山东大学
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Security-Performance Trade-off in DAG-based Proof-of-Work Blockchain Protocols

Shichen Wu, Puwen Wei, Ren Zhang, Bowen Jiang

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    - - Formal Analysis of Nakamoto Consensus (10)
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    - - New Design: non-DAG-based Protocols (6)
    - - Mining Attacks and Ecosystem Analysis (18)
  - 23 papers involve PoS:
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    - - New Design (12)

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  - 23 papers involve PoS:
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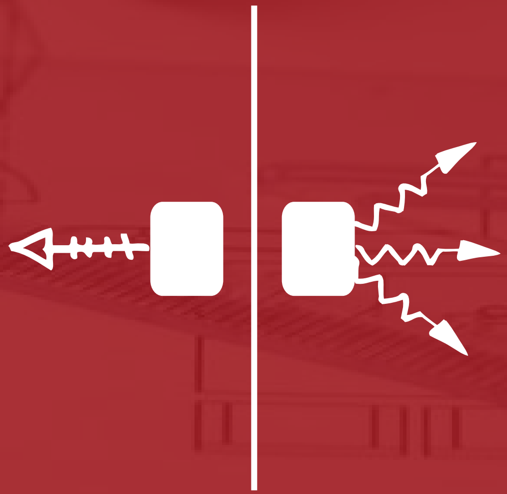
- To sum up:
  - Security Analysis
    - PoW: more secure than previously believed
    - PoS: more attack vectors discovered
  - New PoS Designs: not sure we can ever achieve PoW's security
  - PoS ecosystems: lack of studies raises concerns

1. NC & DAG

2. New Model

3. LP Attack

4. Examples & Simulation



- Nakamoto Consensus and its limitation
- The solution: DAG-based blockchain
- Does DAG solve the problem?
- The phenomena in DAG blockchain

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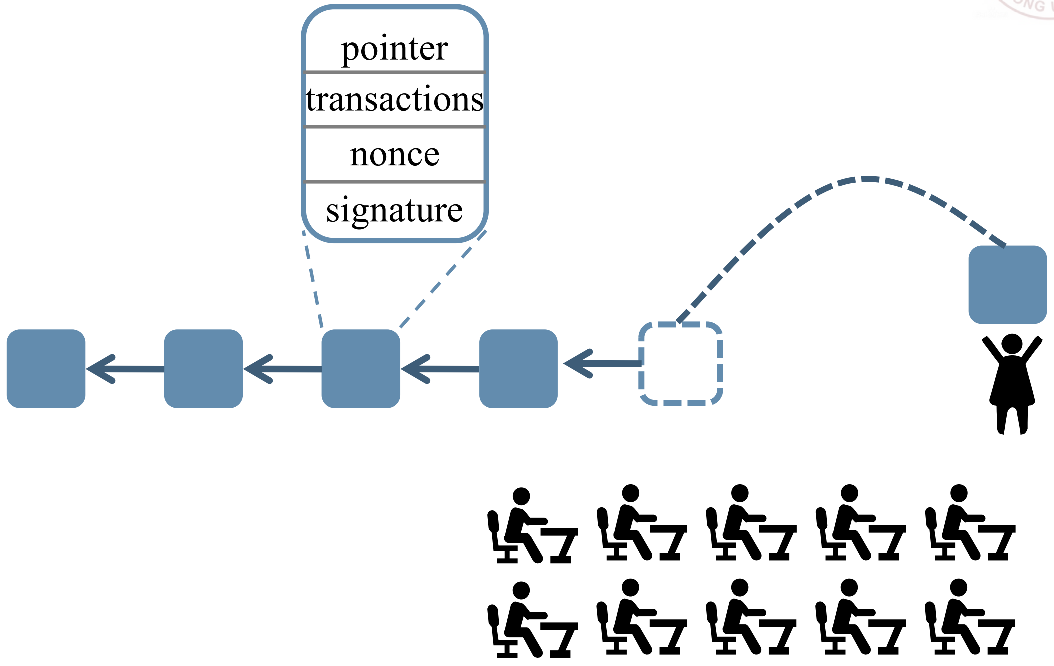

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$$\boxed{Hash(pointer, tx, nonce) < \ Target}$$

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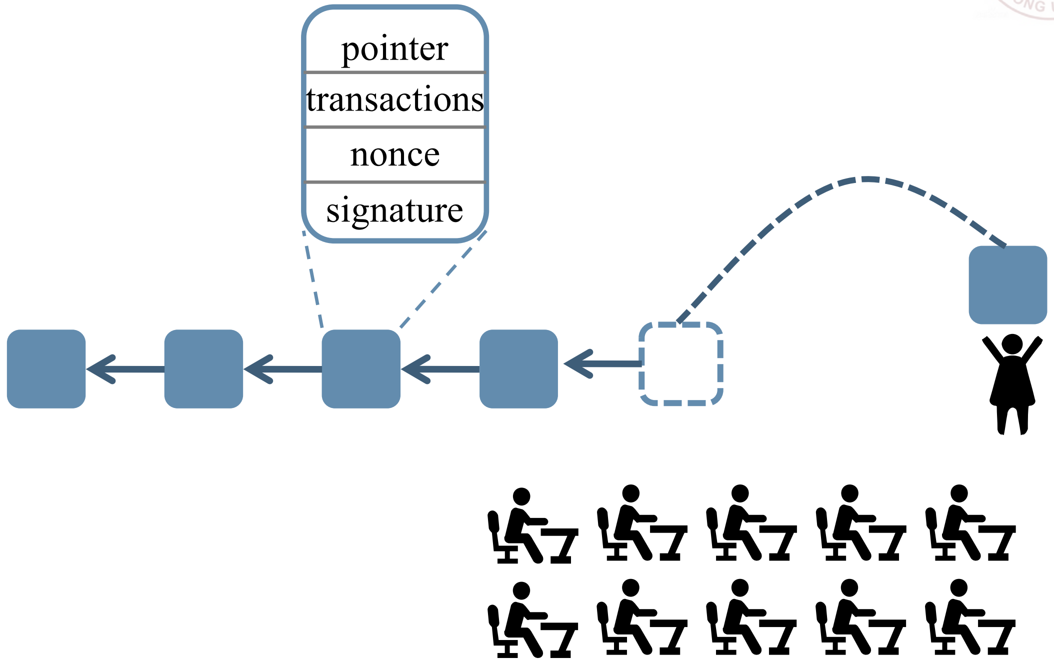

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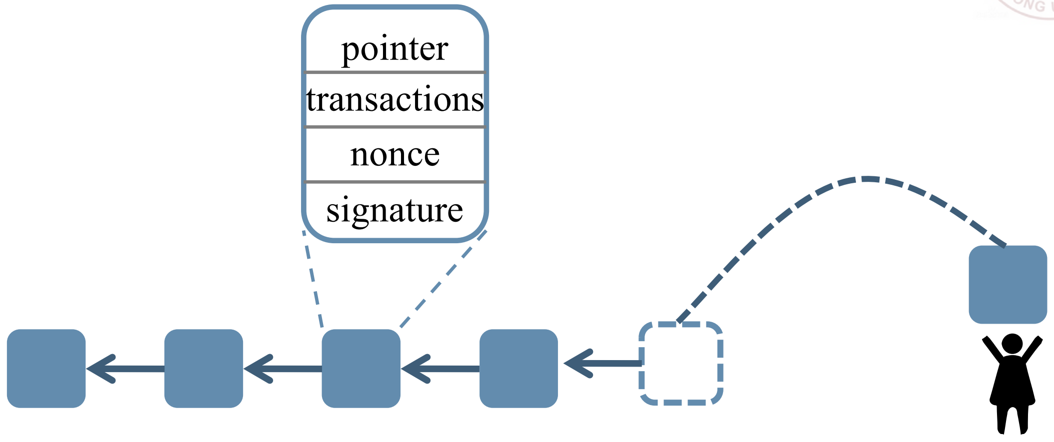
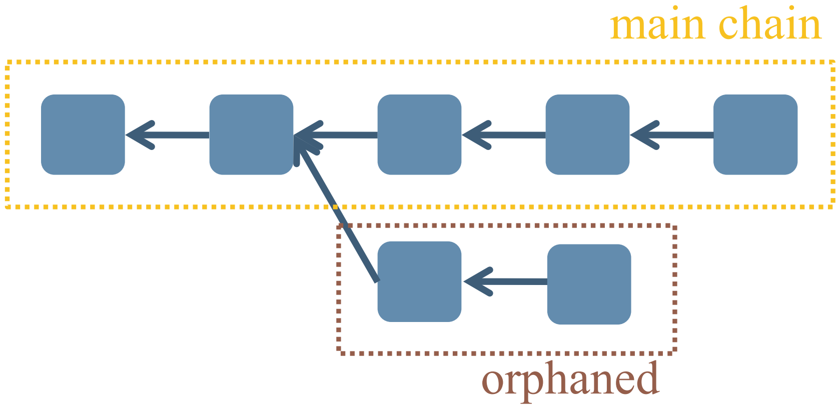
change

    - extend chain: Longest-Chain rule
      - the longest fork means the most mining power





Limitations of NC

- Security-Performance Tradeoff

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- Security-Performance Tradeoff
  - security of NC is rooted in

"block generation interval >> the time for propagation"

- the smaller the gap, the worse the security

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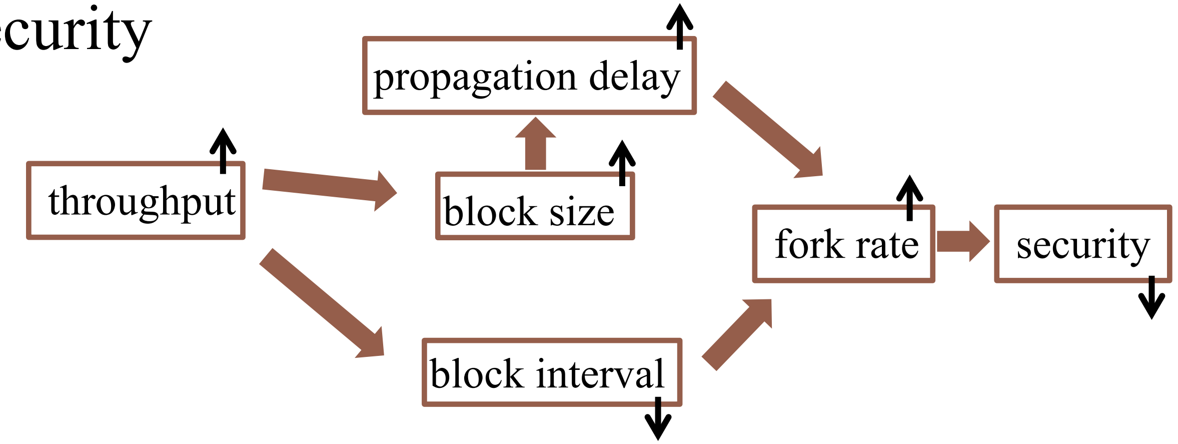
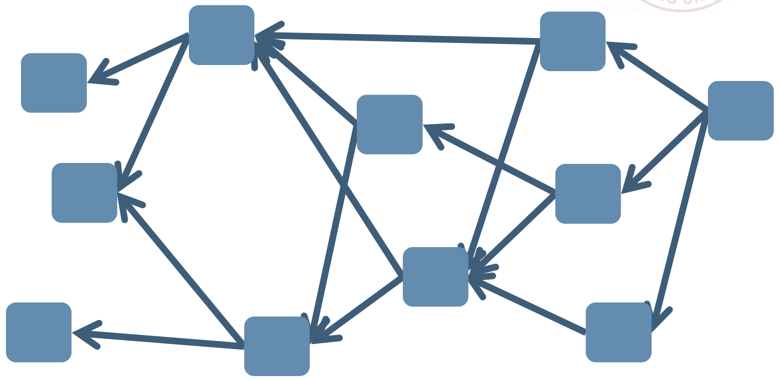
  - however!
  - higher throughput requires larger block and shorter block interval, which reduces the security



- **NC has to maintain a poor performance.**
  - 7 TPS

DAG-based Blockchain

- **Structure:** Chain → Directed Acyclic Graph



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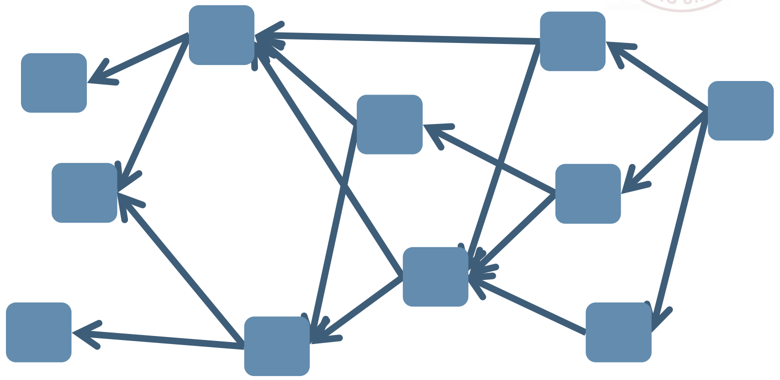

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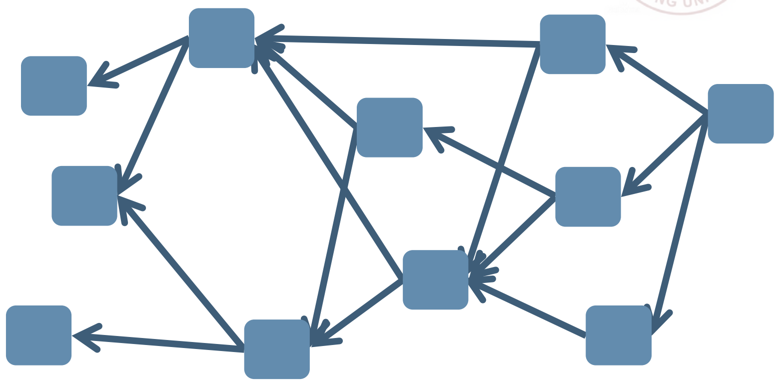

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    - SPECTRE, PHANTOM, Conflux

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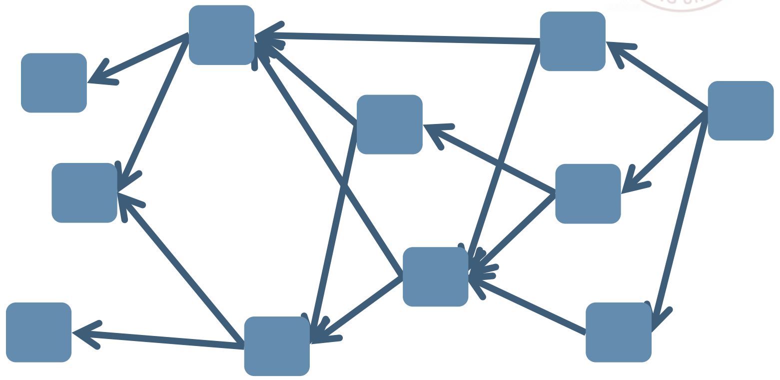

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State-of-the-art:

Prism (CCS’ 2019), OHIE (S&P 2020)

Prism & OHIE

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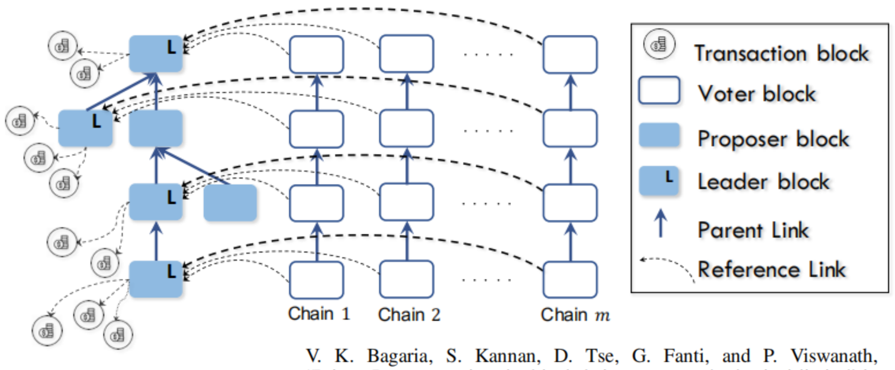
    - tx blocks, proposer blocks, voter blocks



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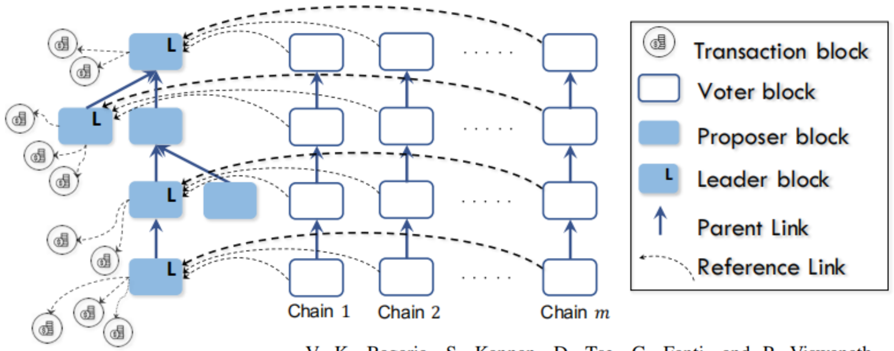

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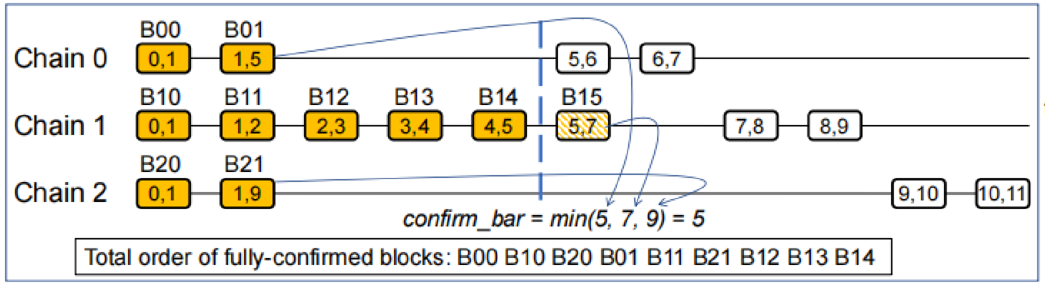
  - OHIE [S&P'20] (multiple parallel chains)
    - m parallel NC chains, m times throughput
    - security comparable to NC



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DAG Breaks Trade-off

- Security-Performance tradeoff has been broken
  - Prism and OHIE achieve 90% and 50% bandwidth utilization
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- Security-Performance tradeoff really has been broken?

?

Problems of analyses for DAG-based blockchain

- Assumption of Decoupling
  - some priority blocks are small enough and enjoy a priority propagation policy
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- Assumption of Decoupling
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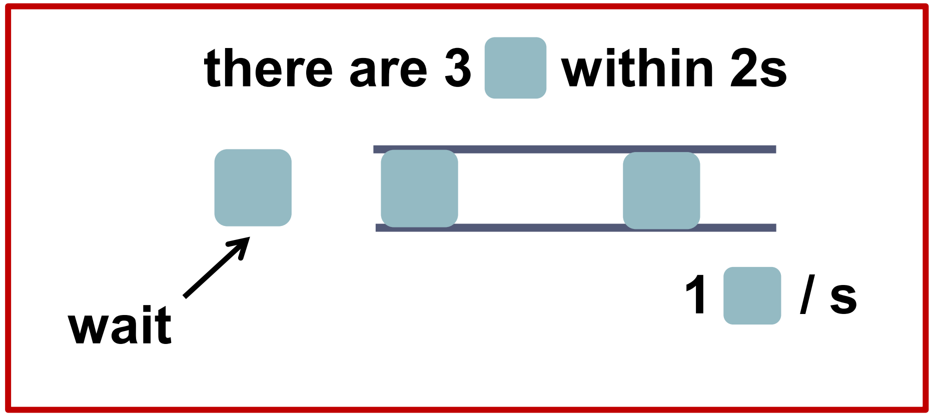
  - But it's not easy in a high-throughput DAG-based blockchain system

Block Jam

- If the total number of blocks propagated over a period of time **exceeds** the network's processing capacity, some blocks will have more propagation delay



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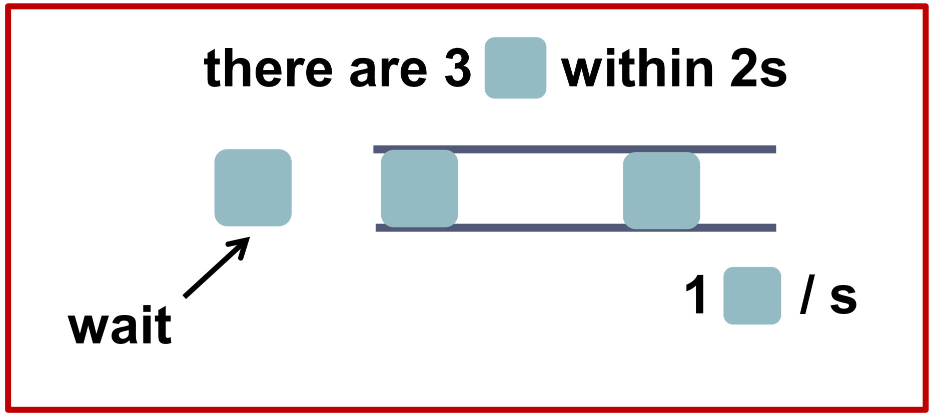

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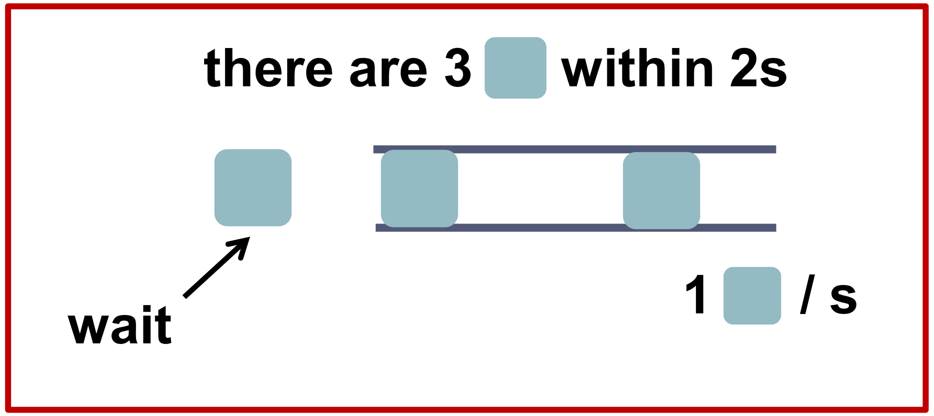

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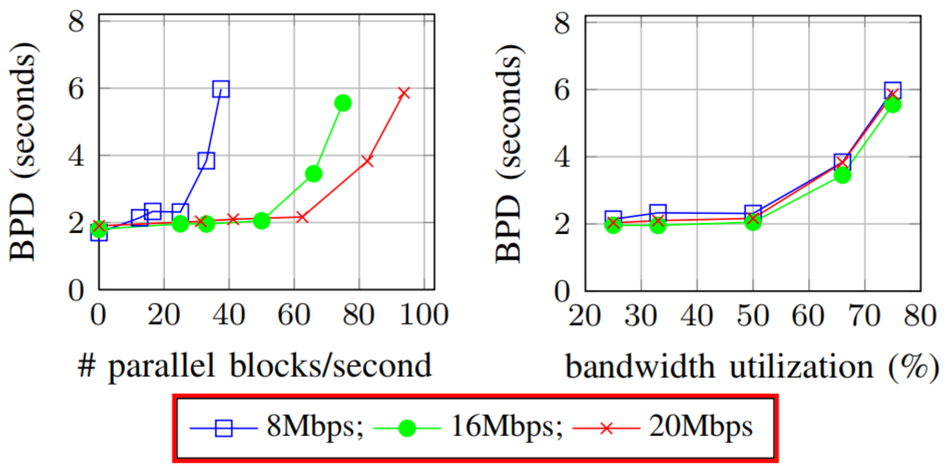
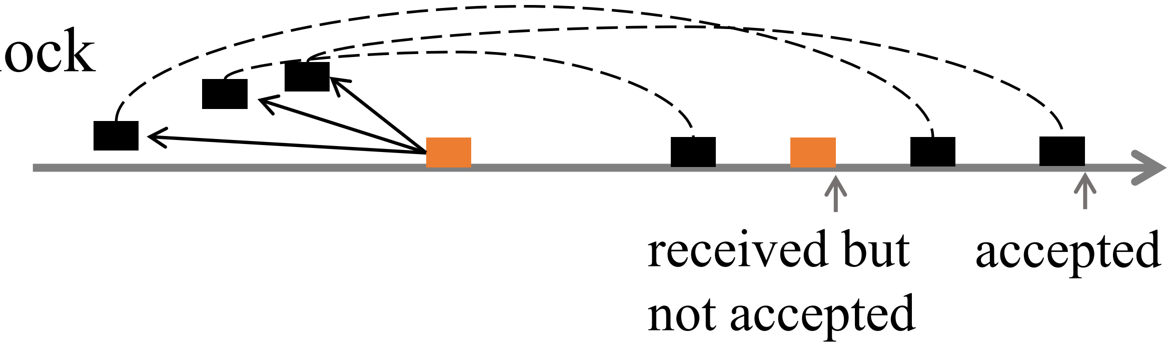


Late Predecessor

- If a miner receives a block but does not receive all its predecessors, the miner cannot accept the block



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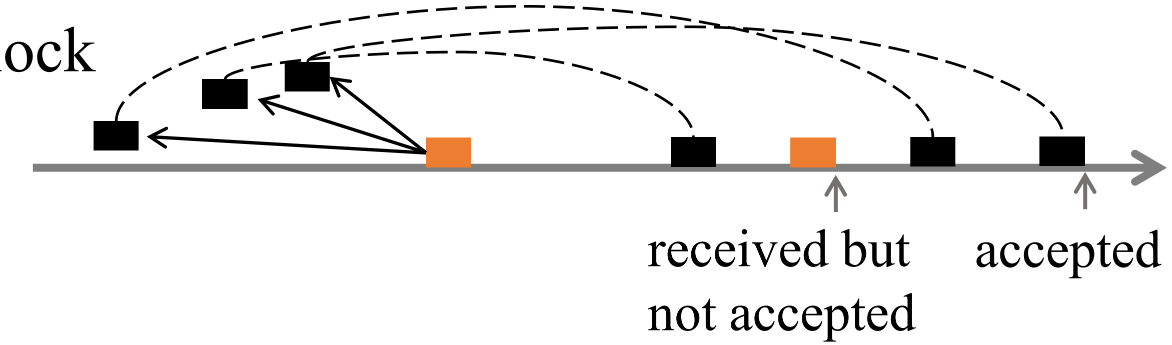

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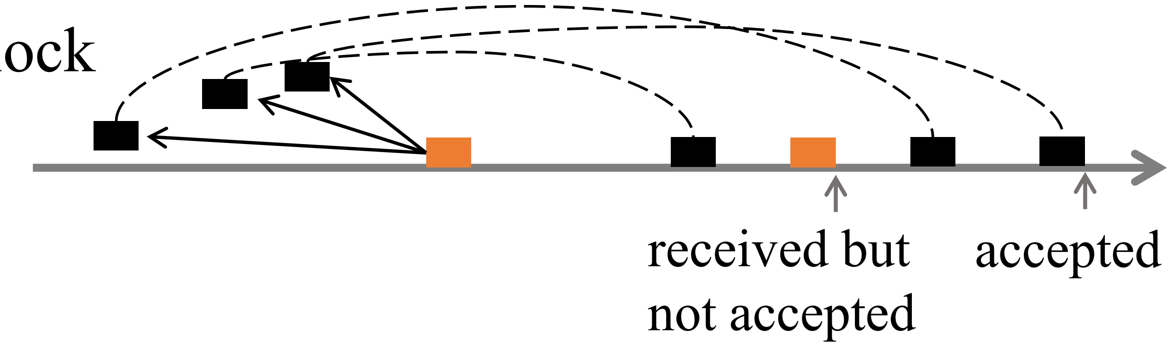

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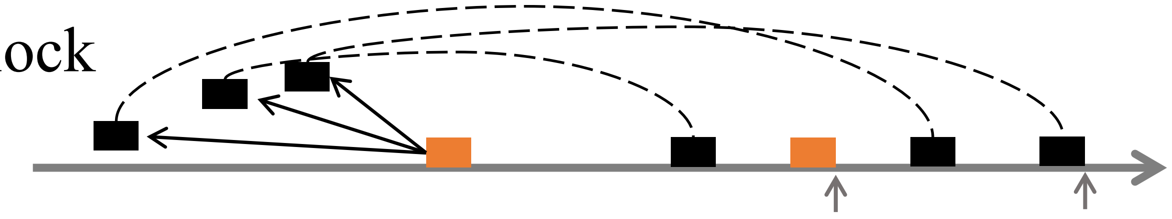

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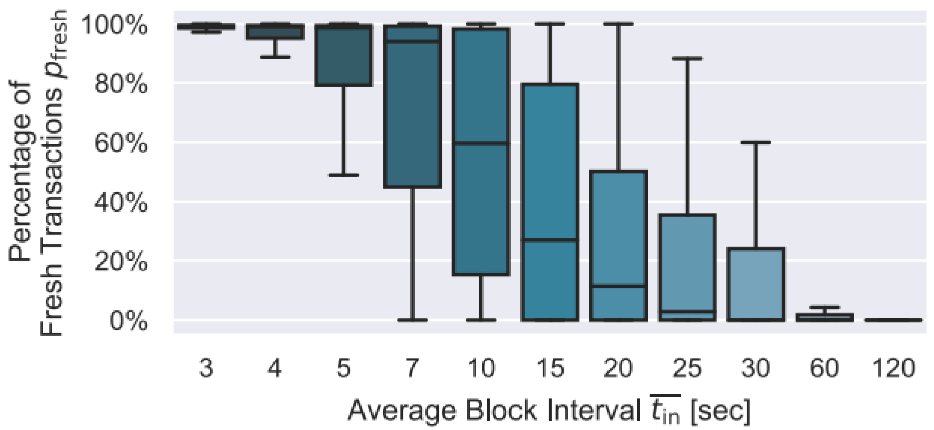

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4. Examples & Simulation

- Why we need a new model?
- Characteristics of CBM
- Apply CBM to DAG-based blockchain

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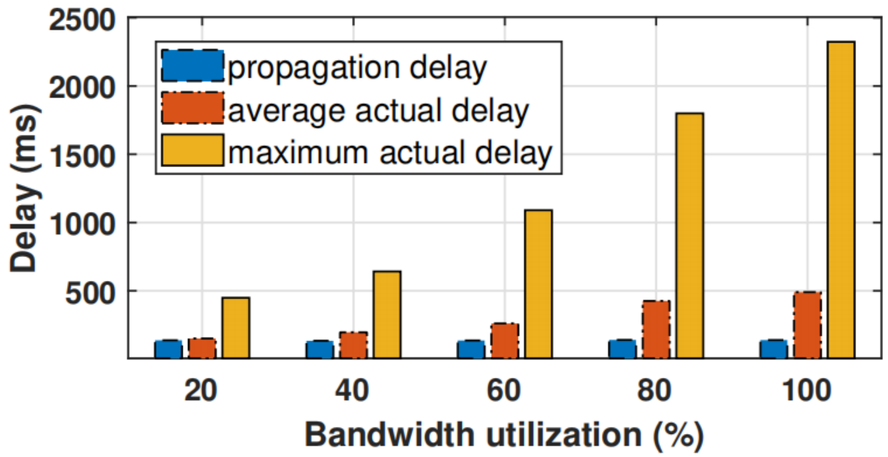
Delay of proposer blocks



*actual delay is the interval between the block's generation and the arrival of its latest predecessor at a certain node

- UDBM
  - a uniform upper bound of delay on all blocks
  - adversary strategy: delay all receivers to the bound

- We deploy Prism with SimBlock
  - a maximum delay bound would overestimate the security requirement

Congestible Blockchain Model

- CBM

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  - time assumption
    - the upper bound may be different
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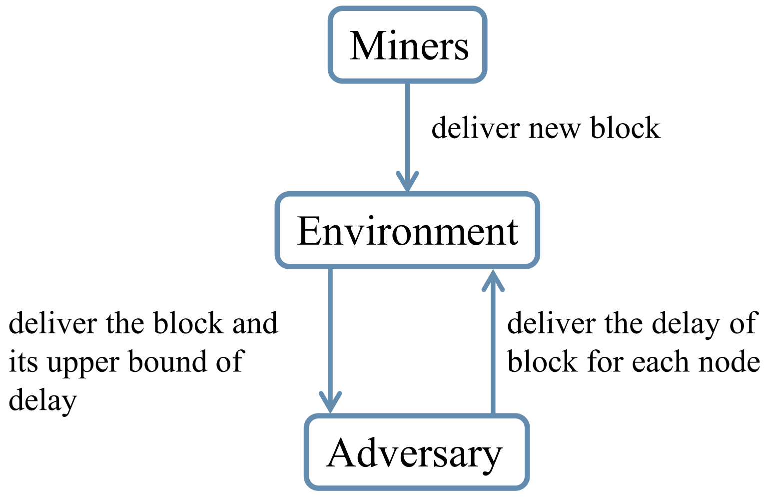

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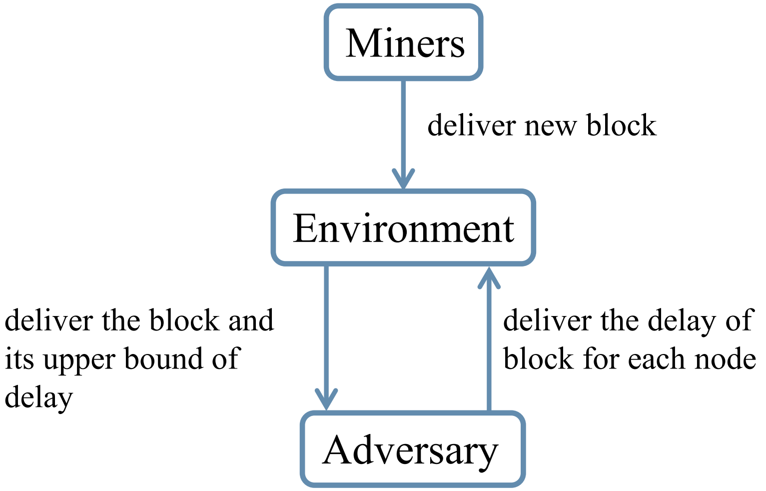
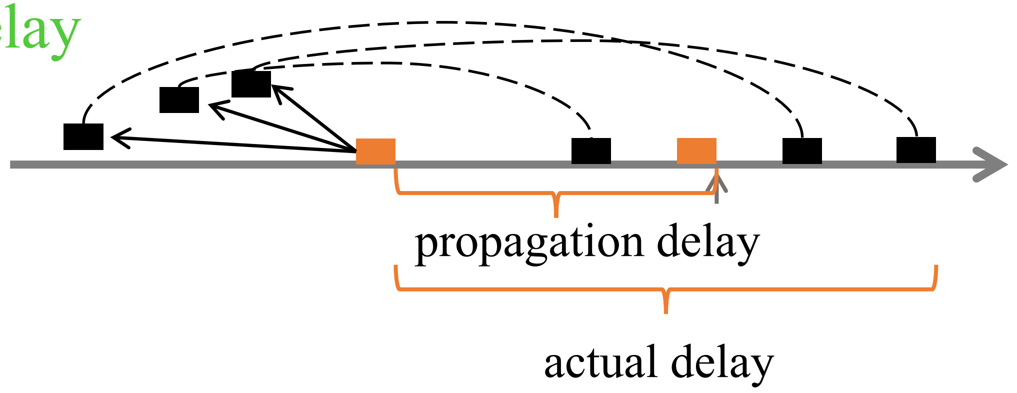


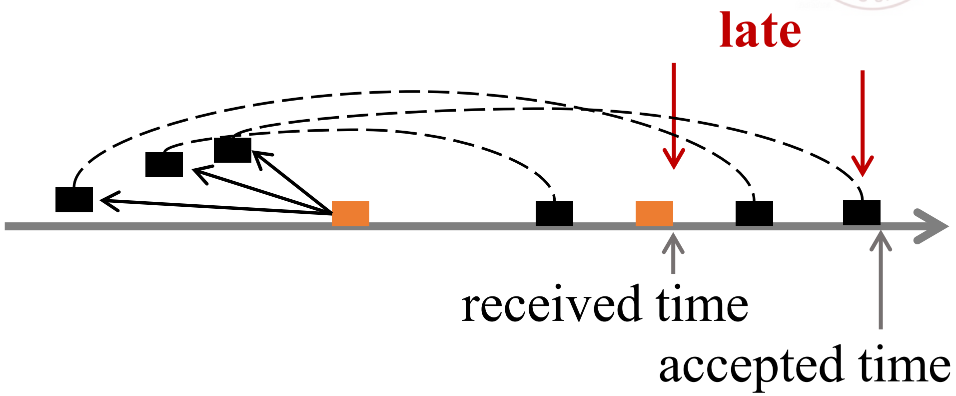
  - block processing: distinguish the status
    - received, accepted, confirmed, orphaned
    - actual delay = propagation delay + processing delay



  - same adversary & mining & security property

Apply CBM to DAG-based blockchain

- Defining late-predecessors (LP)
  - B^* is late if $B^* \leftarrow B^+$, but B^+ is received first
  - interval between receiving B^* and B^+ is lag time



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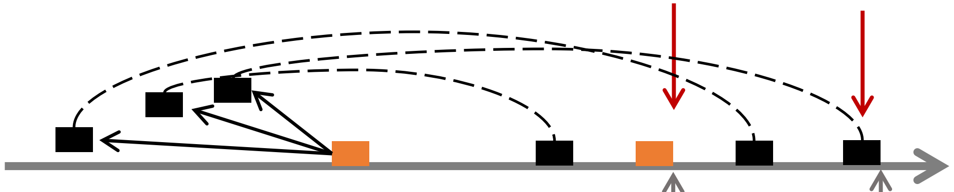

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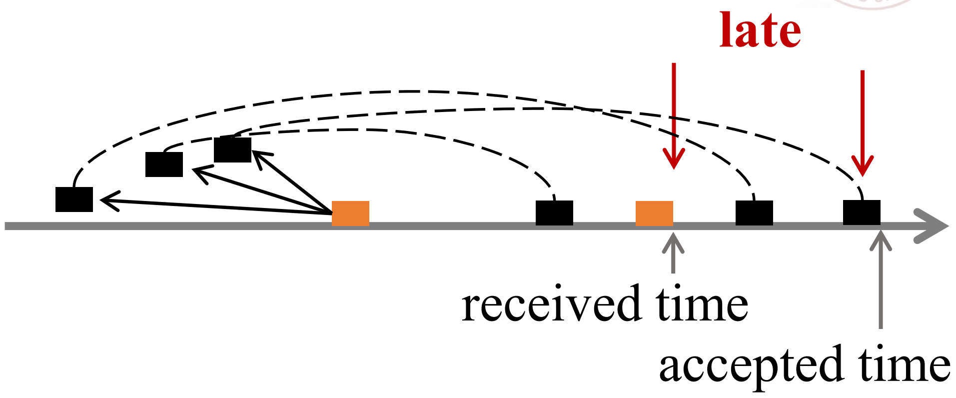

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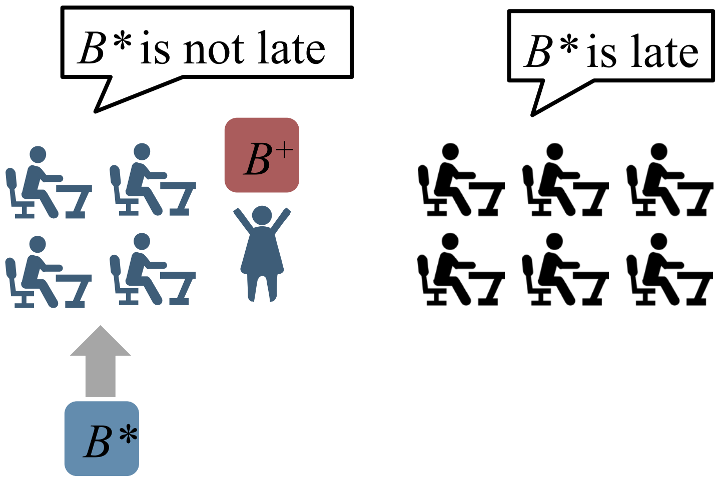
  - Max actual delay cannot be reached for all nodes



- Only the maximum actual delay is insufficient

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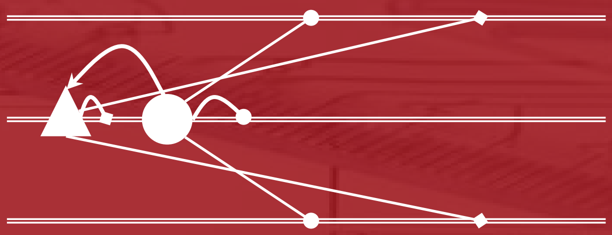

- Adversary’s capability and target
- Simple case: one predecessor
- General case: Concrete attack strategy
- Results and security analysis

Defining the attacker's utility

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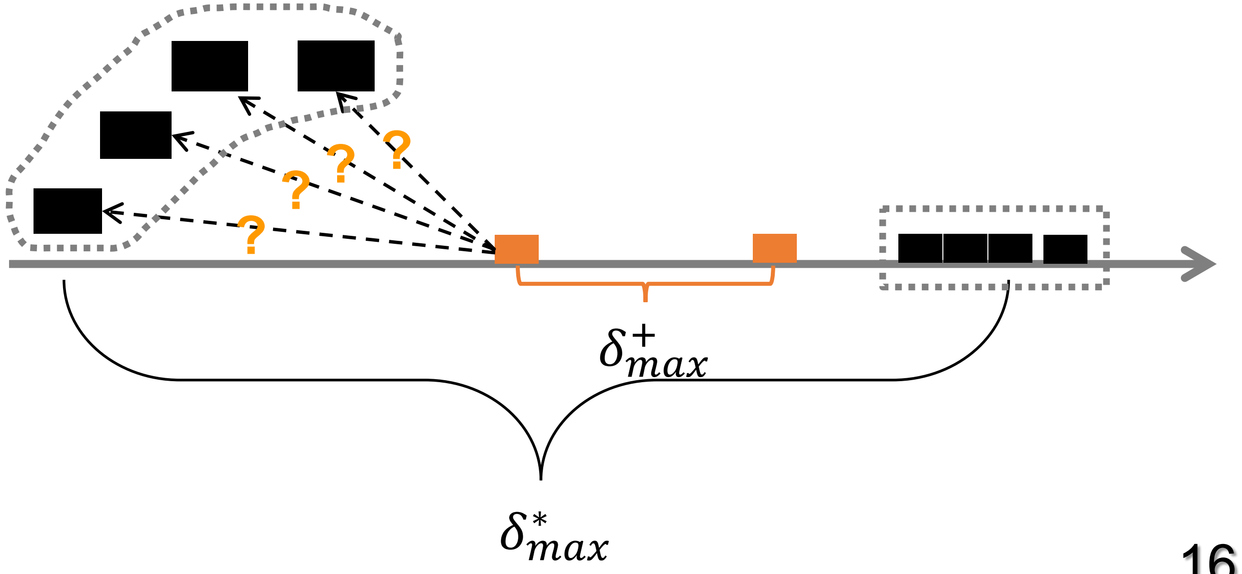

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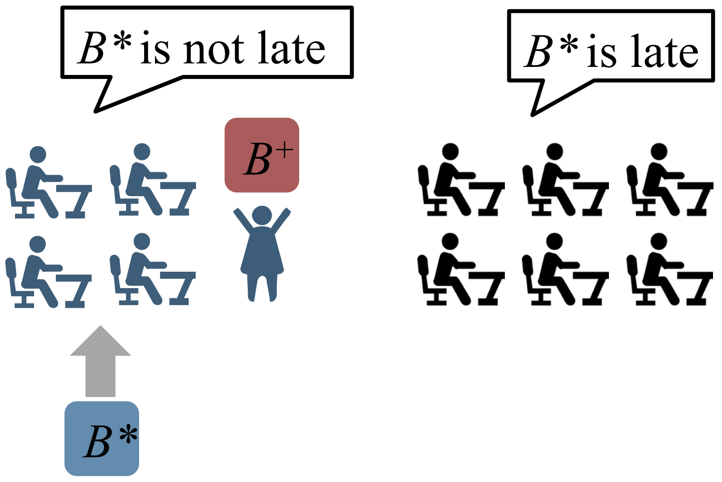

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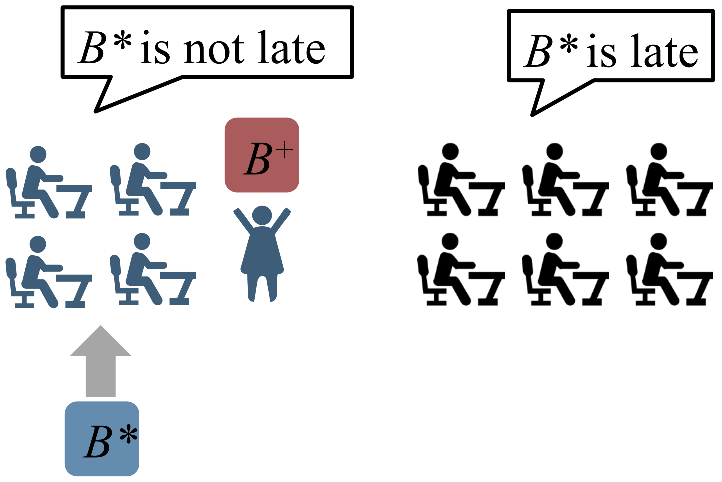
- Since block mining process is random and unpredictable, adversary maximizes the expectation.



Propagating one potential Late-predecessor

- Maximize the “damage” of one potential LP

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given B^* (mined earlier) and B^+

- the probability of $B^* \leftarrow B^+$
- the lag time of B^* and B^+ for each node

Propagating one potential Late-predecessor

- Maximize the "damage" of one potential LP

given B^* (mined earlier) and B^+

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  - some nodes (ρ%) receive B^* before B^+ is mined
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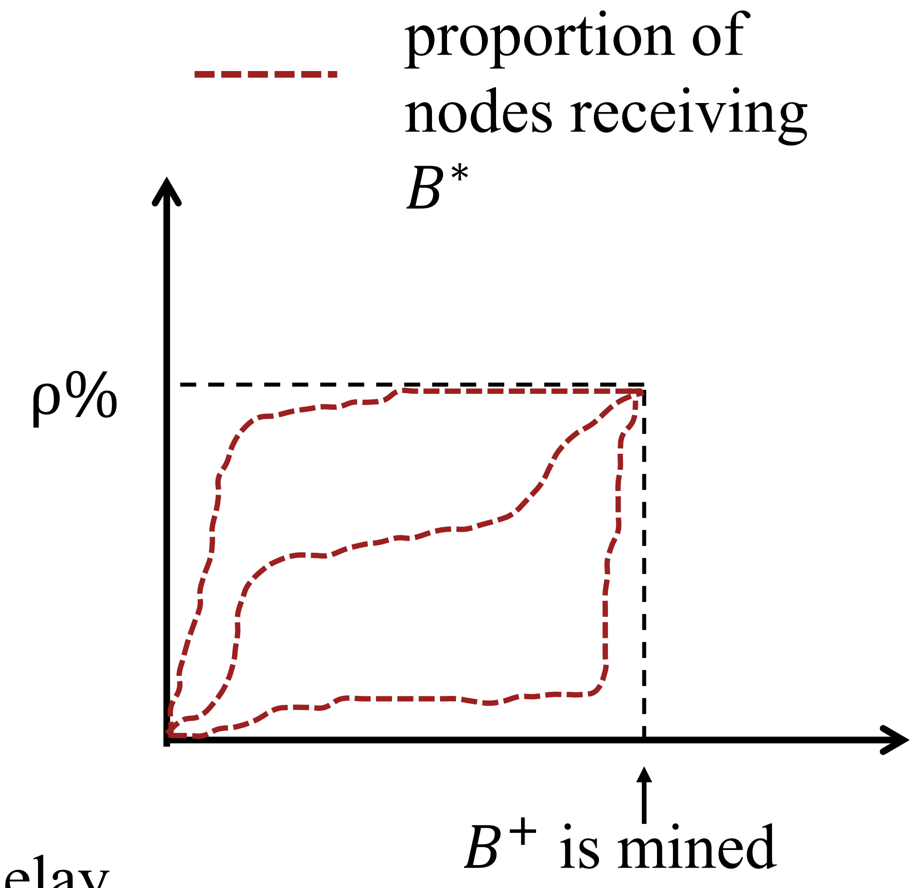

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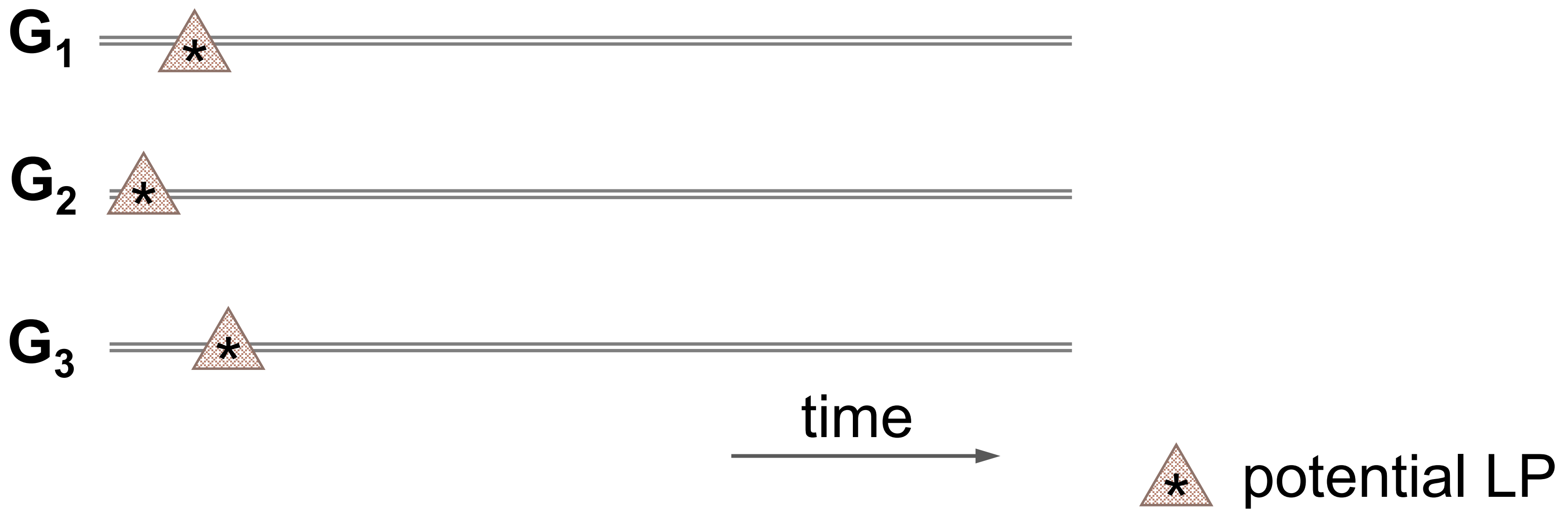

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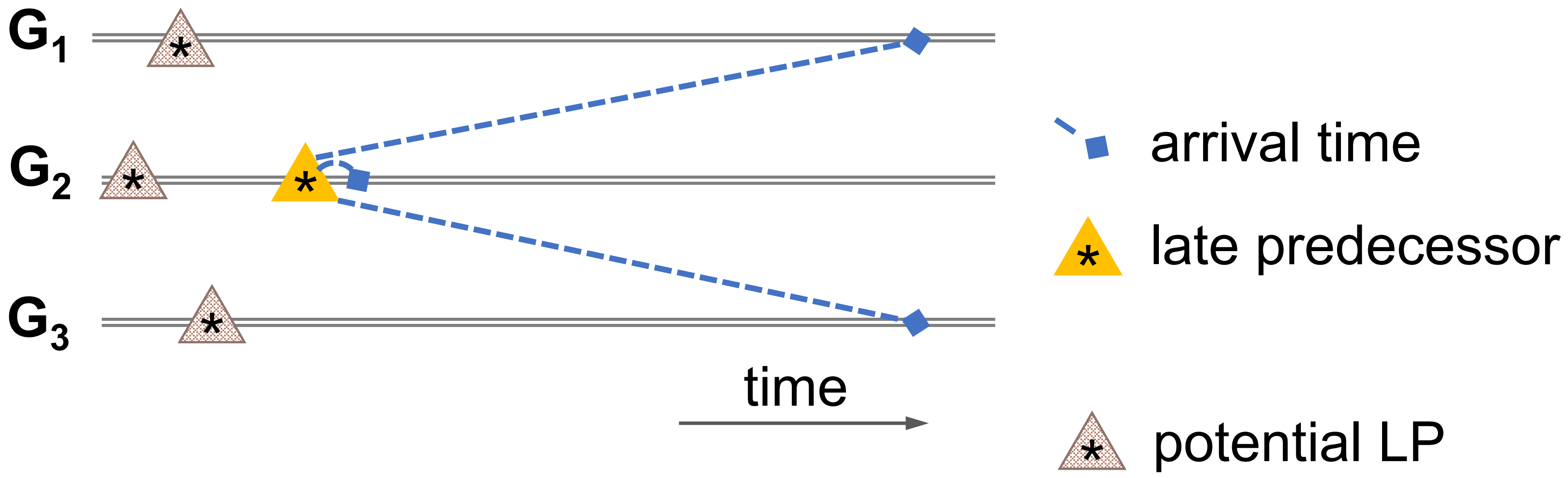

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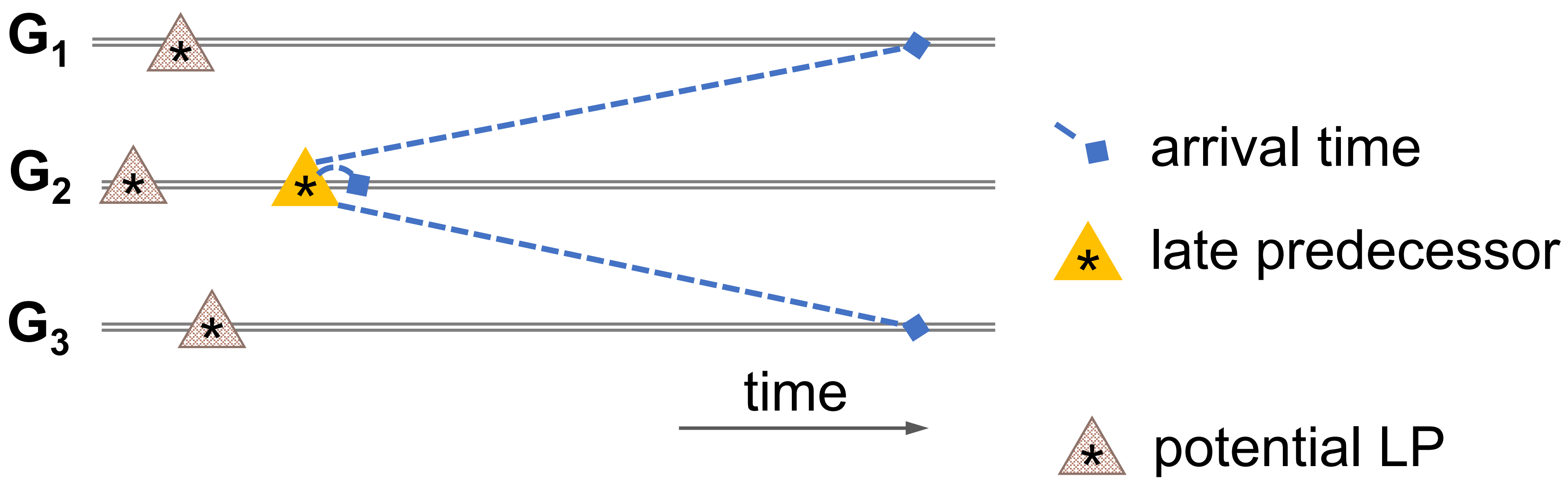

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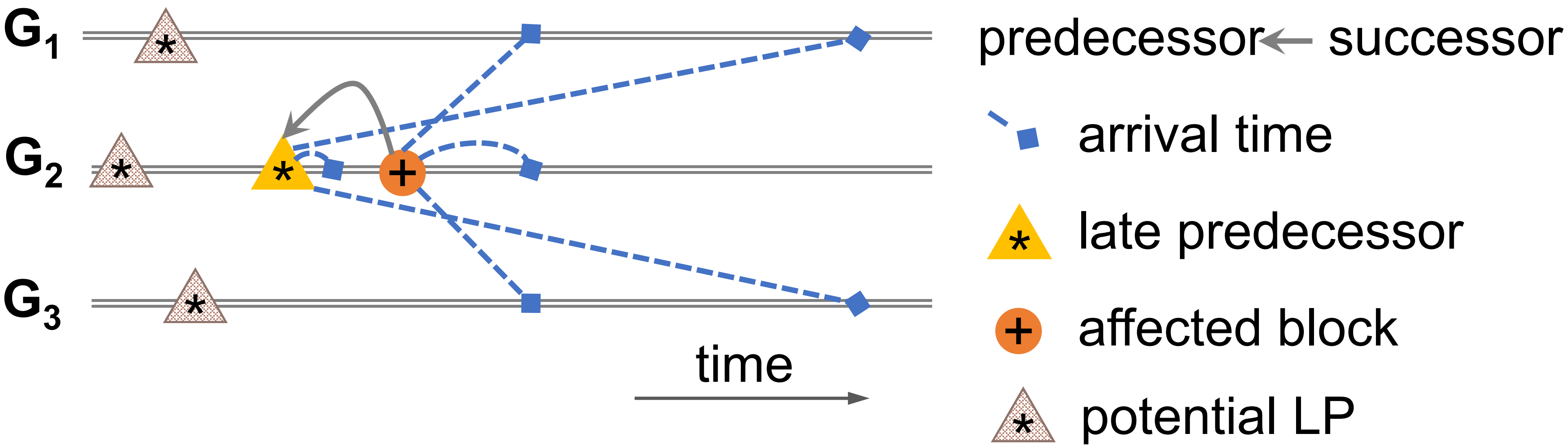

Attack Results

- Optimal ***s***

TABLE I: The optimal s that maximizes $\mathbb{E}[\Delta^+]$, where k is the expected number of in-propagation blocks in $\mathcal{B}^*$ in a round.

k	(0.5,2.53)	[2.54,9.81)	[9.82,18.64)	[18.65,20]
s	2	3	4	5

- Computing the result

$$\boxed{\mathbb{E}[\overline{\Delta}^+] = \delta^+_{\max} + (1 - 1/s)(k - s(1-\omega))f^*}$$

$$k = f^* \cdot (\delta^*_{\max} - \delta^+_{\max}) \qquad \omega = (1 - f^*/s)^{\delta^*_{\max} - \delta^+_{\max}}$$

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- longer propagation delay of LP
- higher generation rate of LP

⊳ longer actual delays

Security Properties in the Presence of an LP Attacker

- As nodes have different delays for the same late predecessor, we cannot replace the delay in existing UDBM analyses.

- Chain growth
  - using average actual delay to compute discounted computing power

- Chain quality
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- Common prefix
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higher average actual delay
leads to
lower security level

1. NC & DAG

2. New Model

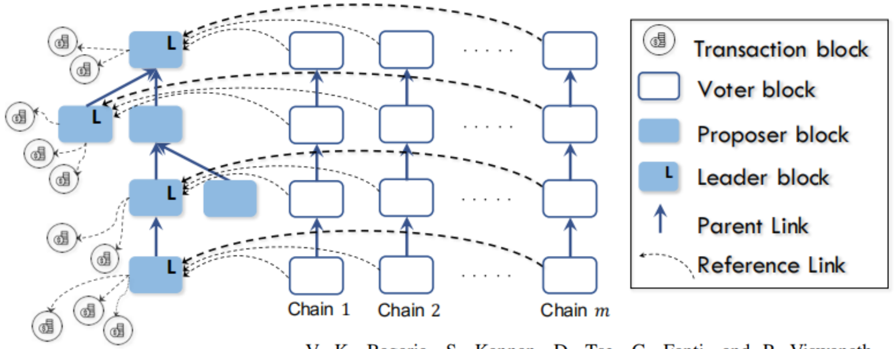
3. LP Attack

4. Examples & Simulation

- Prism’s security-performance trade-off
- OHIE’s security-performance trade-off
- Simulation of Prism and OHIE

Prism's security-performance trade-off

- Original paper of Prism claims that
  - changing the parameters of transaction blocks (size and rate) doesn't affect the security



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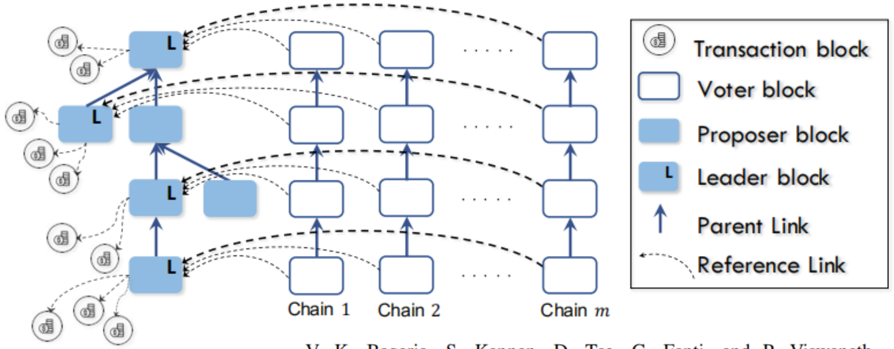

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  - delay of proposer blocks is related to tx block's
    - propagation delay
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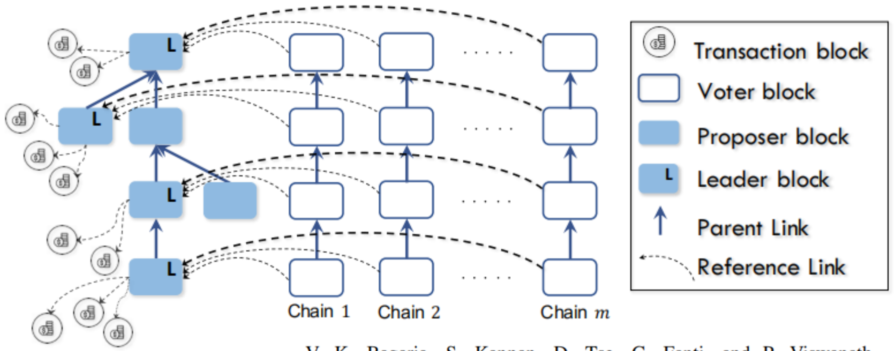

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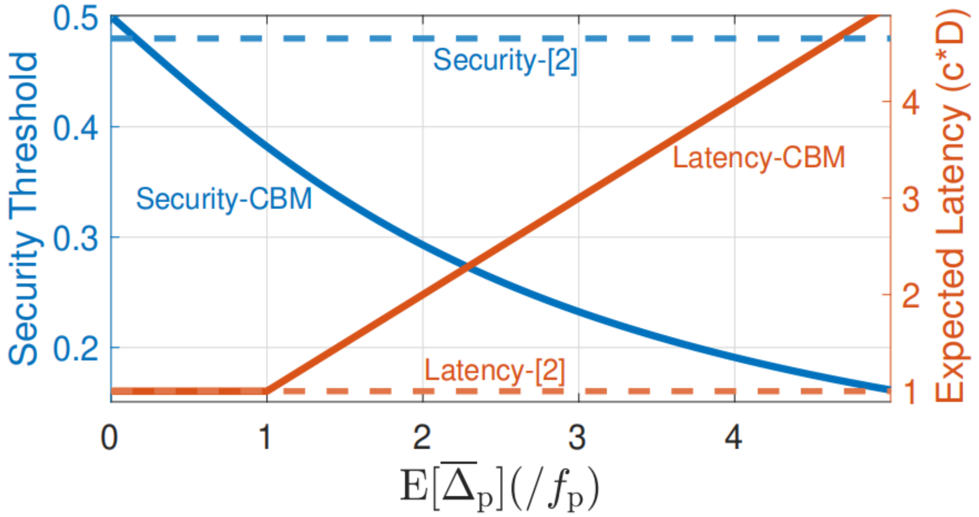
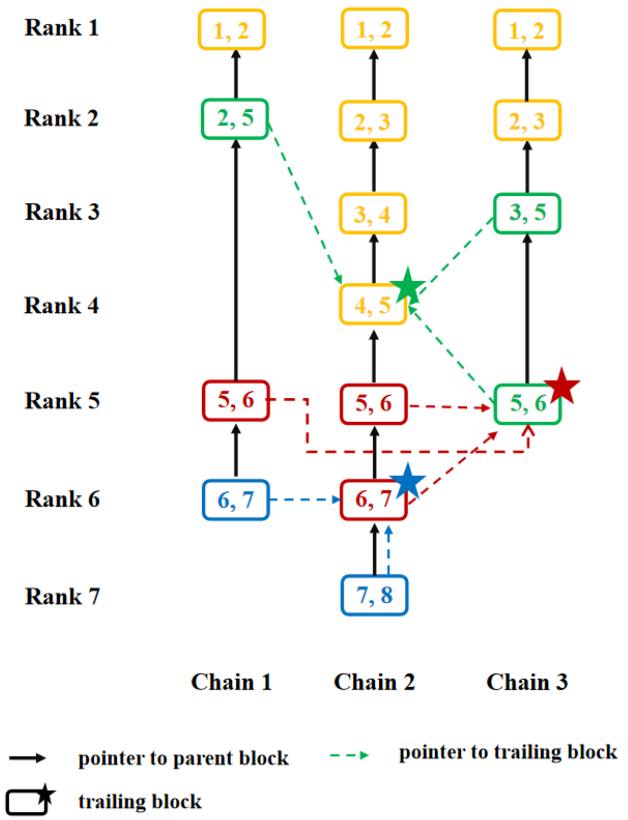


- Security-performance trade-off in Prism still exists
  - throughput ↑ security ↓ latency ↑

OHIE's security-performance trade-off

- OHIE's performance relies on the short and stable block propagation delay.
  - More than 50% of the network capacity

    → propagation delay increases



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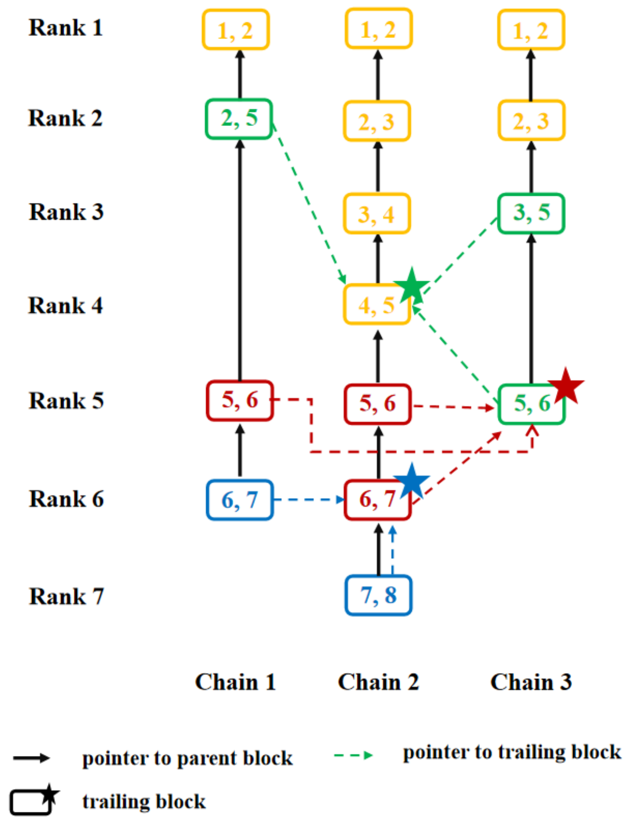

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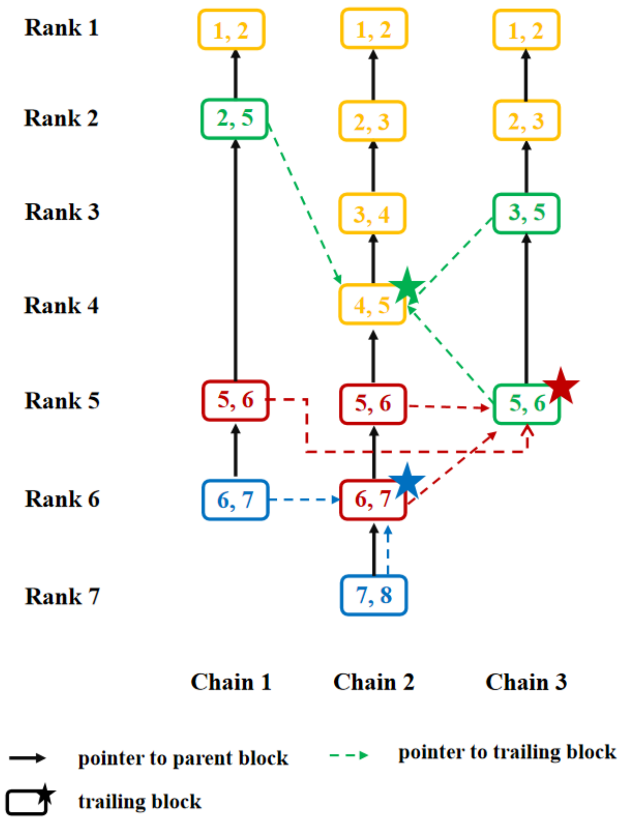
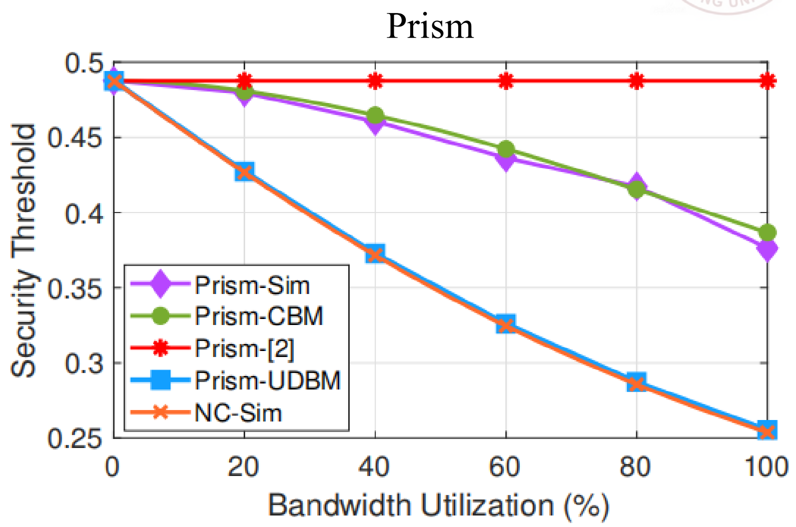
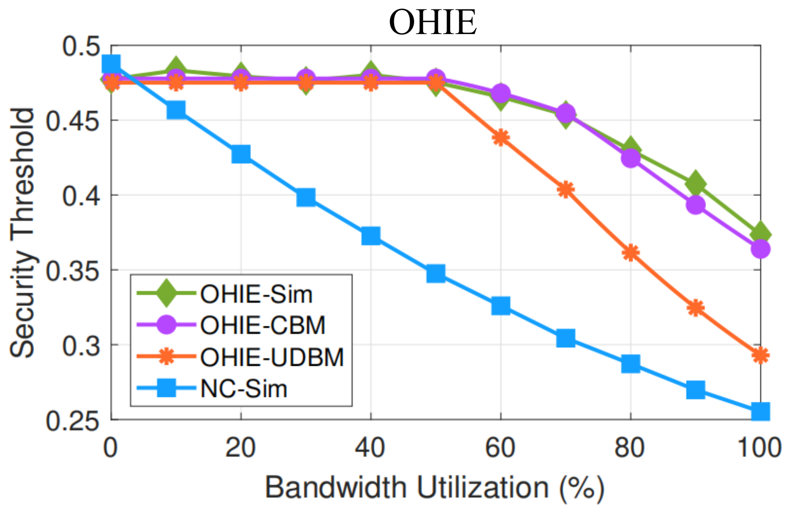
  - actual delay of all blocks increases
- Security is lower when increasing throughput of OHIE by
  - increasing the block size
  - increasing the number of parallel chains (more frequent trailing blocks)



Simulation

- We modify SimBlock by adding 1000 LoC to evaluate Prism's and OHIE
- Results





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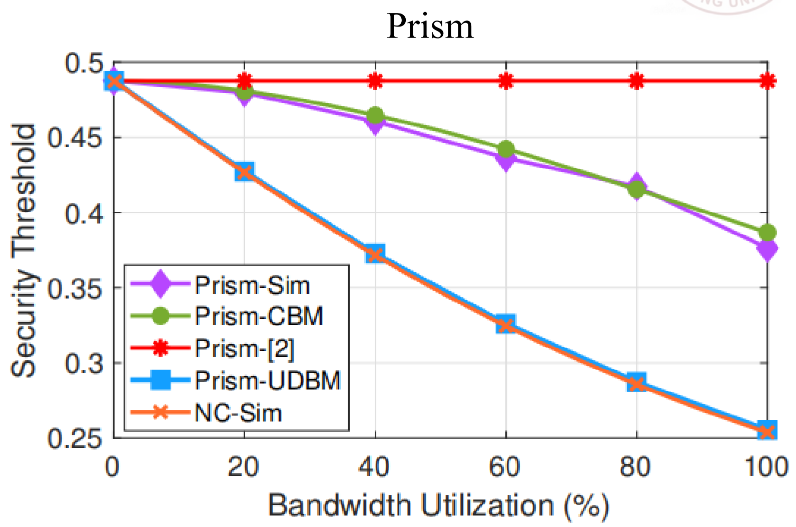

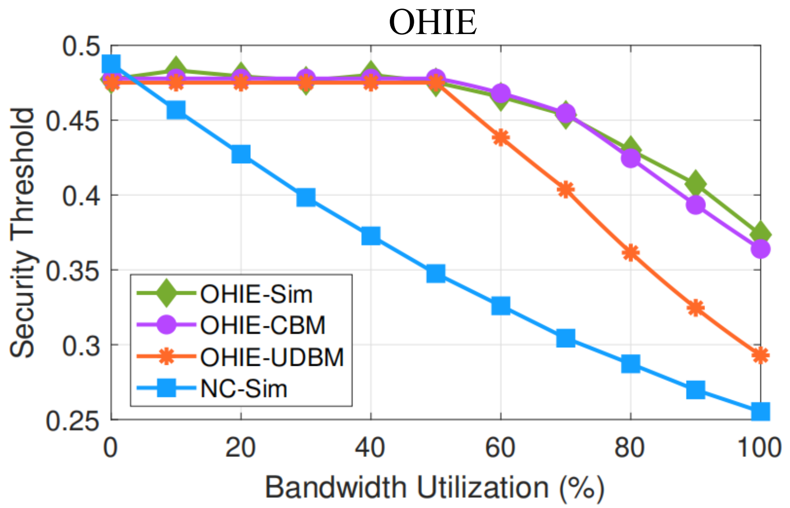

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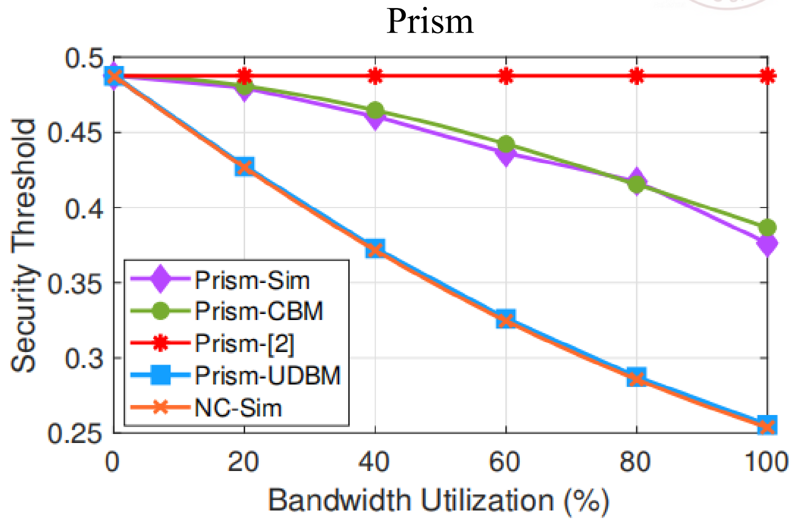

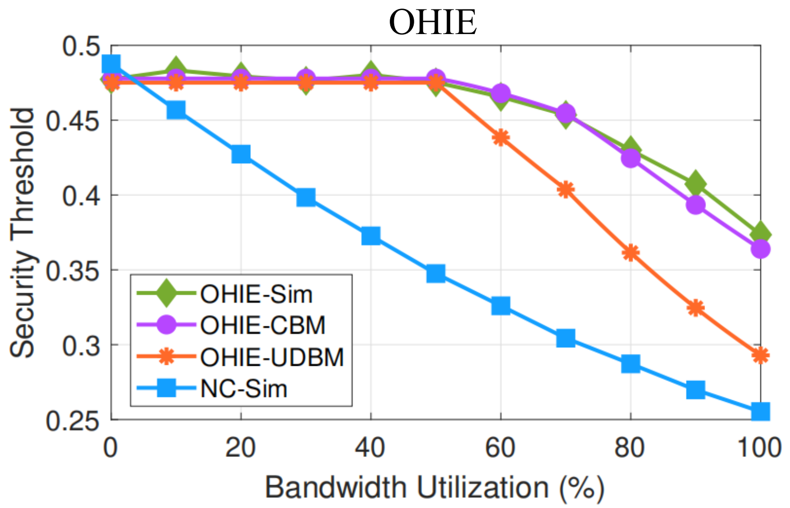

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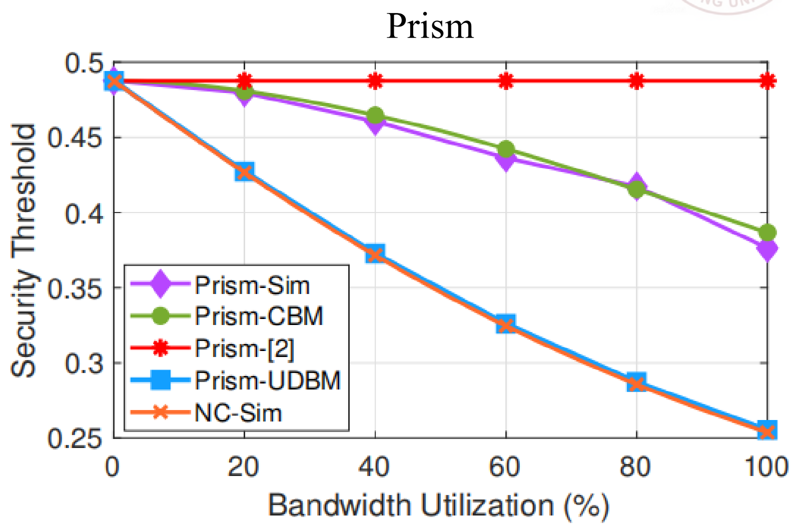
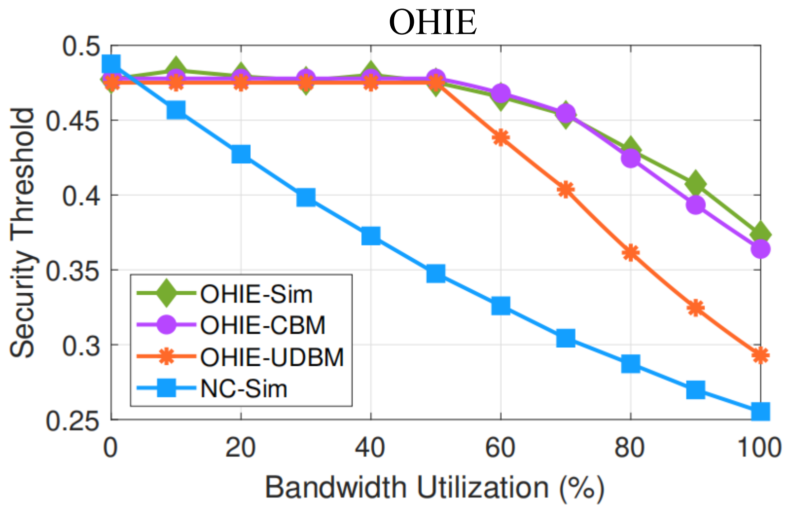
- Existing DAG-based protocols still have not overcome the trade-off between security and performance





5

Conclusion & Future works

Our works:

- identified vulnerabilities in previous works
- proposed a new model called CBM
- presented a sound attack strategy
- exemplified analysis on Prism and OHIE.

5

Conclusion & Future works

- Future works:
  - Generalizability of CBM
  - Practicality and Optimality of Our Attack
  - Generalizability of the Tradeoff
  - Improving DAG-based Protocols

Thank you!

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