Towards Building Secure and Efficient Decentralized Systems

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EECS, Syracuse University

Towards Building Secure & Efficient **Decentralized Systems**

Modern infrastructures evolves to be more open and decentralized.

- Financial ledgers: blockchains
- Web infrastructures: transparency logs
- Cloud computing: decentralized storage

Towards Building Secure & Efficient **Decentralized Systems**

Intention of decentralization & open-membership designs:

- Trustworthy & more accountable

Towards Building **Secure** & Efficient Decentralized Systems

But two consequences of decentralized & open systems:

- Larger attack surface …

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How to understand & harden security?

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But two consequences of decentralized & open systems:

- Larger attack surface …

How to understand & harden security?

- Higher unit cost for basic operations …

How to optimize the application cost?

Example Projects Presented in this Talk

- How to understand & harden the security in emerging large-scale systems?
  - Securing blockchains under DoS vectors (CCS'21, NDSS'21, IMC'21)
- How to analyze & optimize perf./costs in security-centric large-scale systems?
  - Cost-optimizing DApps without losing security (FSE'21, Middleware'20, ICDE'19)

Talk Outline

Theme 1: Securing blockchains under DoS vectors

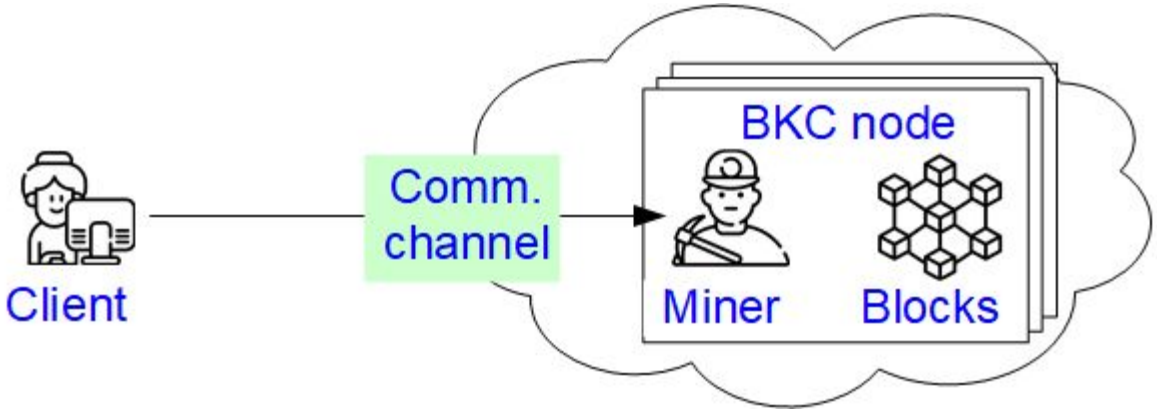
- RQ1: DoS security on TxRelay (published in NDSS'21)
- RQ2: DoS security on Tx propagation (ACM IMC'21)
- RQ3: DoS security on Mempool (ACM CCS'21)

Theme 2: Optimizing the DApp cost without losing security

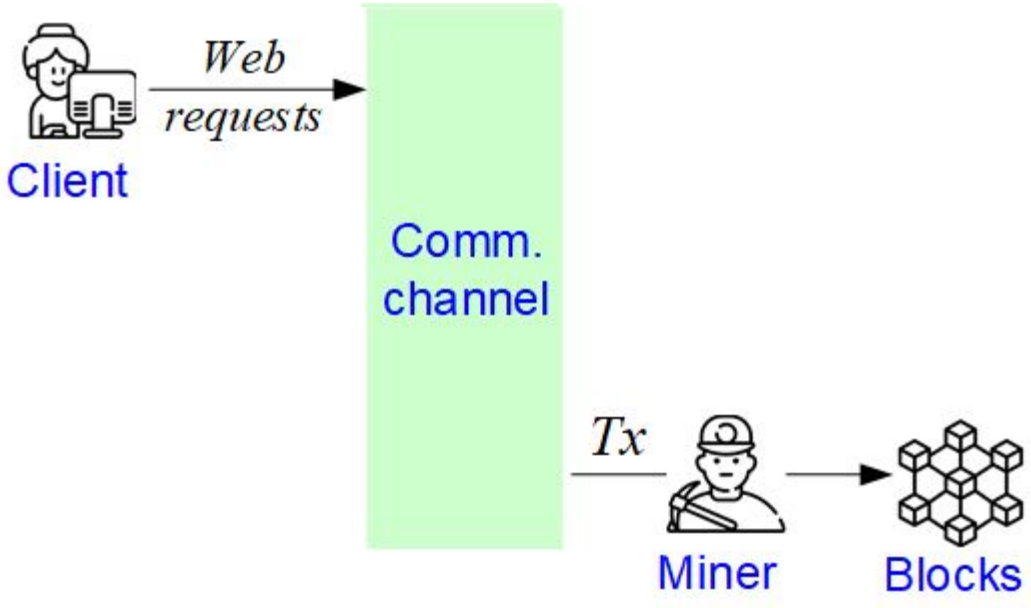
Overview of Other Research Themes

Future Research Directions

Blockchain Security under DoS



Blockchain Security under DoS



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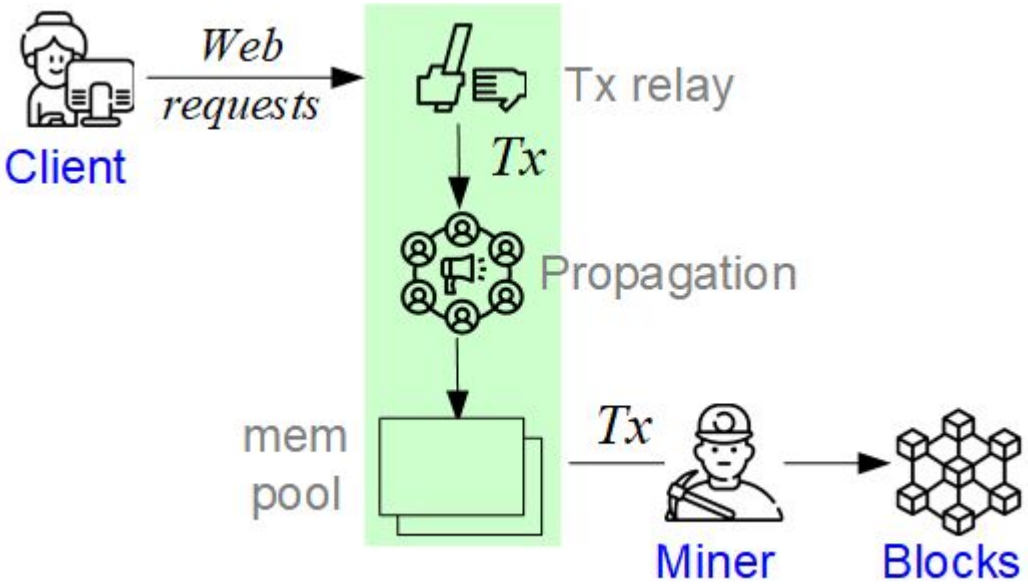

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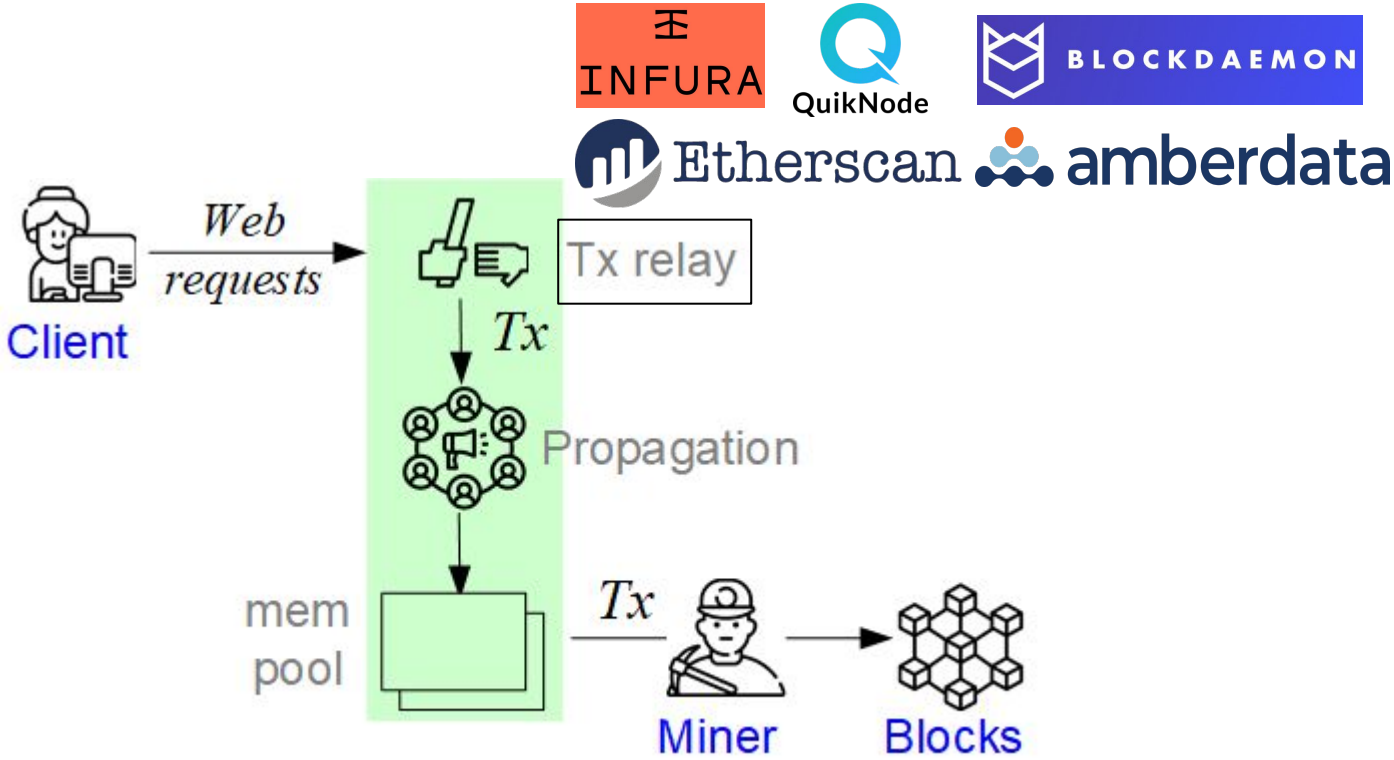

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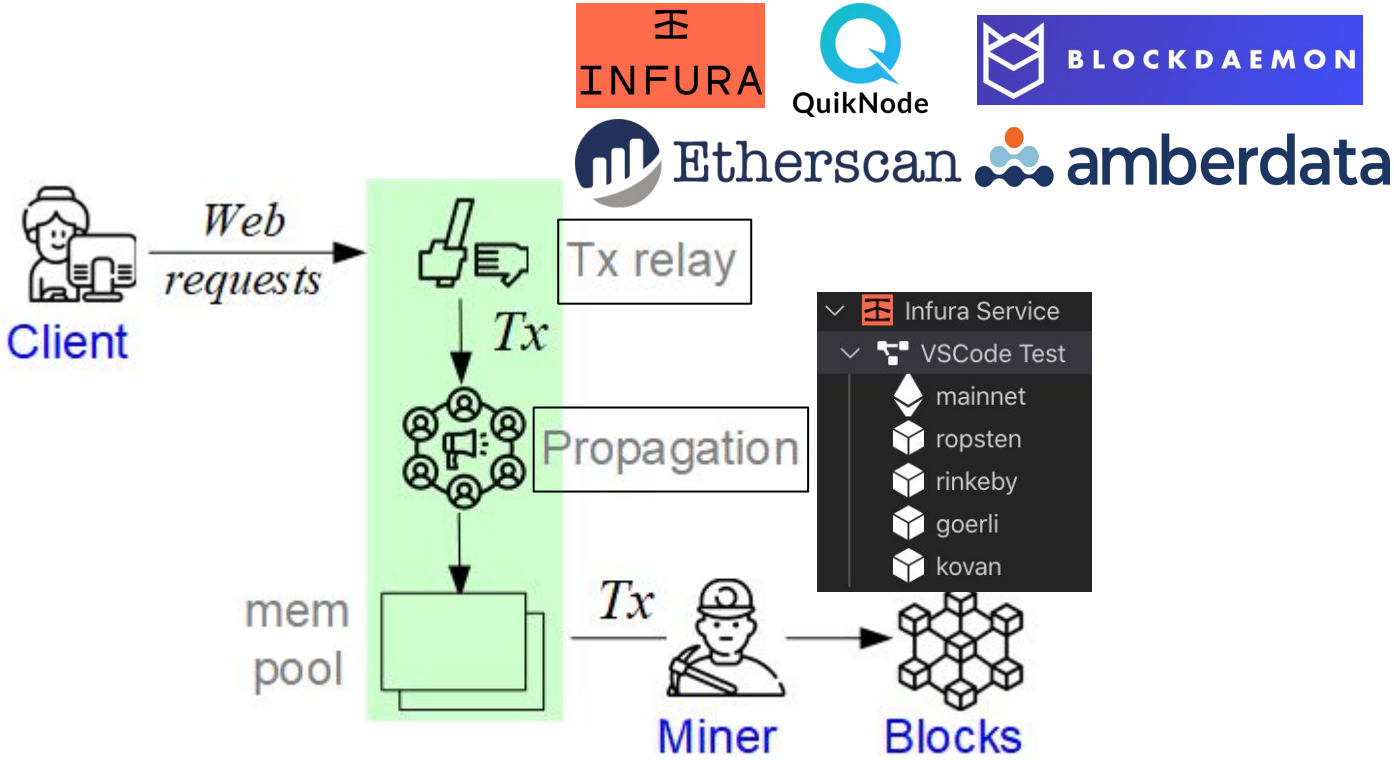

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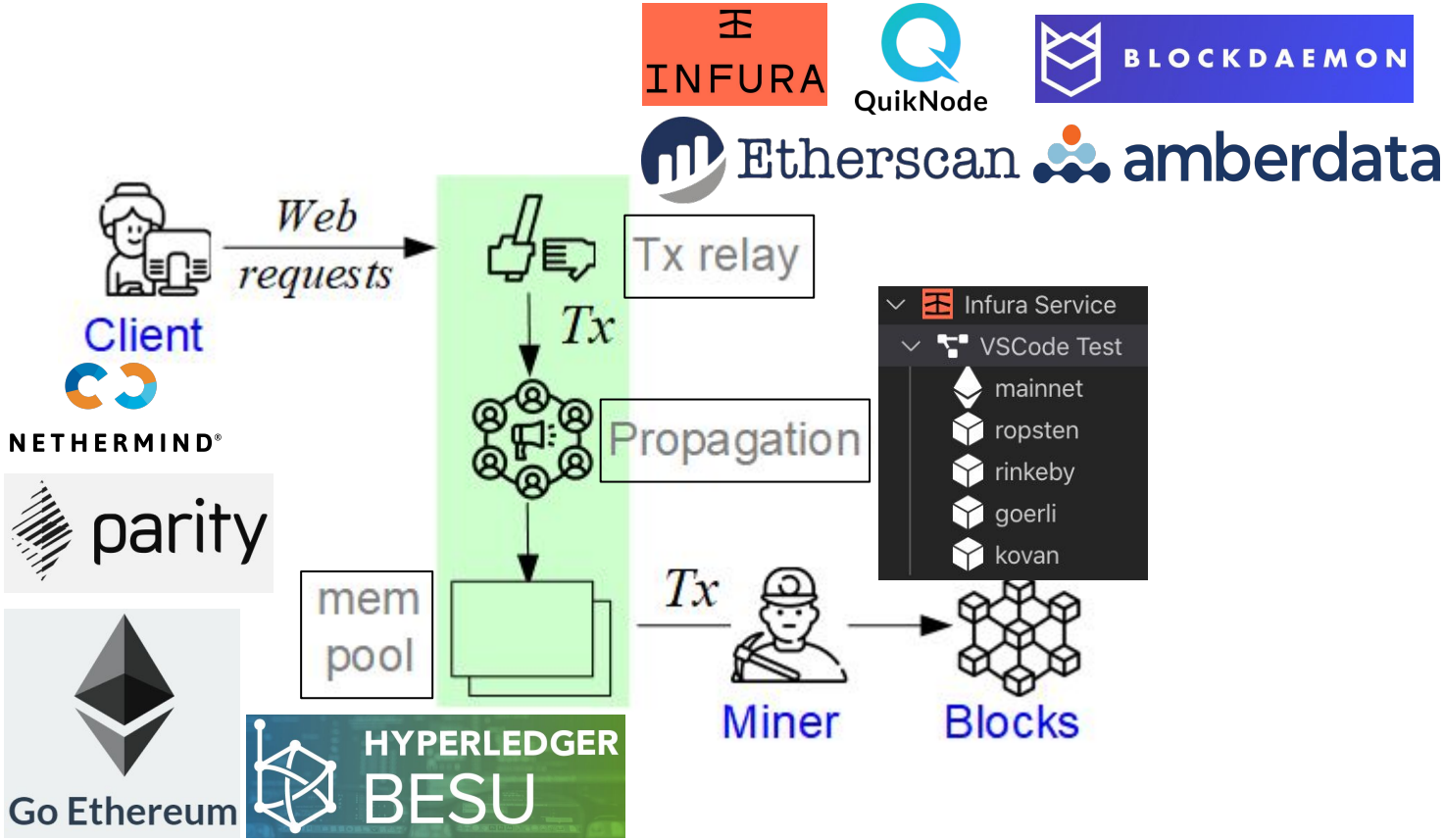

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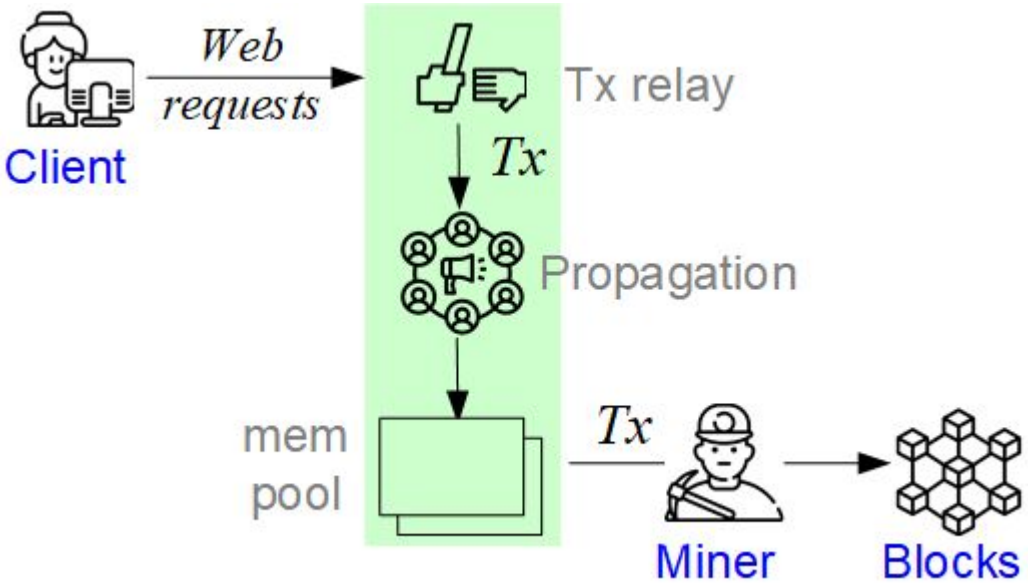

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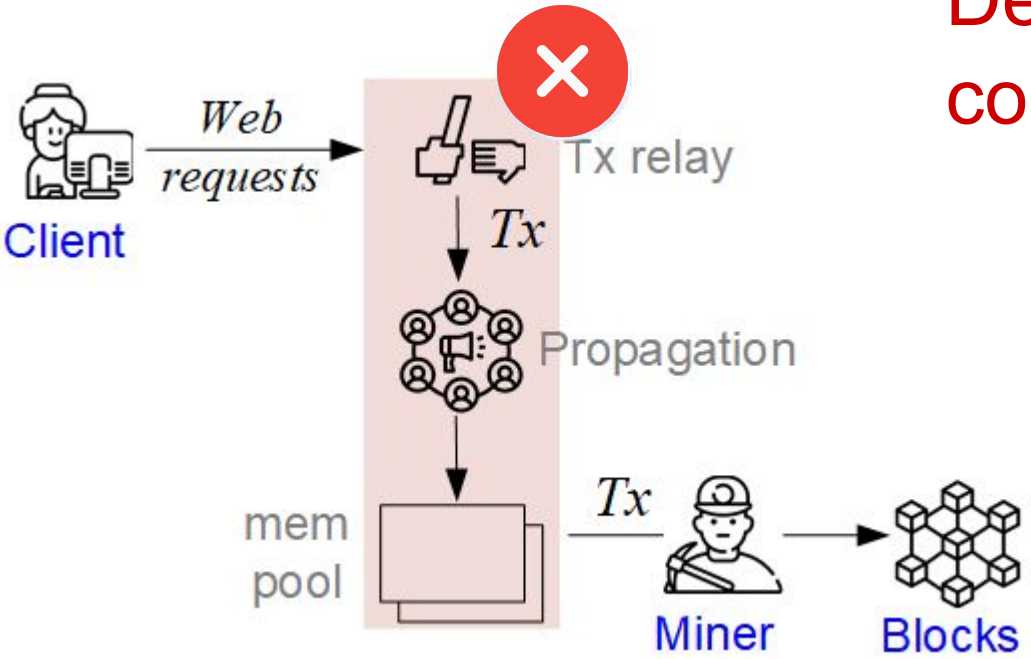
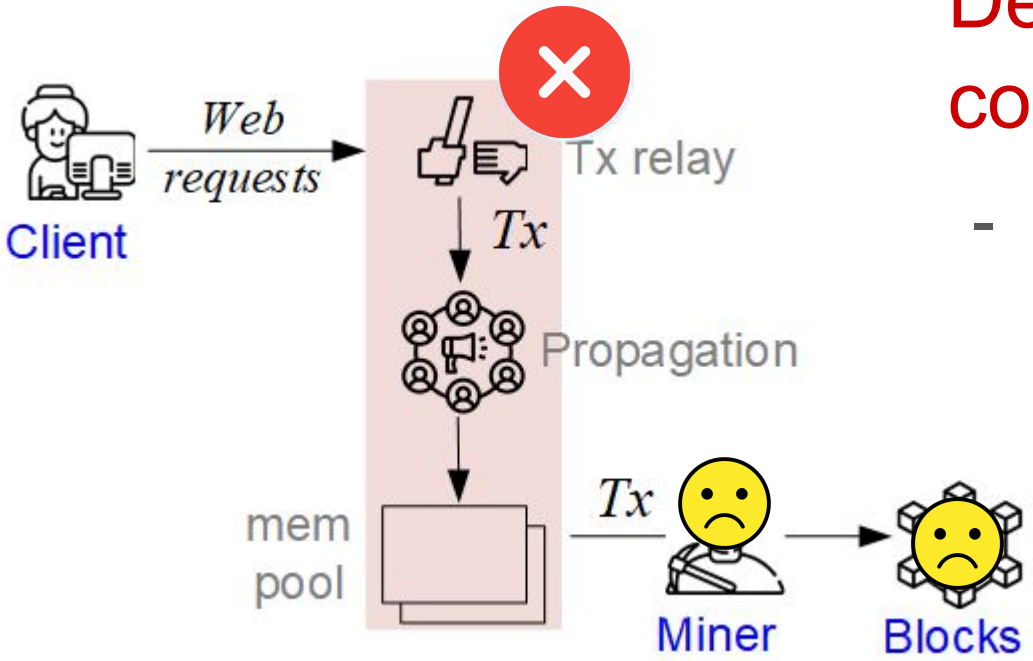


Denial of Blockchain comm. channel service?

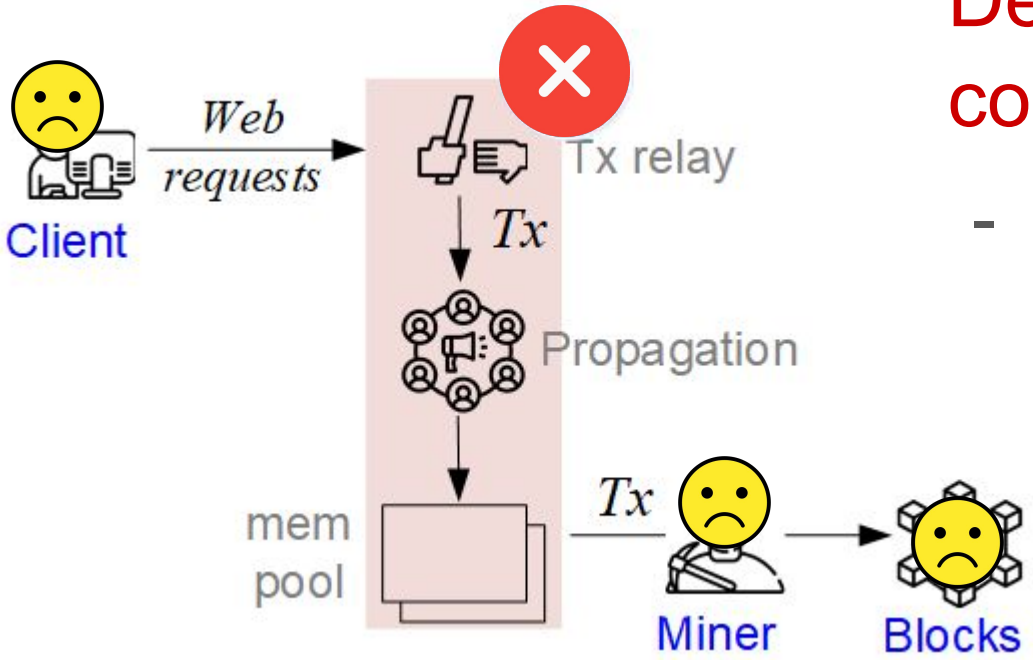
Blockchain Security under DoS



Denial of Blockchain comm. channel service?

- Miner unable to include txs; empty blocks.
  - low revenue, lose miners, 51% attacks

Blockchain Security under DoS



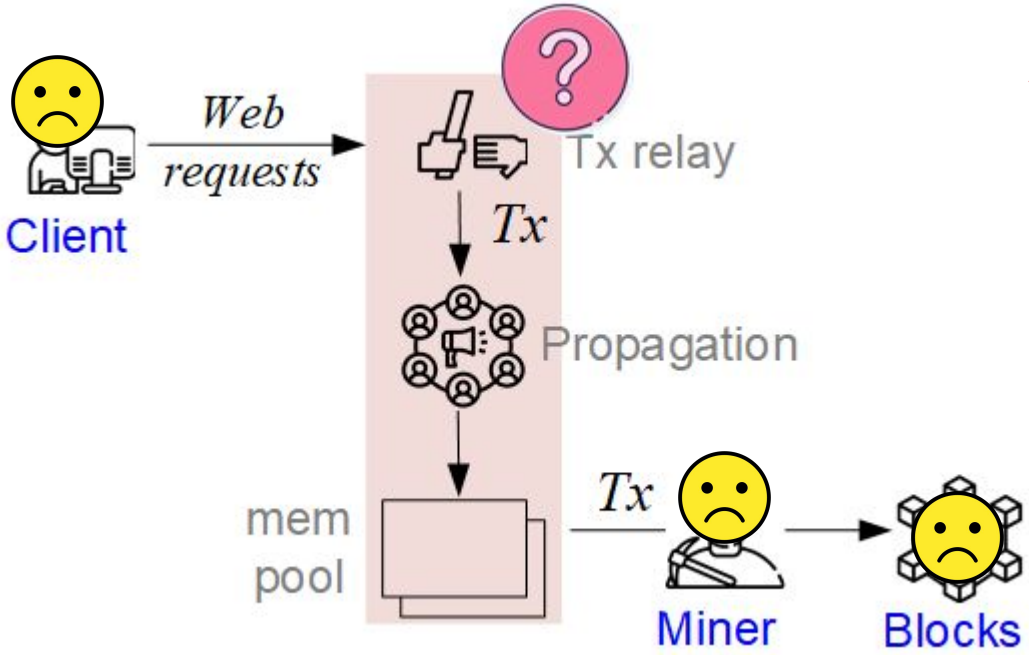
Denial of Blockchain comm. channel service?

- Miner unable to include txs; empty blocks.
  - low revenue, lose miners, 51% attacks

Clients cannot send txs.

- Frontrunning, lose clients

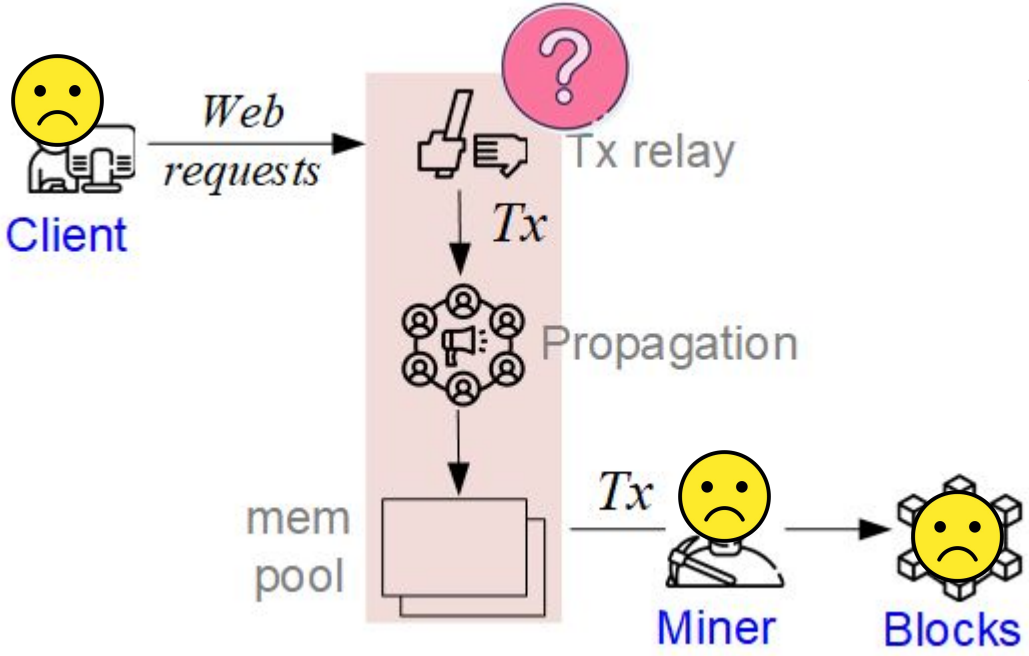
Blockchain Security under DoS



Research statement:

Whether & how resilient are Ethereum blockchains against denial of comm. channel service?

Blockchain Security under DoS

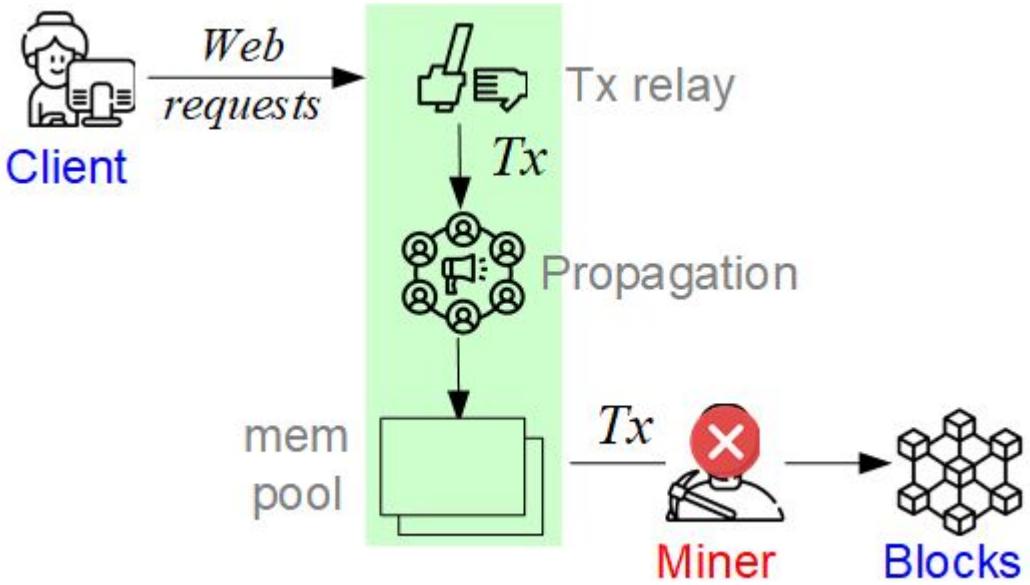


Research statement:

Whether & how resilient are Ethereum blockchains against denial of comm. channel service?

Rank	Name	Symbol	Market Cap	Price
1	Bitcoin	BTC	$1,027,956,378,947	$54,567.67
2	Ethereum	ETH	$428,418,048,937	$3,635.44

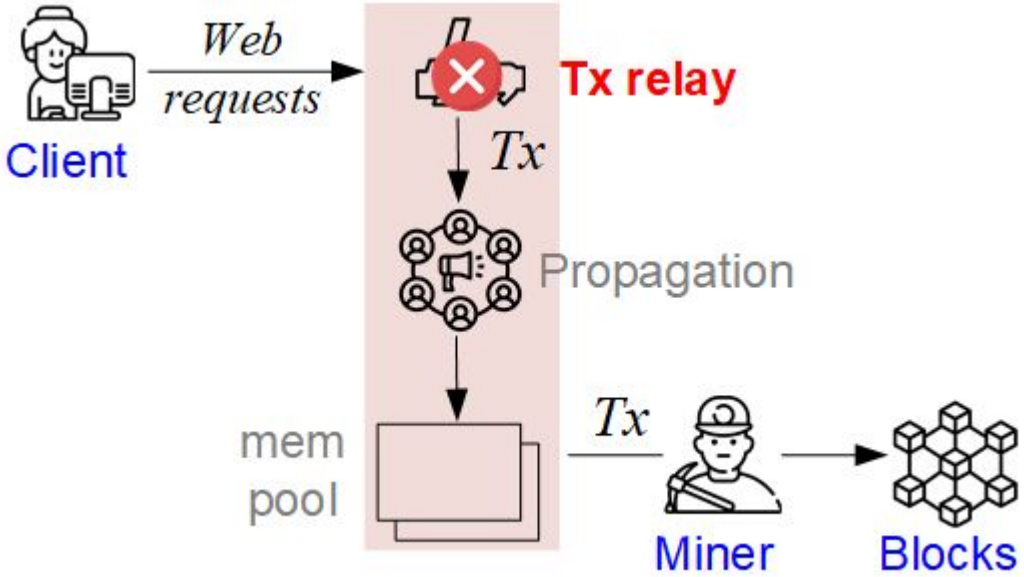
Blockchain Security under DoS: Related Works



Existing works

- BDoS (CCS'20), selfish mining (FC'14), 51% attacks
- Smart-contract DoS (NDSS'20), Bribery (SP'21)

RQ1. Blockchain Security under DoS Tx Relay



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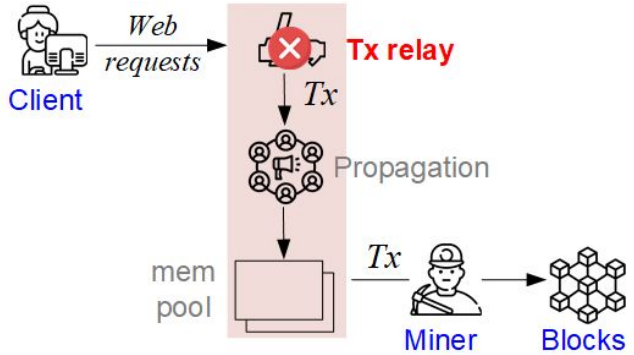
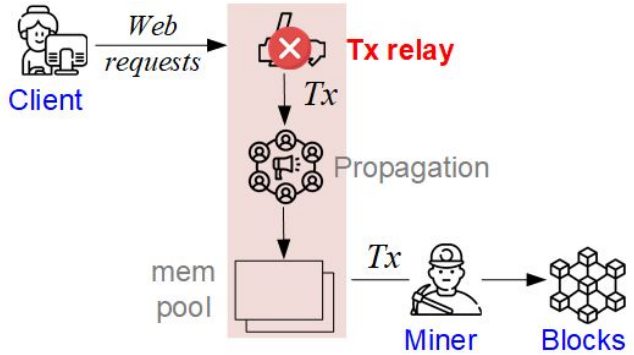


Formulated problem:

- Observe a vulnerable relay API (eth_call)
- If exposed, straightforward DoS exploiting eth_call



RQ1. Security under DoS Tx Relay

Formulated problem:

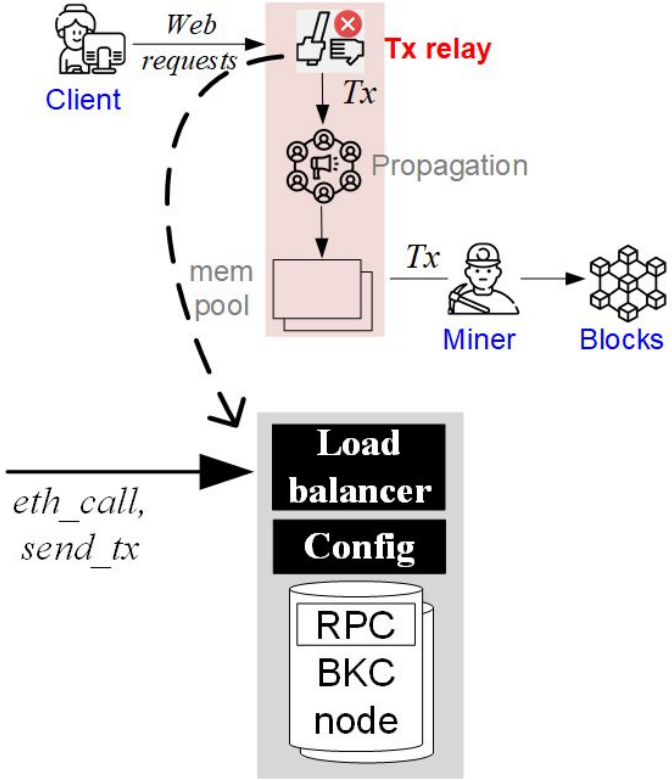
- Observe a vulnerable relay API (eth_call)
- If exposed, straightforward DoS exploiting eth_call

RQ1 (Exploitability measurement): Under the DoS exploiting the vulnerable API, how exploitable are real-world blackbox relay services are?

RQ1. Security under DoS Tx Relay

Proposed method (intuition)

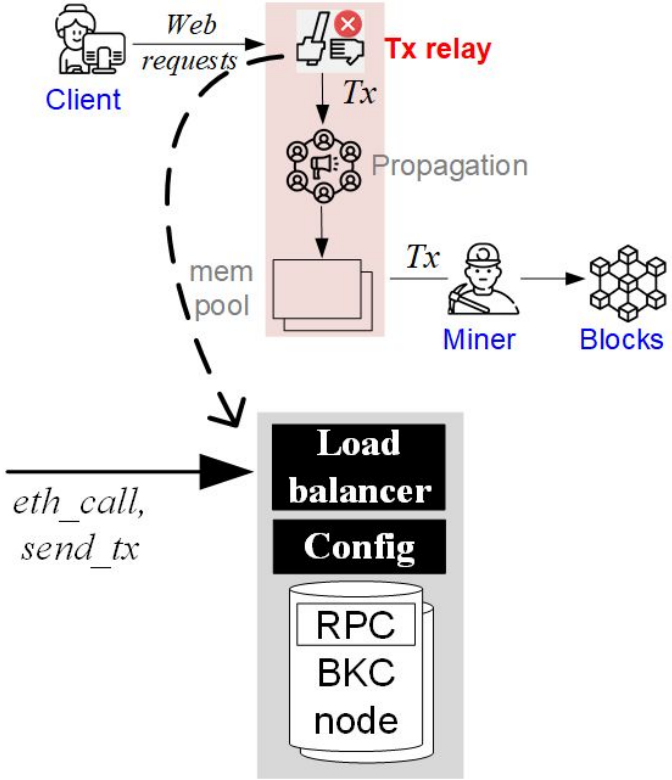
- Detect presence of load balancing inside tx relay services.



RQ1. Security under DoS Tx Relay

Proposed method (intuition)

- Detect presence of load balancing inside tx relay services.
- Send two double-spending txs to a RPC service & observe if both requests succeed.
  - Both requests succeed ⇒ load balancing detected.
  - One request fail ⇒ No load balancing detected.



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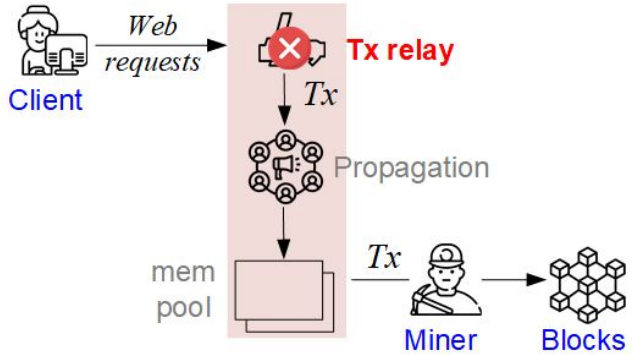
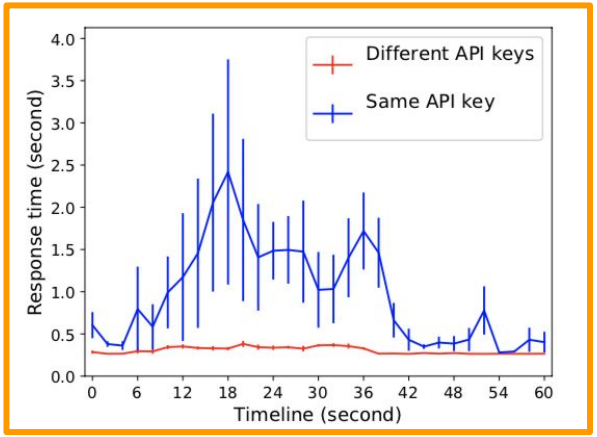


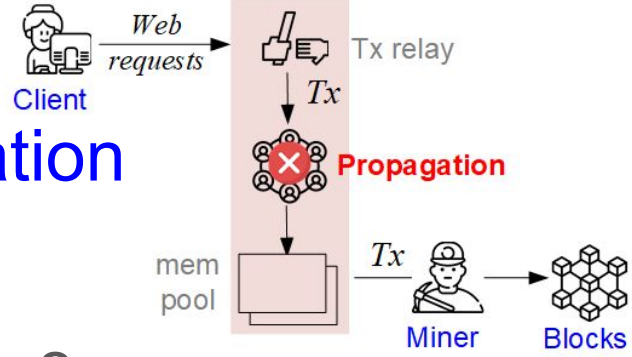
Results: on mainnet services

Type	RPC services	1IP-1key (LB0)	1IP-2key (LB1)	2IP-1key (LB2)	Gas limit
i	ServiceX1	✗	✗	✗	✗
	ServiceX2	✗	✗	✗	✗
	ServiceX3	✗	✗	✗	50
ii	ServiceX4	✗	✓	✗	✗
	ServiceX5	✗	✗	✓	✗
iii	ServiceX6	✓	✓	✓	10
	ServiceX7	✓	✓	✓	✗
	ServiceX9	✓	✓	✓	5
	ServiceX8	✓	✓	✓	1.5



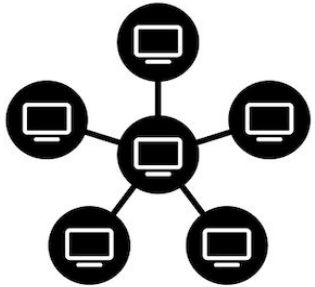
Publication: NDSS 2021

"As Strong As the Weakest Link: How to Break and Fix Blockchain DApps at RPC Service?"
Kai Li, Jiaqi Chen, Xianghong Liu, Yuzhe Tang, XiaoFeng Wang, Xiapu Luo.

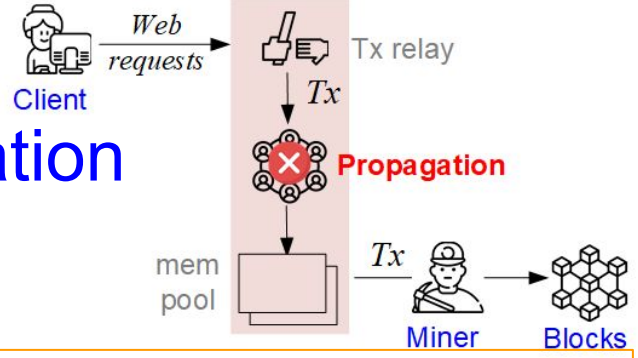


RQ2. Security under DoS Tx Propagation

Motivation: How resilient is Ethereum's Tx Propagation under single-point-of-failure?



- Single-point-of-failure by existing single-node attacks (e.g., eclipse attacks, DoERS, DETER)

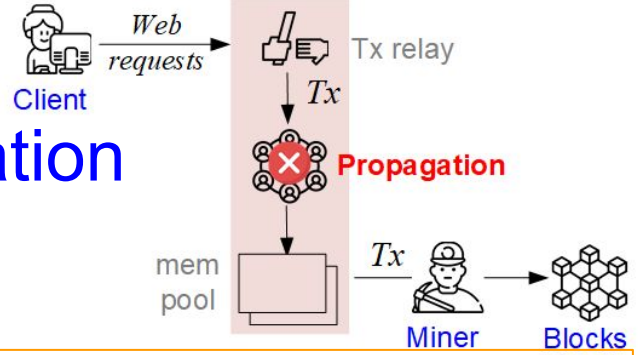


RQ2. Security under DoS Tx Propagation

Formulated problem:

RQ2 (Network measurement): What's Ethereum's network topology?

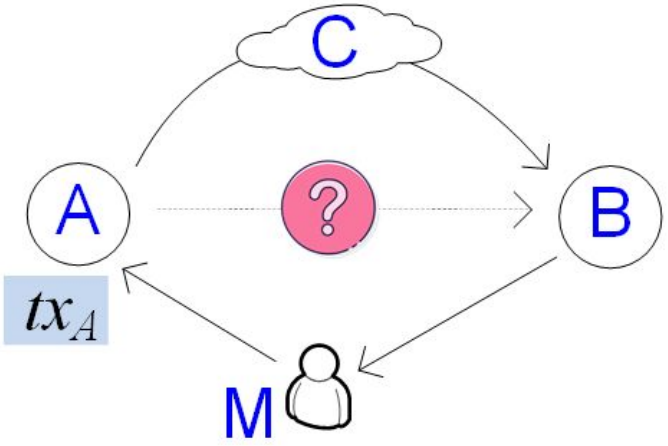
Related works	Blockchain	Measurement Target
[Neudecker et al. TR'18]	Bitcoin	Nodes
*[Miller et al. TR'**15**], [IEEE ATC'16], TxProbe [FC'19]*	Bitcoin	Edges
[FC'20]	Monero	Edges
[IMC'18], [FC'21]	Ethereum	Nodes
?	**Ethereum**	**Edges**

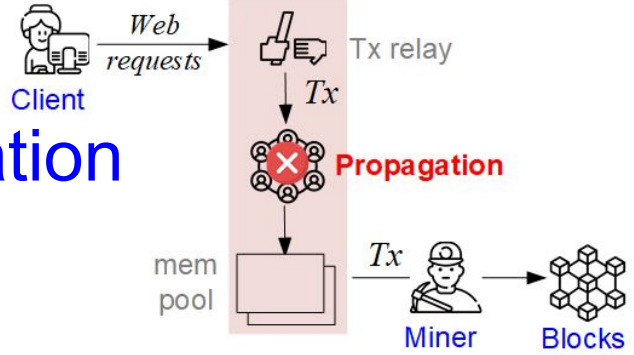


RQ2. Security under DoS Tx Propagation

Formulated problem:

RQ2 (Network measurement):
How to measure if remote Ethereum nodes (A & B) are connected?

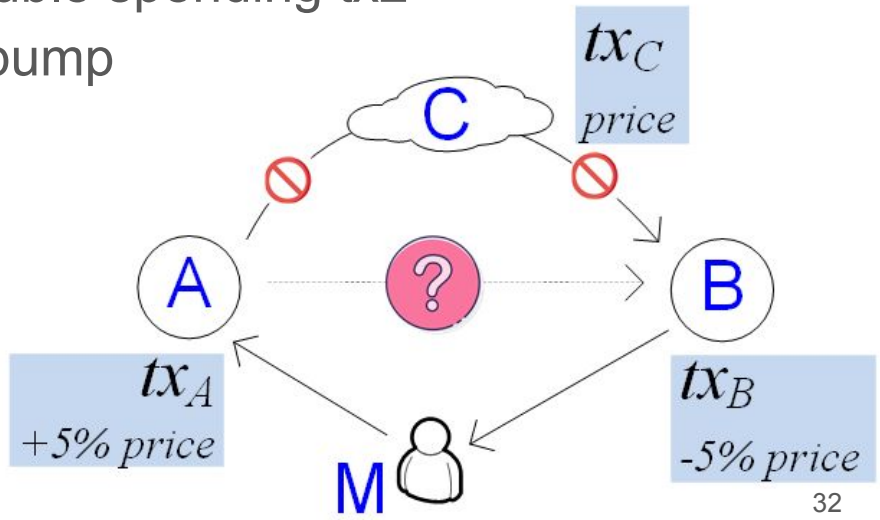


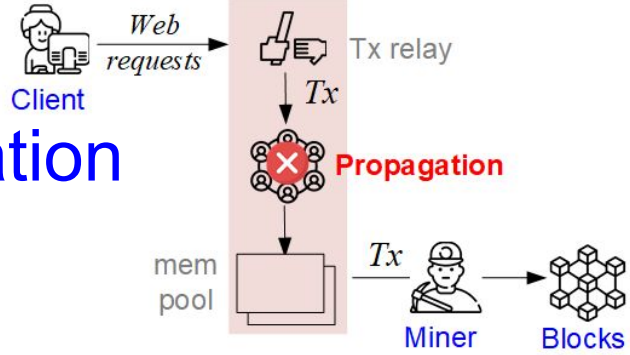


RQ2. Security under DoS Tx Propagation

Proposed method (intuition)

- Preliminary: tx replacement policies
  - Old tx1 replaced by a newer, double spending tx2 if tx2 has sufficient (10%) price bump
- Key insight:
  - Price bump & future txs to enforce isolation.

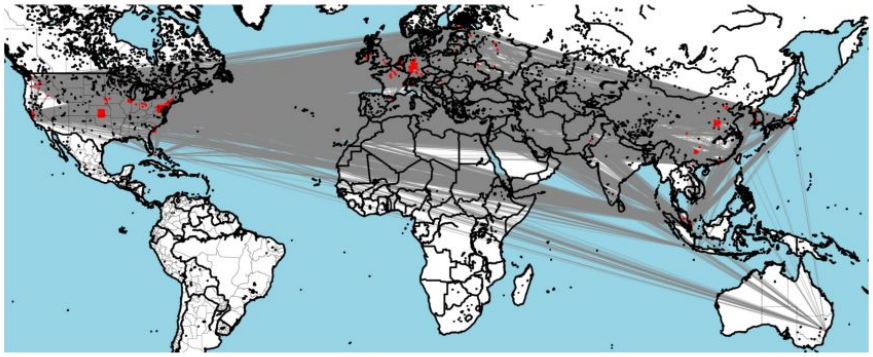




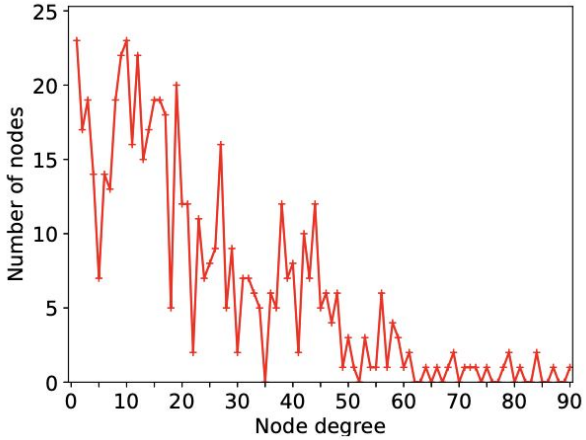
RQ2. Security under DoS Tx Propagation

Results: Full-network topology in testnets

- Lower modularity & fewer cliques than random graphs
- Resilient to single-point-of-failure, but unsecure for low-degree nodes



(b) Geo distribution of Rinkeby



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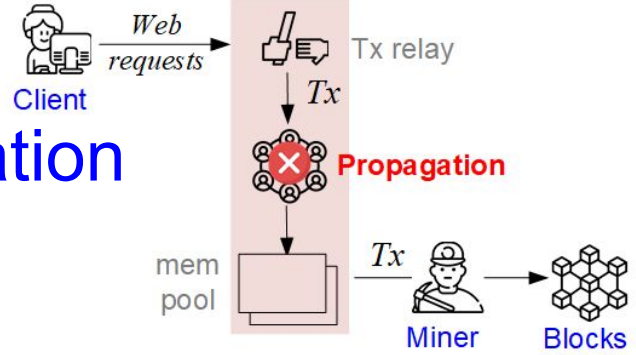


Results: Critical-node subnet in mainnet

- Biased node connections towards popular services

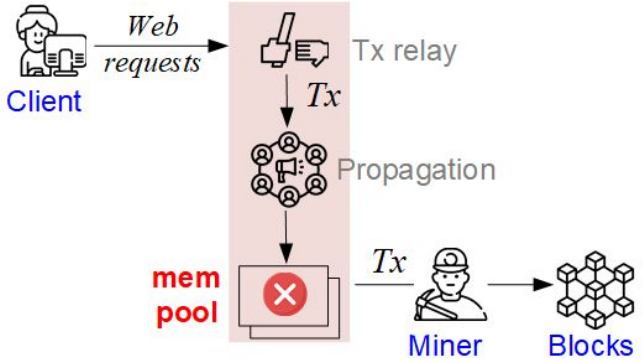
- Centralization leads to risks

Table 6: Connections among critical nodes

Type	Conn.	Type	Conn.
SrvR1- SrvM1	✓	SrvM1- SrvM1	✗
SrvR1- SrvM2	✓	SrvM1- SrvM2	✓
SrvR1- SrvM3	✓	SrvM1- SrvM4	✓
SrvR1- SrvM4	✓	SrvM1- SrvM3	✓
SrvR2- SrvM1	✗	SrvM2- SrvM2	✓
SrvR2- SrvM2	✗	SrvM2- SrvM3	✓
SrvR2- SrvM3	✗	SrvM2- SrvM4	✓
SrvR2- SrvM4	✗	SrvM3- SrvM4	✓
SrvR2- SrvR1	✗	SrvR1- SrvR1	✓

Publication: **ACM IMC 2021**

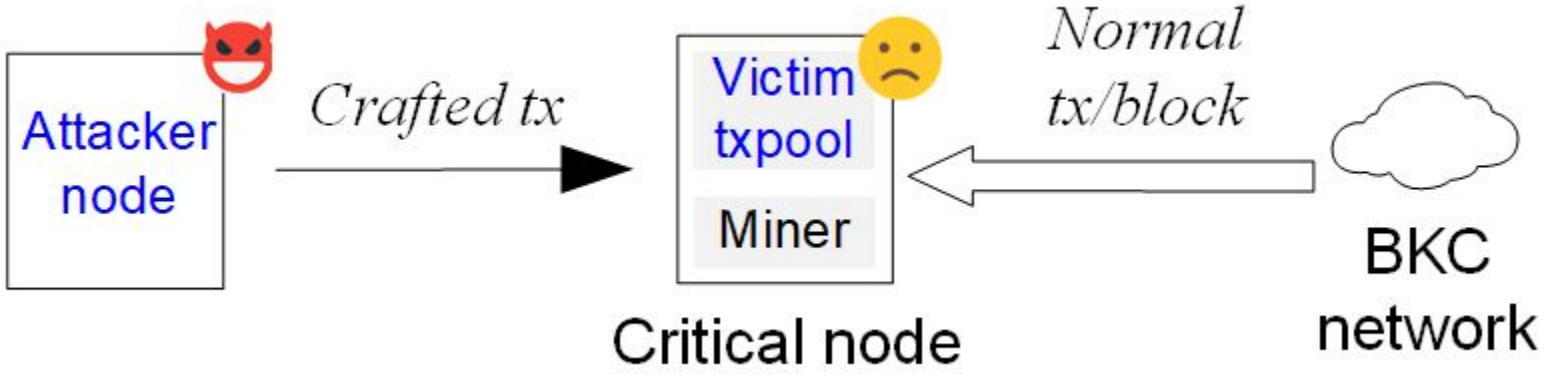
TopoShot: Uncovering Ethereum's Network Topology Leveraging Replacement Transactions.
Kai Li, Yuzhe Tang, Jiaqi Chen, Yibo Wang, Xianghong Liu



RQ3. Security under DoS Mempool

Formulated problem:

RQ3 (Attack design): Whether possible and how to spam a remote mempool at low cost?



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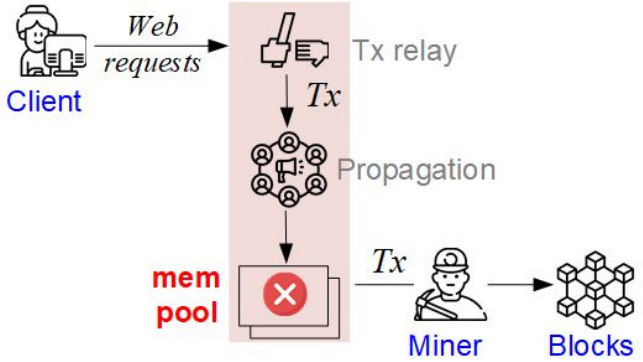
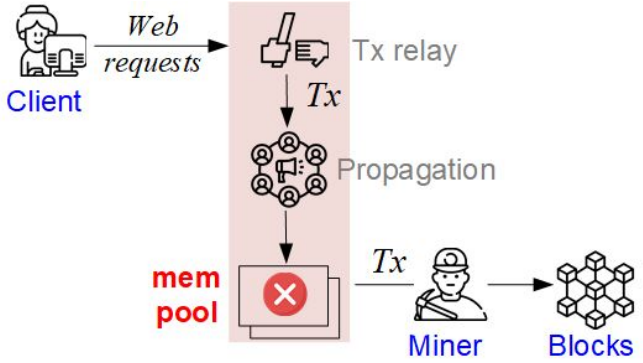


Proposed method (intuition):

- Exploit the design flaw in auction-based tx admission.
  - Ethereum uses auction to determine tx admission priority.
    - Necessary to mitigate spamming (Bitcoin16)
  - Protocol level: Assume all txs are profitable…
  - Implementation level: False assumption!
    - Unconfirmed Ethereum txs are invalid and unprofitable.
- Idea: Send unprofitable and high-priced txs to occupy an Ethereum node's mempool.

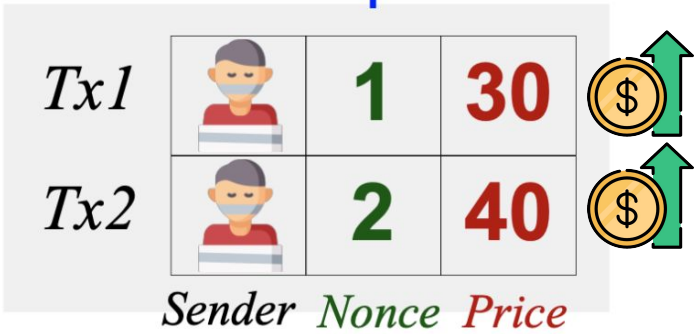
RQ3. Security under DoS Mempool



Proposed method (intuition): Attack

Attacker node

Victim txpool



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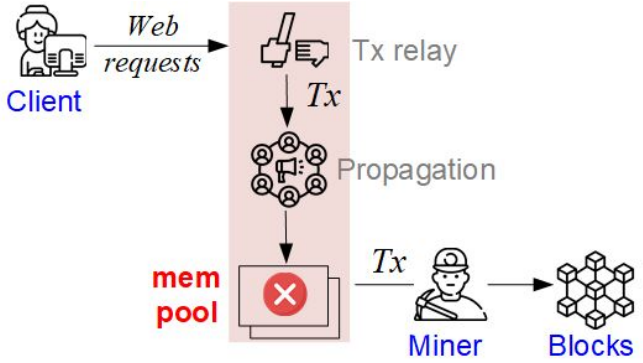

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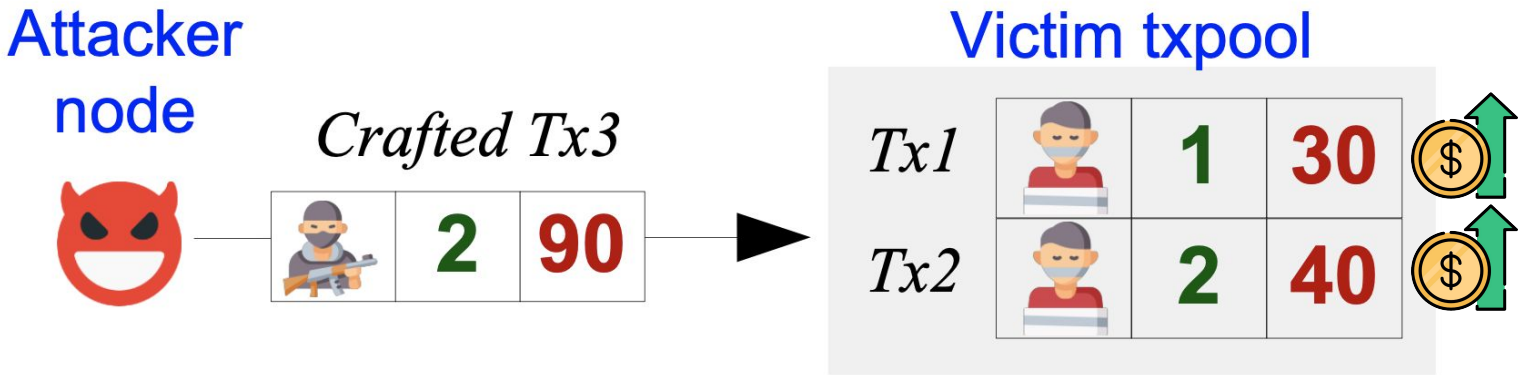

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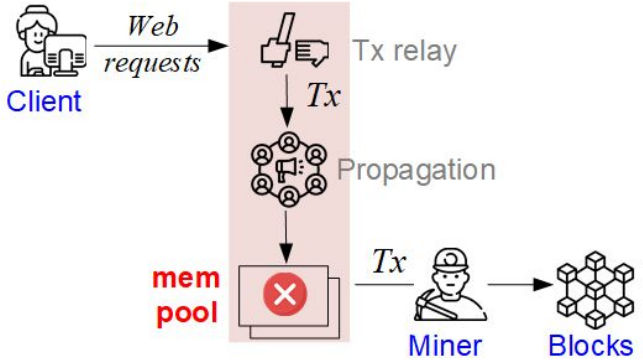


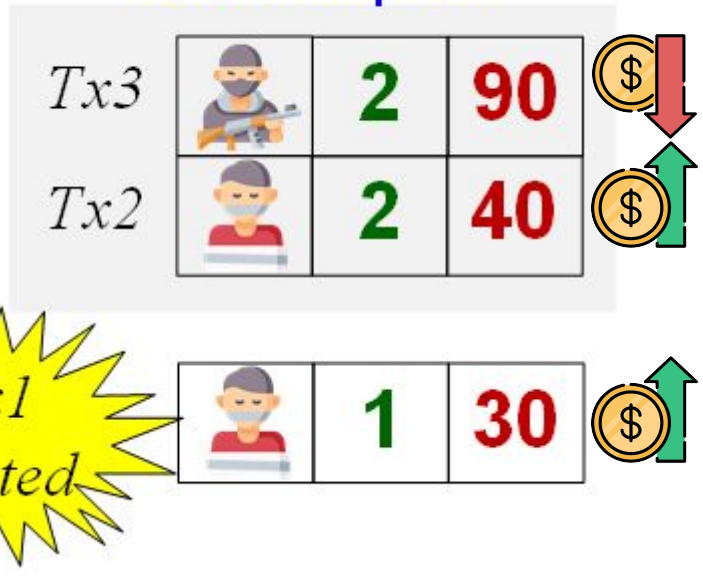
Proposed method (intuition): Attack

Attacker node

admitting tx3 leads to

1. evict tx1

Victim txpool



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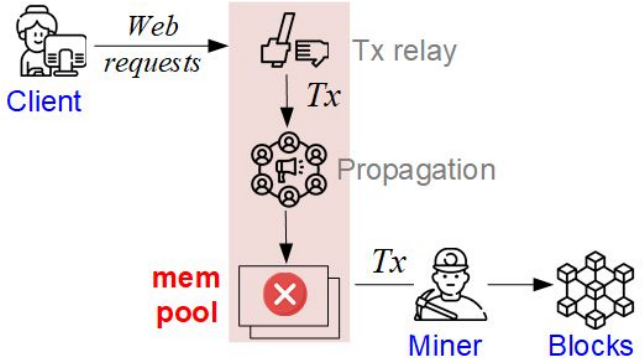


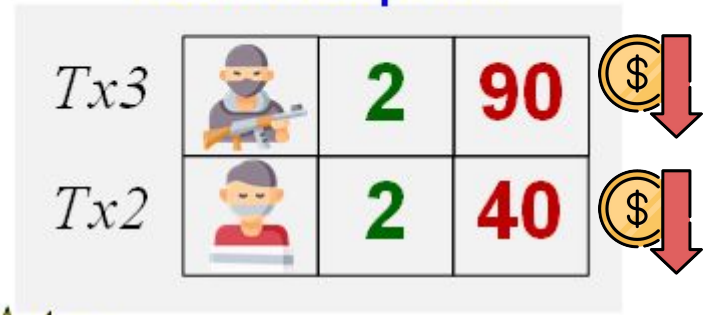
Proposed method (intuition): Attack

Attacker node

admitting tx3 leads to

1. evict tx1
2. turn tx2 to future

Victim txpool



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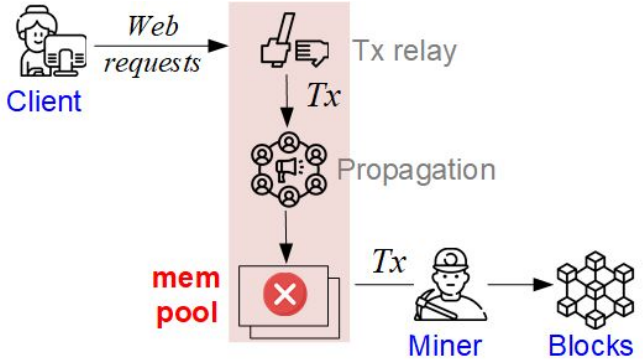
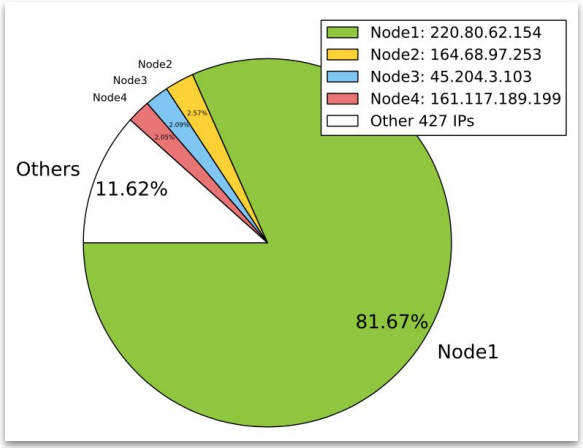
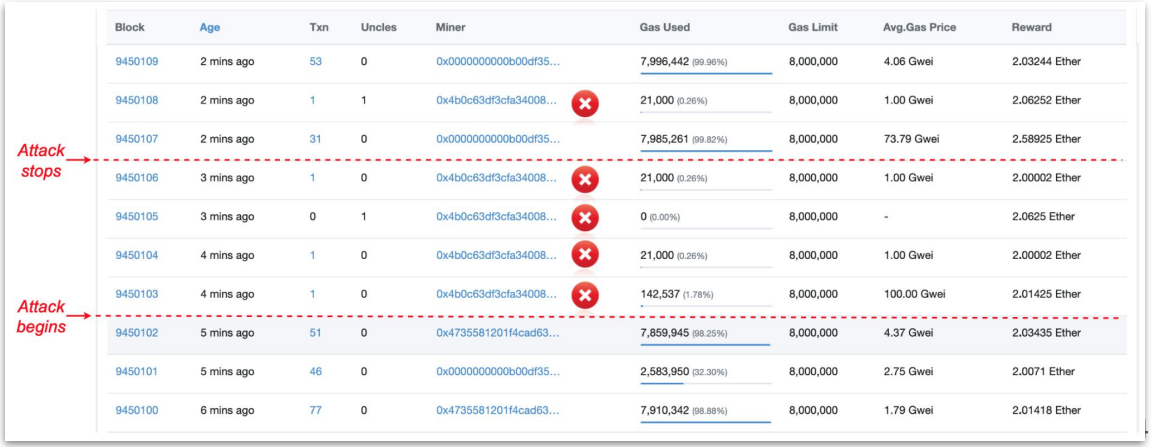


Results: Attack success & cost in testnets

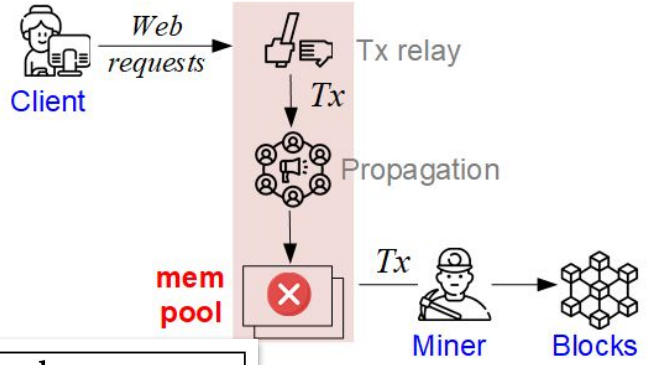
- Launching two supernodes joining Ropsten testnets.
- Using the node discoverability method to discover top miners.





Block	Age	Txn	Uncles	Miner	Gas Used	Gas Limit	Avg.Gas Price	Reward
9450109	2 mins ago	53	0	0x0000000000b00df35...	7,996,442 (99.96%)	8,000,000	4.06 Gwei	2.03244 Ether
9450108	2 mins ago	1	1	0x4b0c63df3cfa34008...	21,000 (0.26%)	8,000,000	1.00 Gwei	2.06252 Ether
9450107	2 mins ago	31	0	0x0000000000b00df35...	7,985,261 (99.82%)	8,000,000	73.79 Gwei	2.58925 Ether
9450106	3 mins ago	1	0	0x4b0c63df3cfa34008...	21,000 (0.26%)	8,000,000	1.00 Gwei	2.00002 Ether
9450105	3 mins ago	0	1	0x4b0c63df3cfa34008...	0 (0.00%)	8,000,000	-	2.0625 Ether
9450104	4 mins ago	1	0	0x4b0c63df3cfa34008...	21,000 (0.26%)	8,000,000	1.00 Gwei	2.00002 Ether
9450103	4 mins ago	1	0	0x4b0c63df3cfa34008...	142,537 (1.78%)	8,000,000	100.00 Gwei	2.01425 Ether
9450102	5 mins ago	51	0	0x4735581201f4cad63...	7,859,945 (98.25%)	8,000,000	4.37 Gwei	2.03435 Ether
9450101	5 mins ago	46	0	0x0000000000b00df35...	2,583,950 (32.30%)	8,000,000	2.75 Gwei	2.0071 Ether
9450100	6 mins ago	77	0	0x4735581201f4cad63...	7,910,342 (98.88%)	8,000,000	1.79 Gwei	2.01418 Ether

RQ3. Security under DoS Mempool

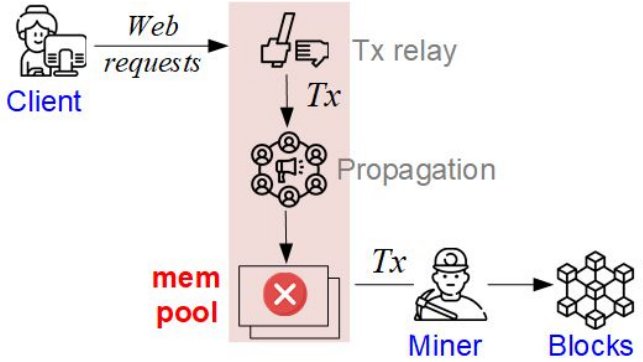


Results: Exploitability probes in mainnet

Service name	# of nodes	t_{1m}/X	t_{2m}/Z	Client-codename
Mining pools				
SrvM1	59	✓	✓	Geth-*turbo*
SrvM2	8	✓	✓	Geth-*ethereumsolo*, Geth-*ethereumppIns*
SrvM3	6	✓	✓	Geth-XX
SrvM4	2	✓	✓	Geth-XX
RPC services				
SrvR1	48	✓	✓	Geth-*omnibus*
SrvR2	1	✓	✓	Geth-*ethshared*

Publication: **ACM CCS 2021**

DETER: Denial of Ethereum's Txpool Service.
Kai Li, Yibo Wang, Yuzhe Tang



RQ3. Security under DoS Mempool

Mitigation scheme:

- Goal: DETER security versus miner revenue.
- Ideal: Decline any unprofitable txs.
- But profitability cannot be known upon admission?
- Heuristics: decline future txs (M0), decline exploitable tx eviction (M1).
- Evaluation: M0/M1 impl.'ed as middleware on mempool

Schemes	Miners' revenue (Ether)	DETER security	
		t_1/X	t_2/Z
Geth (default)	16.5388	✓/✗ (Table 2)	
M_0 (in Appendix 14.1)	15.9506(−3.56%)	✗	✗
M_1	16.5423(+0.002%)	✗	✗

Bug Reporting

- DETER/DoERS bugs confirmed by Ethereum client developers, RPC services & mining pools.

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- DETER/DoERS bugs confirmed by Ethereum client developers, RPC services & mining pools.
- Bug bounty rewarded: >$22,000
  - Acknowledgements https://bounty.ethereum.org/
- Quick code fix deployed, and advanced fixes in progress.

Talk Outline

Theme 1: Securing blockchains under DoS vectors

Theme 2: Optimizing the DApp cost without losing security

- RQ4: Reducing data movement costs
  - By batched processing (FSE'21)
  - By workload-aware data placement (Middleware'20)

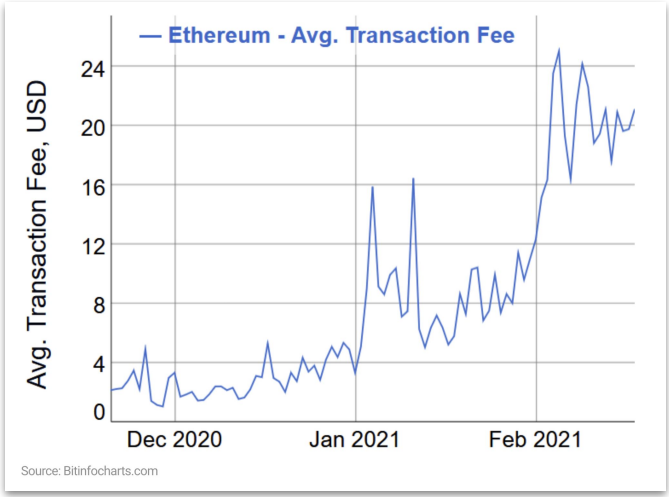
Overview of Other Research Themes

Future research directions

Theme 2[3M]: DApp Cost Efficiency

Observation: Fees are skyrocketing!

- Fees set by a market/auction (FPA)
- High fees as a result of economics:
  - More demand than supply.

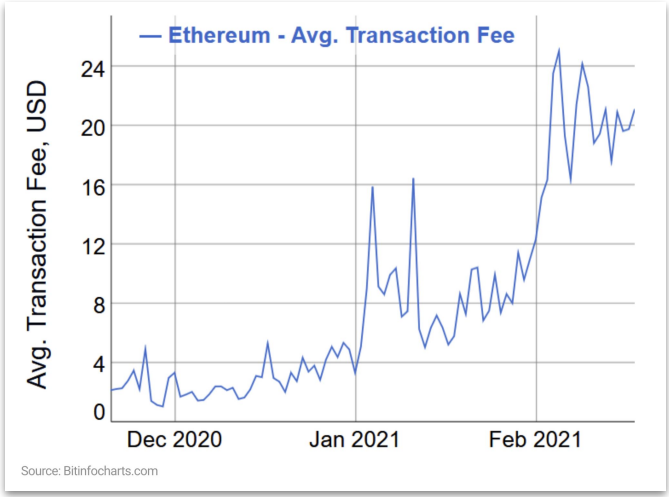


Theme 2^{3M}: DApp Cost Efficiency

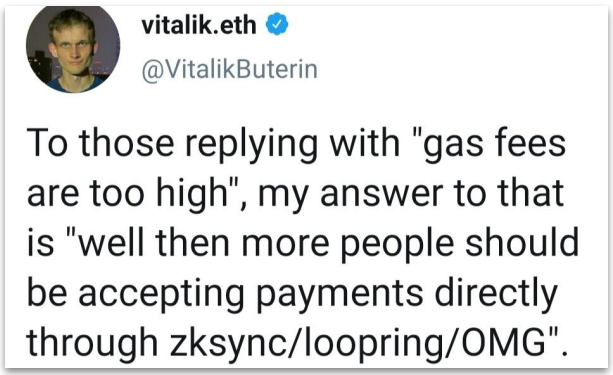
Observation: Fees are skyrocketing!

- Fees set by a market/auction (FPA)
- High fees as a result of economics:
  - More demand than supply.

Consequence: Scared away customers



Too Costly Ethereum is Pushing DeFi Users Away, Fuelling BNB Rally



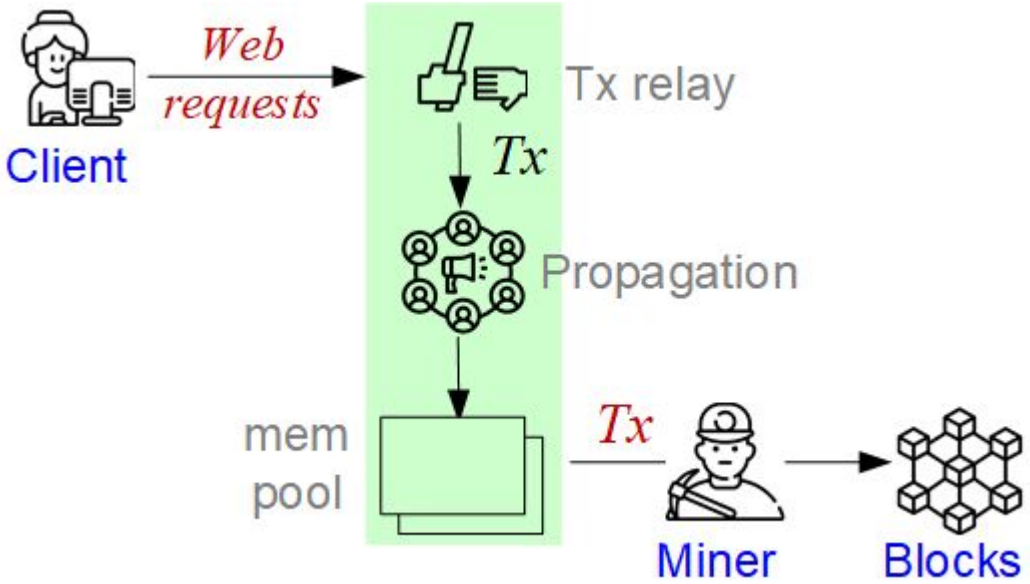
Theme 2^{3M}: DApp Cost Efficiency

Goal: Make DApps'/smart-contracts' use of blockchain efficient, without modifying underlying blockchains.

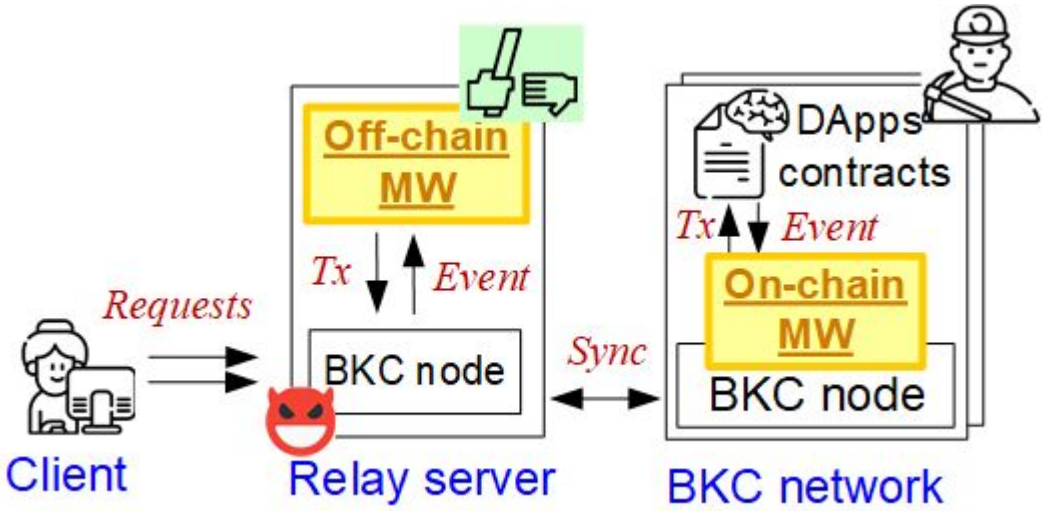
- Ease of deployment as a middleware onto operational blockchain.
- Distinct from research on "more efficient blockchains"

Theme 2^{3M}: DApp Cost Efficiency

Recall the communication-channel view of blockchain ecosystem



Theme 2[3M]: DApp Cost Efficiency: System Model



Two middlewares in BKC-client comm. channel.

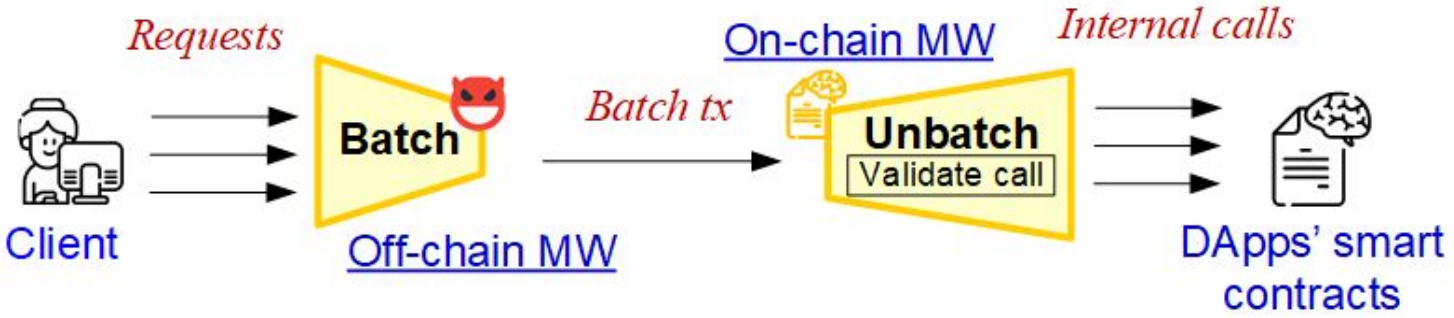
- Untrusted off-chain relay server
- Trusted on-chain smart contract.

Approach: Design & impl. cost-optimization schemes in the two blockchain middlewares.

Theme 2[3M]: DApp Cost Efficiency

Optimization approach 1:

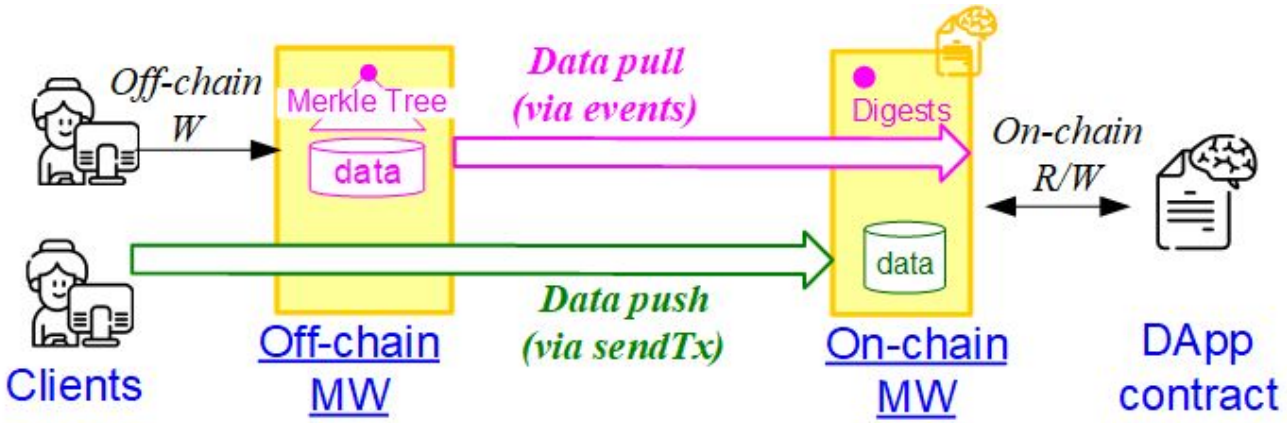
- Batched processing of smart-contract invocations (FSE'21)



Theme 2[3M]: DApp Cost Efficiency

Optimization approach 2:

- Dynamic data replication on/off-chain (Middleware'20)



Talk Outline

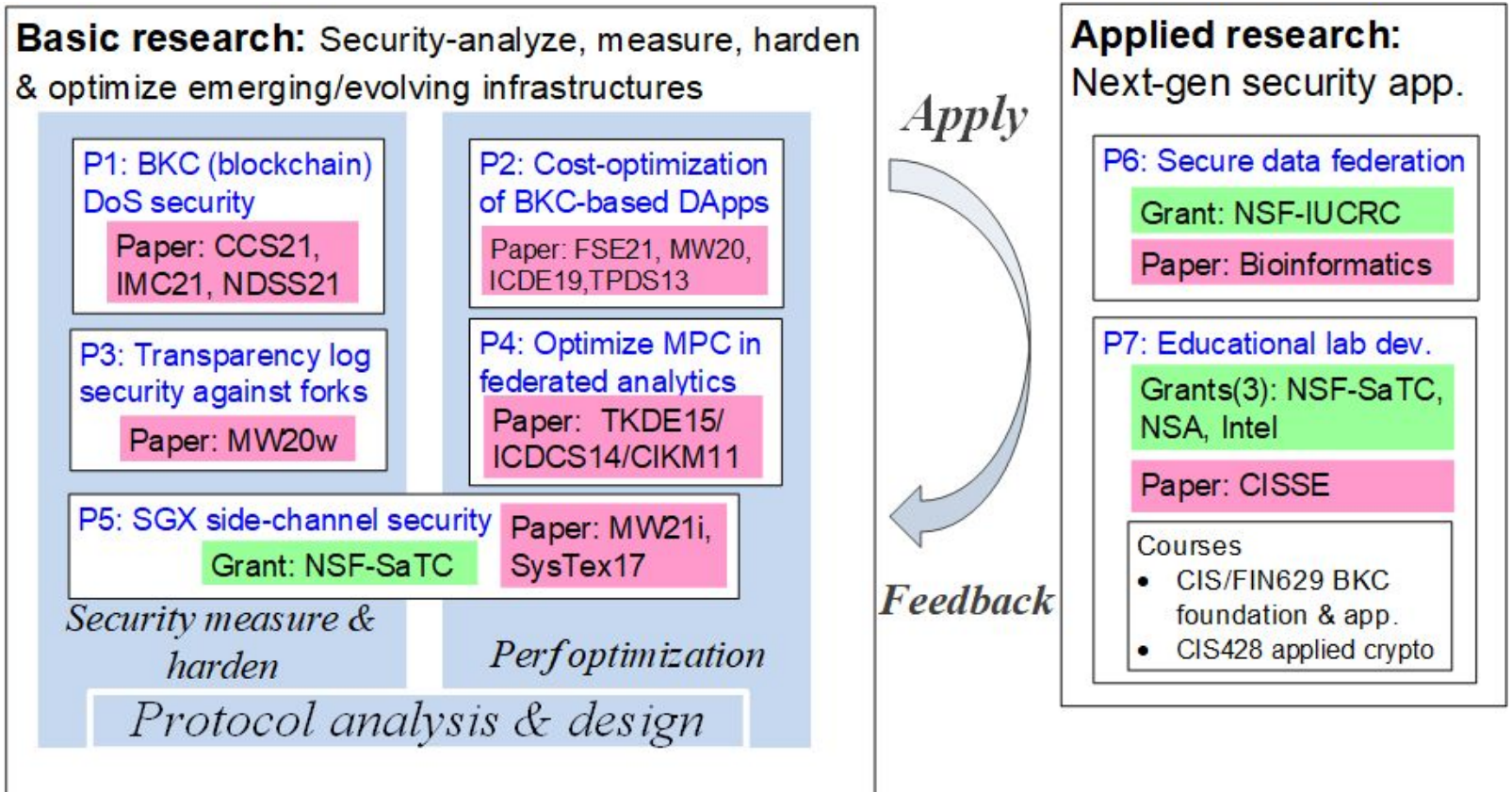
Theme 1: Securing blockchains under DoS vectors

Theme 2: Optimizing the DApp cost without losing security

Overview of Other Research Themes

Future Research Directions

Current Research: *Methods*, Projects, Grants & Papers.



Acknowledgement

- Collaborators: XiaoFeng Wang, Xiapu Luo, Jianliang Xu, etc.

- My students: Kai Li, Yibo Wang, Jiaqi Chen, Yuxuan Zhou, Sencer Burak Somuncuoglu

- Grant support from NSF, NSA, AFRL and industrial gifts from Intel.

Takeaway Points

- Research methodology
  - Target (sub)system: large-scale infrastructures, emerging/evolving features, code in security/cost-critical path.
  - Security research: Understand, measure & harden security?
  - Systems research: Analyze & optimize performance?

- Example research themes in this talk
  - Securing blockchains under DoS vectors (CCS, NDSS, IMC)
    - Hard problem, clever methods, and significant results
  - Cost-optimizing DApps without losing security (FSE, MW, ICDE)

Backup Slides

Bug Reporting & Ethical Considerations

Ethical measurement on mainnet

- On mainnet, the test evicts at most 10% txs in the txpool.
- As remedy, we resent 10% txs after each test to “refill” the txpool.
- No impacts on txs already included in the block.