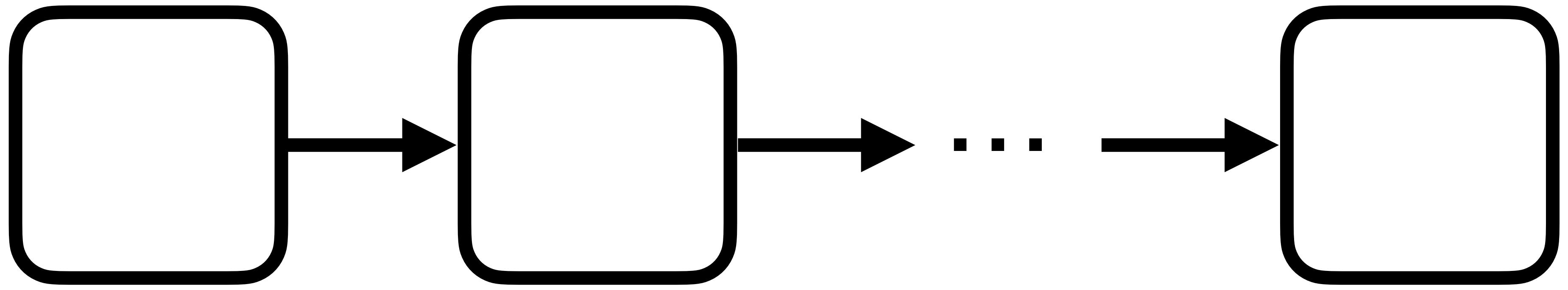

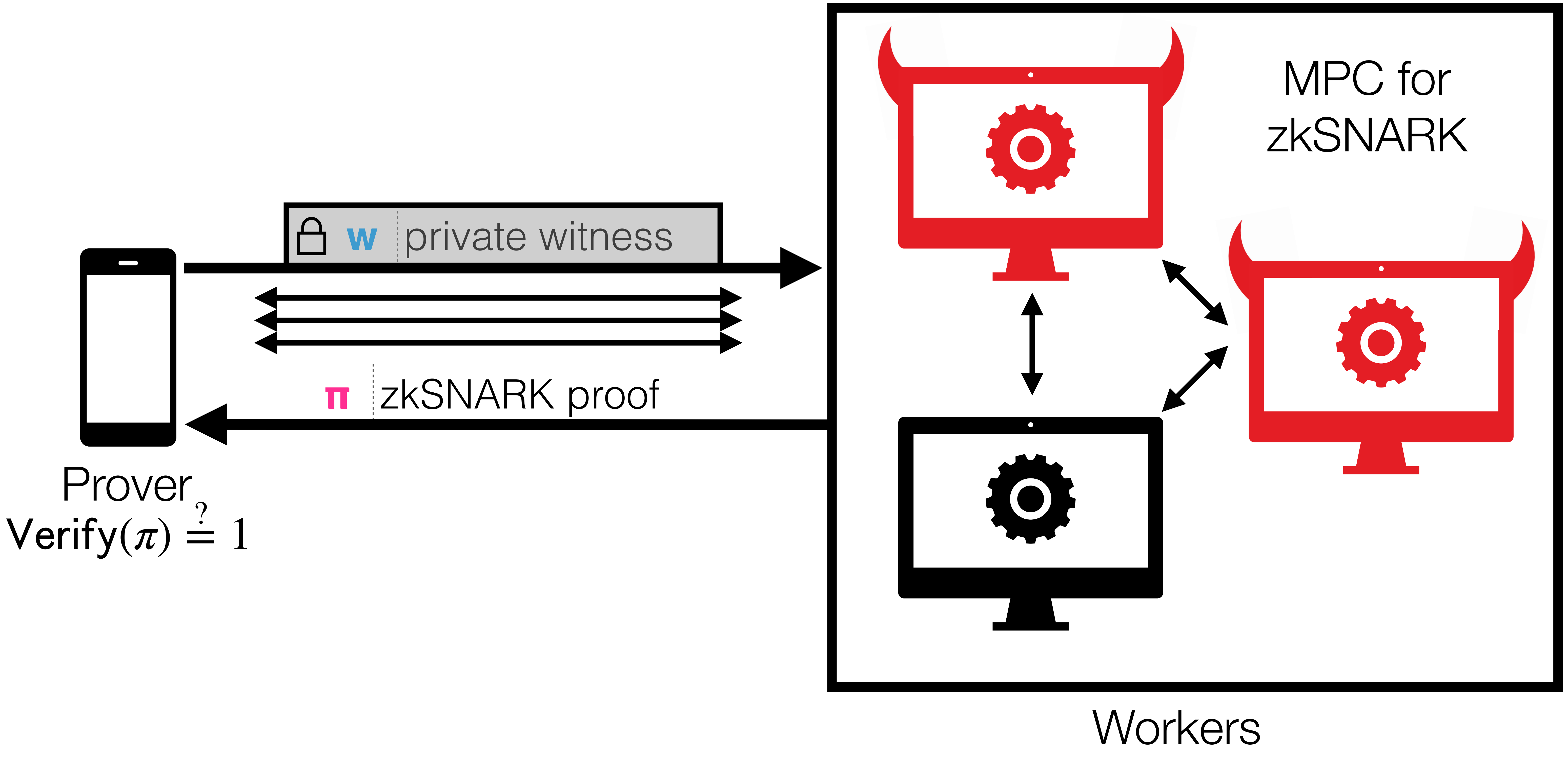

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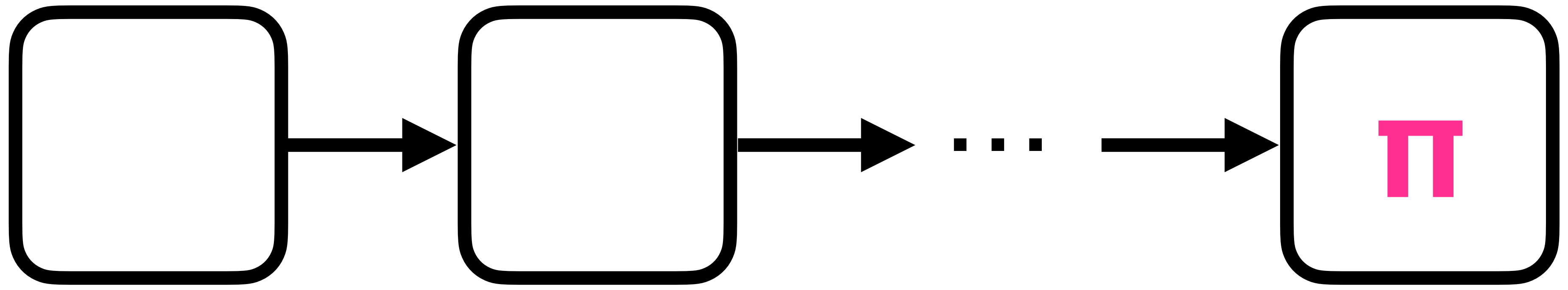

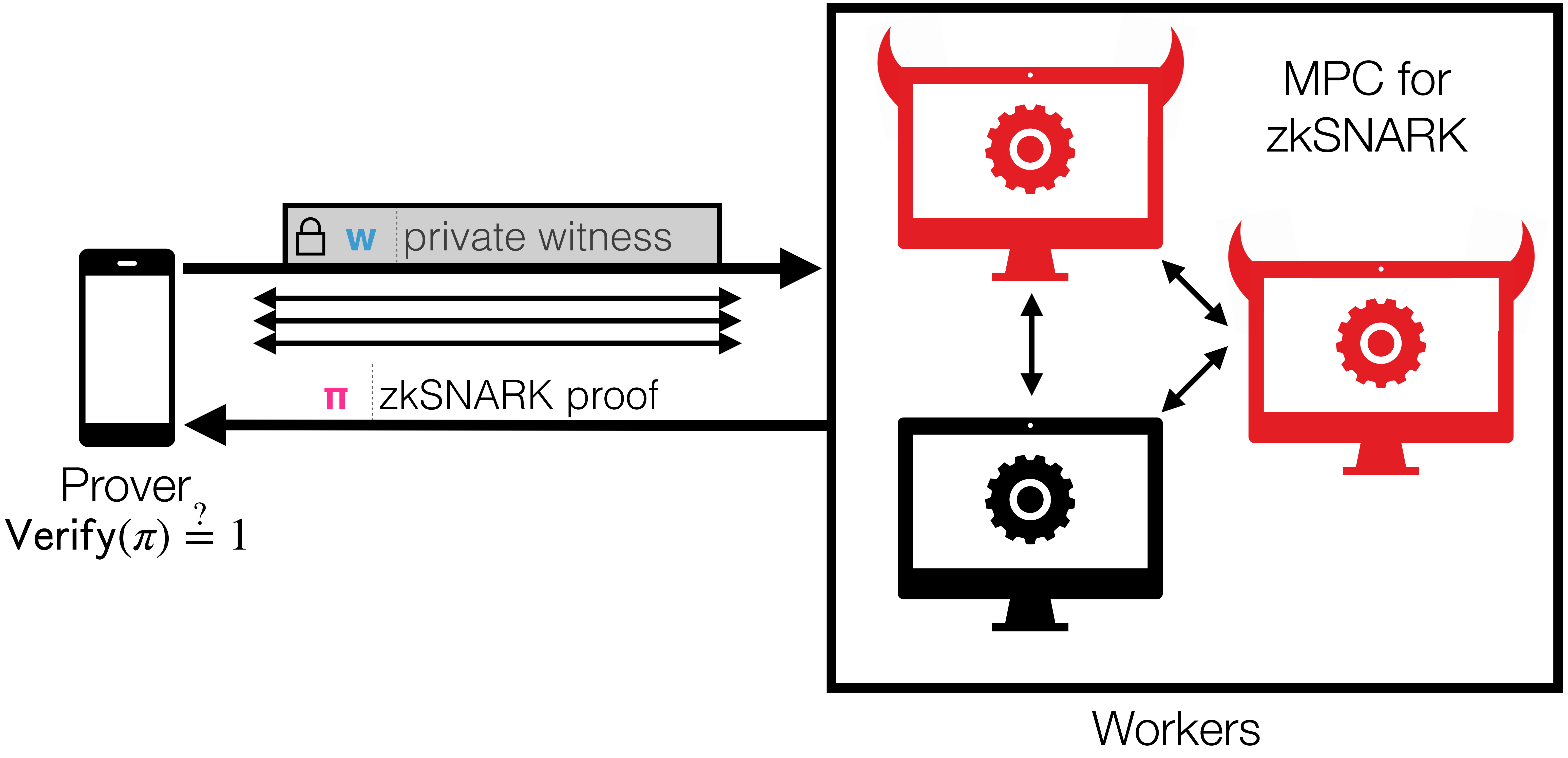

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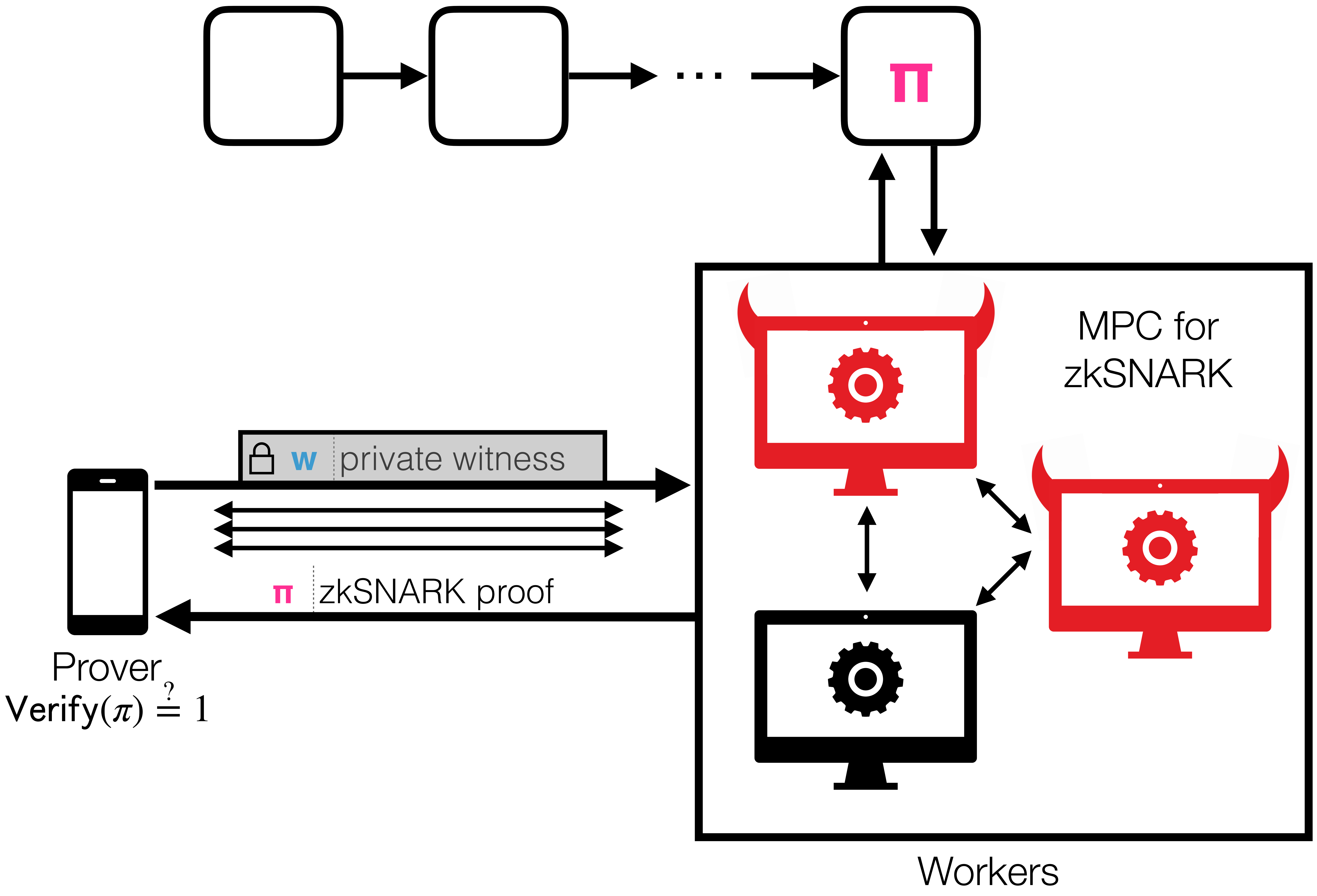

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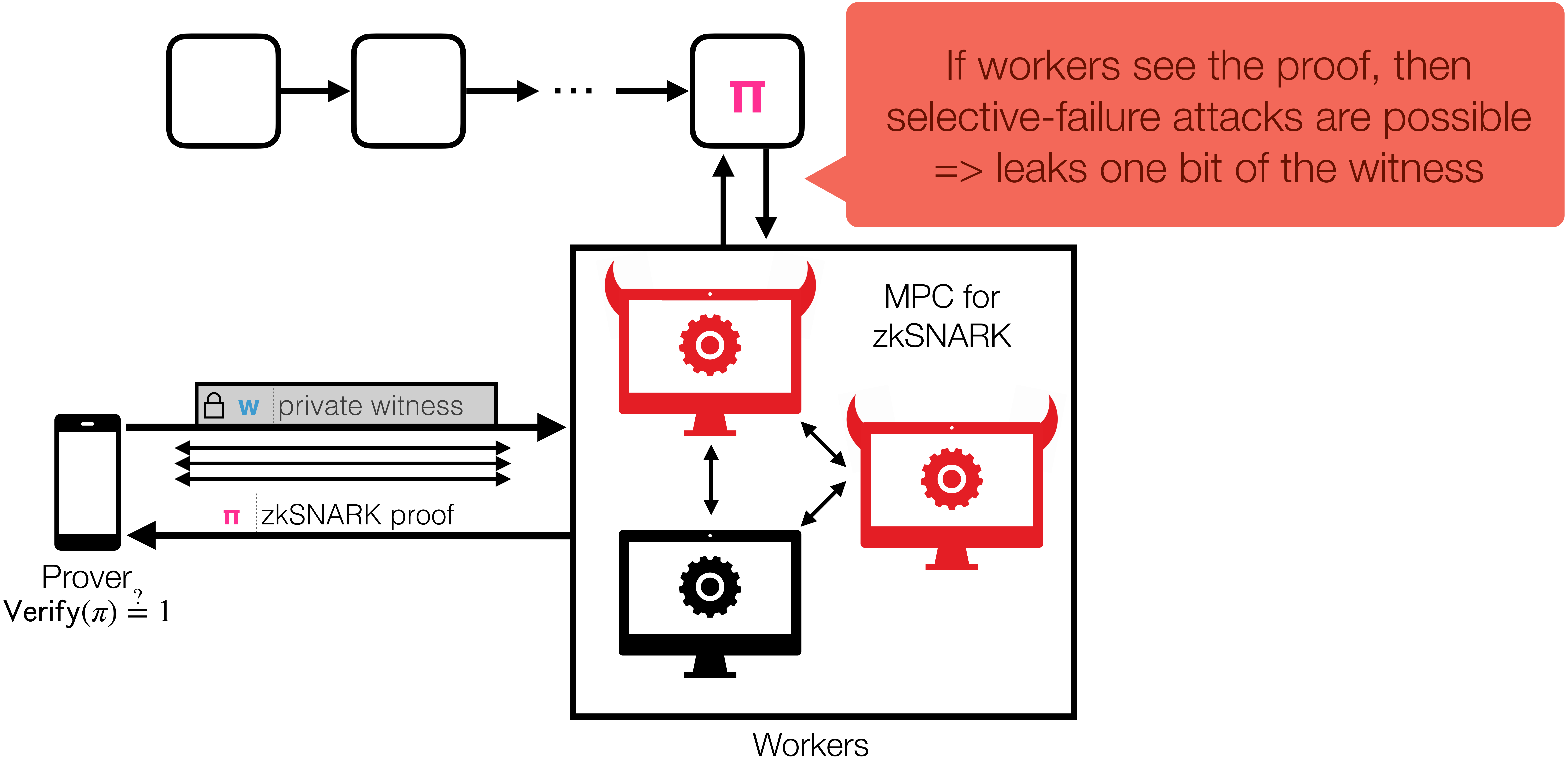

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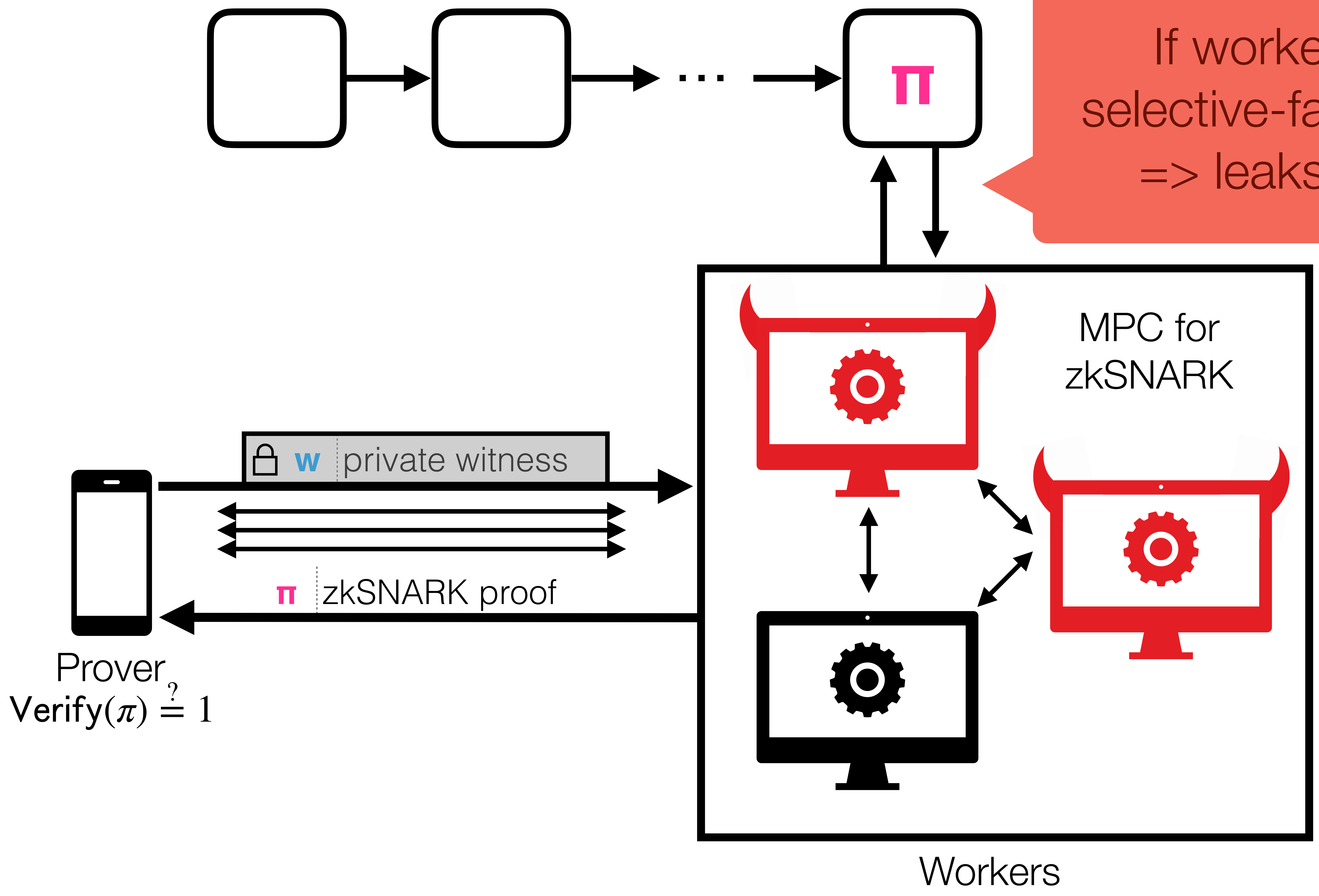


If workers see the proof, then selective-failure attacks are possible => leaks one bit of the witness

Idea:
Use additional properties of algebraic zkSNARKs to eliminate these attacks*

Implementation

ARTIFACT EVALUATED usenix ASSOCIATION AVAILABLE

ARTIFACT EVALUATED usenix ASSOCIATION FUNCTIONAL

ARTIFACT EVALUATED usenix ASSOCIATION REPRODUCED

- We implemented Eos as a Rust library in the `arkworks` ecosystem
- Eos produces a delegation protocol for any “algebraic” zkSNARK

Experimental Setup

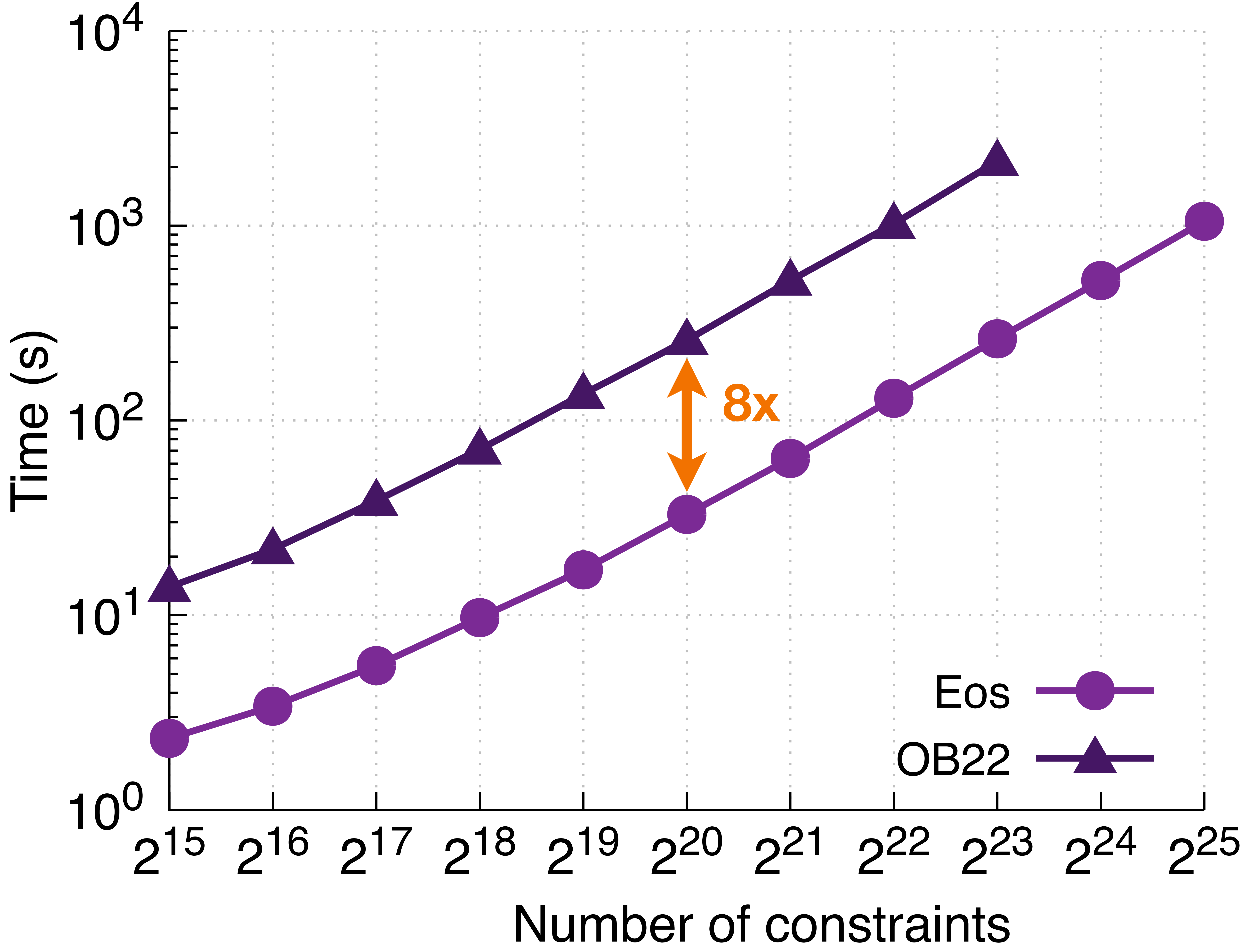
- We evaluated our protocols for the Marlin zkSNARK [CHMMVW20]
- 2 workers (AWS c5.24xlarge) in `us-west-1` and `us-east-1` regions

Eos speeds up proving time by 26x for mobile-phones

Prover	Network Throughput	Speedup	Memory reduction
r4.xlarge (AWS)	3 Gbps	9x	256x
r4.xlarge (AWS)	350 Mbps	6x	256x
Pixel 4A	350 Mbps	26x	256x

Eos vs. local proving for 2^{20} constraints

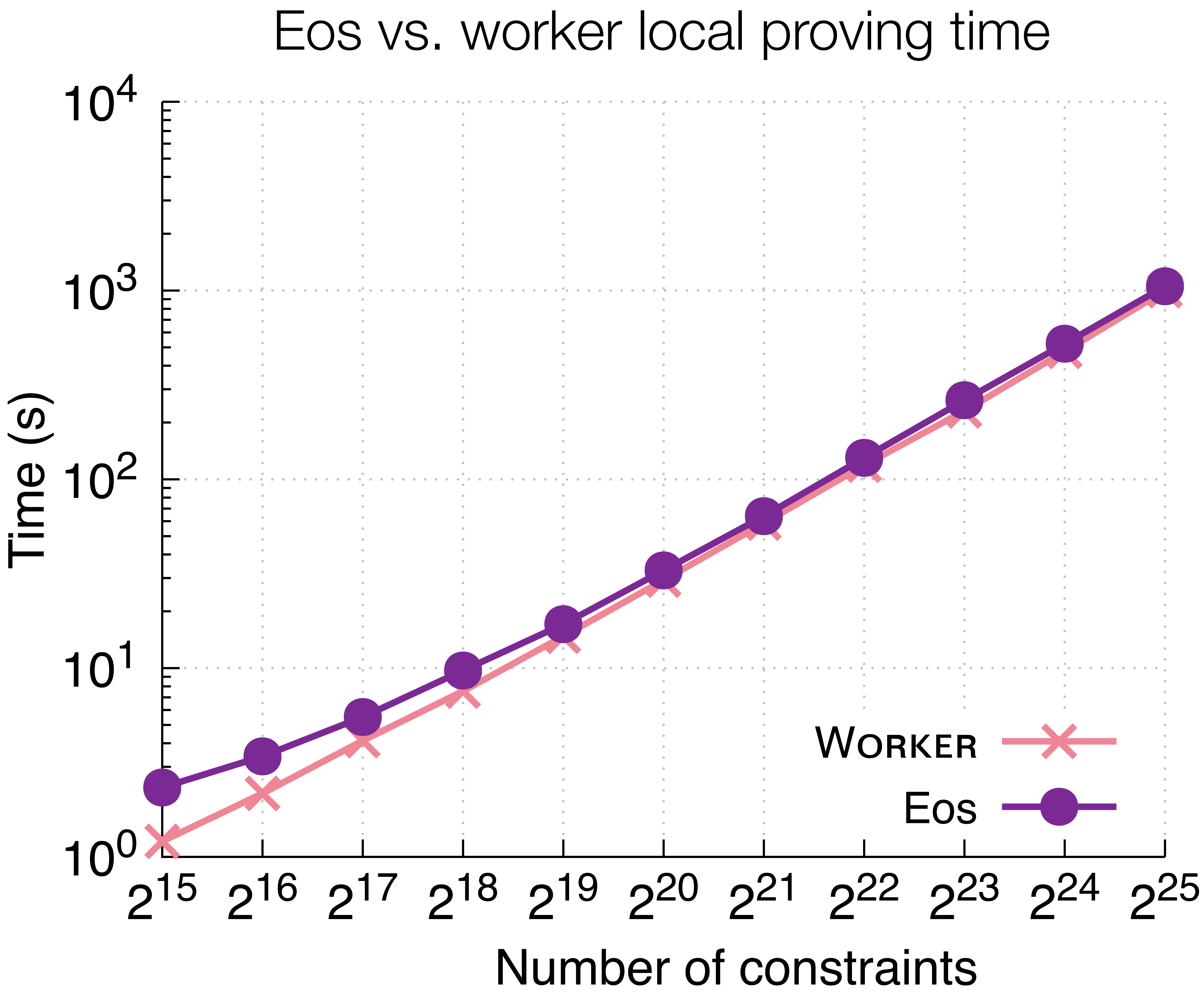
Eos is 8x faster than existing techniques



Eos is only 10% slower than insecure delegation

Eos vs. worker local proving time

Eos is only 10% slower than insecure delegation



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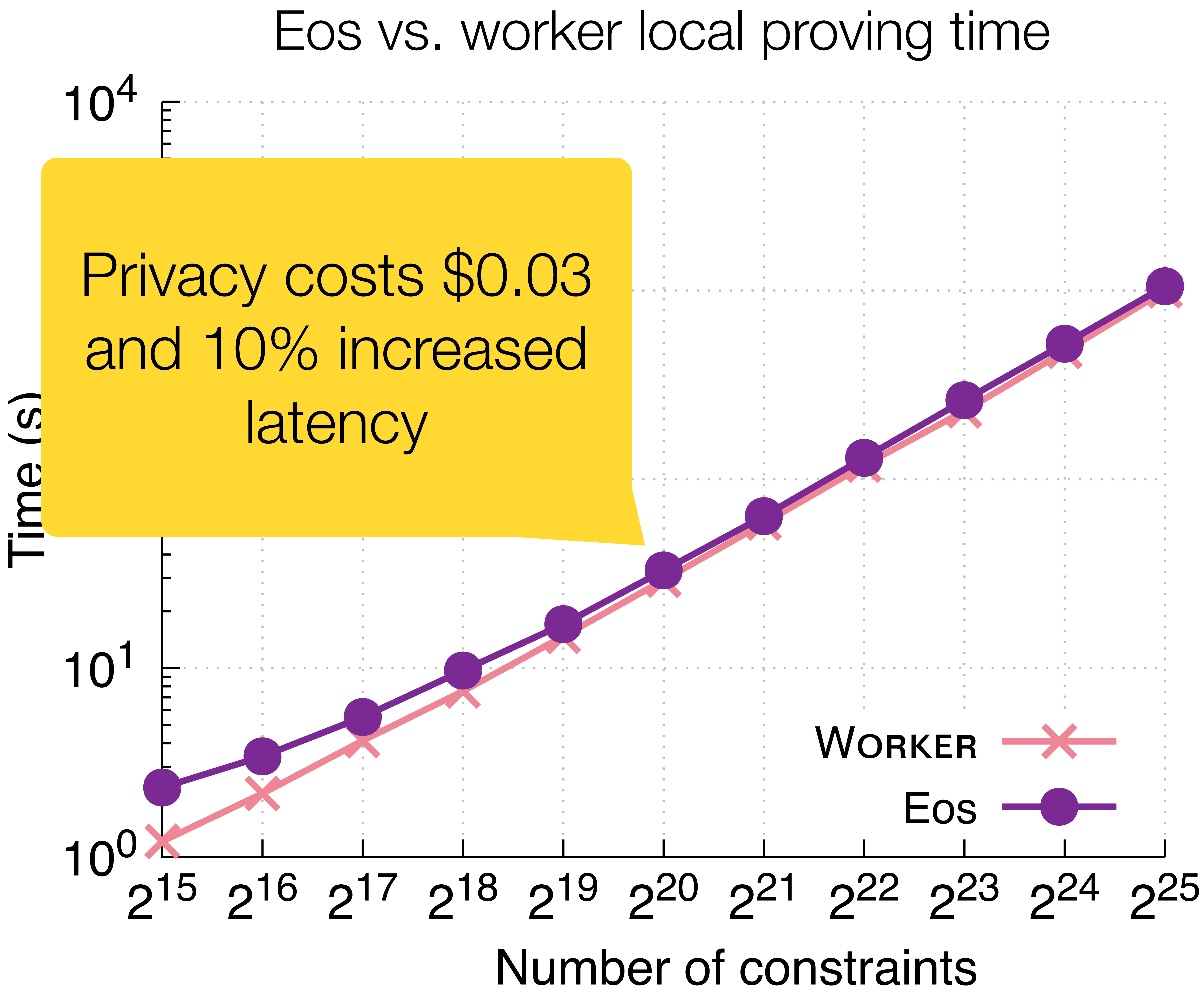

Privacy costs $0.03 and 10% increased latency

Thank You!

Paper/code: www.usenix.org/conference/usenixsecurity23/presentation/chiesa

(Updated version coming soon to ePrint)

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