Classical Consensus

Possible Timing Models

Asynchronous

- A sent message will *eventually* be delivered

Synchronous

- Guarantees on the time of delivers
- e.g. message sent at time t, will be delivered at time t+x

Eventually Synchronous

- A mix between both, where there is a *known upper bound* on the delivered time which is *variable*.

Possible Fault Models

Up to **f out of N processes can fail**

- Typically f < N/2, f < N/3

Honest nodes

- Remain available and do not behave byzantine

Availability failure

- A node might suddenly crash/Internet connectivity drop

Byzantine failure

- Malicious failure of an adversary

Broadcast Models

Consistent Broadcast

- A corrupted sender implies that not every party might terminate/deliver a request.

Reliable Broadcast

- Sender emits value v
- Termination: if sender honest, correct party outputs v
- Reliability: every correct party outputs v
- Consistency: two distinct parties output v1, v2 and v1=v2

https://lpd.epfl.ch/site/_media/education/sdc_byzconsensus.pdf

PBFT, Paxos, RAFT, et al.

Leader election

- Every node can become eventually a leader (e.g. round-robin)

Safety

- The output is guaranteed to be consistent, even under an unstable network and malicious leader
- Although asynchronous eventually synchronous

Liveness

- If no progress, new leader elected
- If network stable and honest leader then liveness

Known Impossibility Results

Fischer, Lynch, Patterson (1985)

- FLP result
- In a fully asynchronous system, there is no deterministic consensus solution that tolerates one or more failures
- No algorithm can always reach consensus in bounded time.

Implication

- Timing assumptions are required for every protocol
- Randomness is crucial

Given any protocol

Is the impossibility result respected?

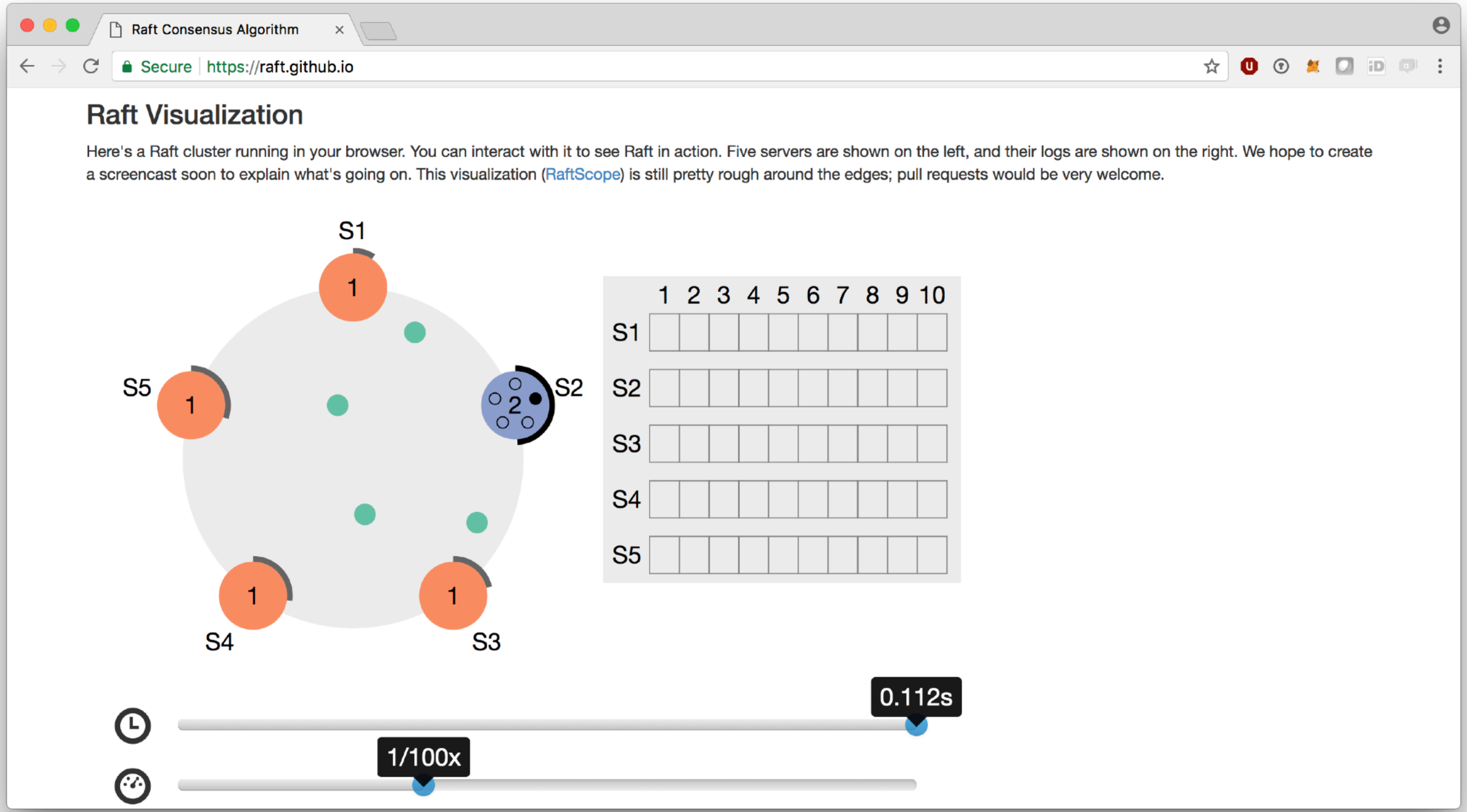
What's the message complexity/number of rounds?

How many nodes are allowed to fail?

Where does the randomness come from?

Can an adversary manipulate the randomness/become leader?

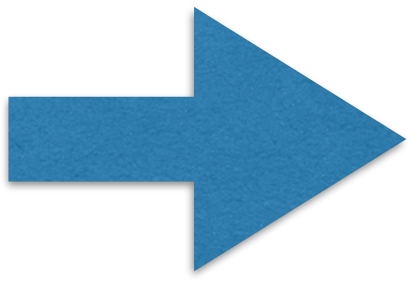
RAFT



http://thesecretlivesofdata.com/raft/ https://raft.github.io/

How does this relate to Bitcoin?

- No need for a final consensus output
- Block/transaction reward as incentive to participate
- **The participating nodes do not need to be known upfront!**

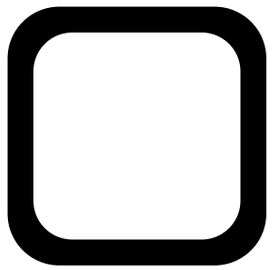


Fundamentally different to the results of years of research

Blockchain Bootstrapping

Bootstrapping

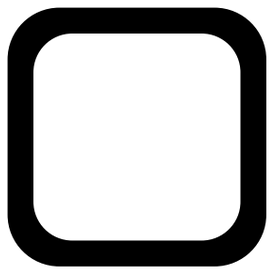
Bootstrapping



Genesis Block

Bootstrapping

where is the chain?



Genesis Block

Bootstrap Methods

where is the chain?

DNS (Domain Name System) Bootstrap

- A few dedicated nodes that serve other IP addresses

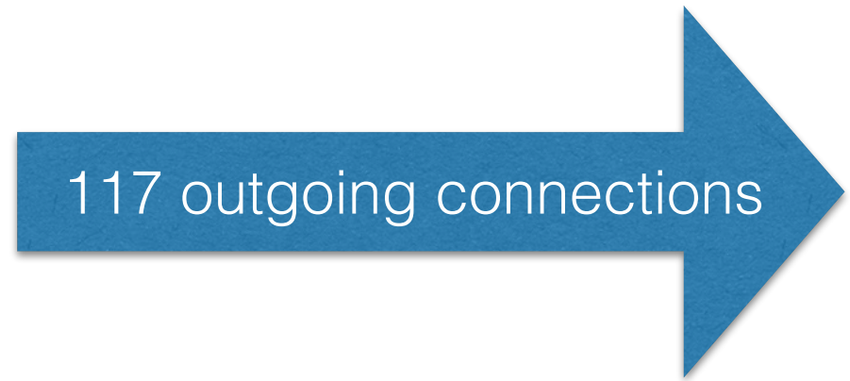
Hardcoded IP's

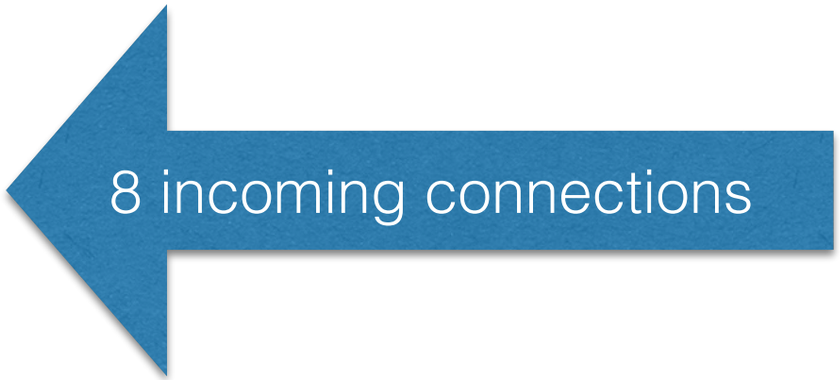
- These IP's need to be static

Chat/Forums

- Ask around for IP's of participants

Bitcoin Node



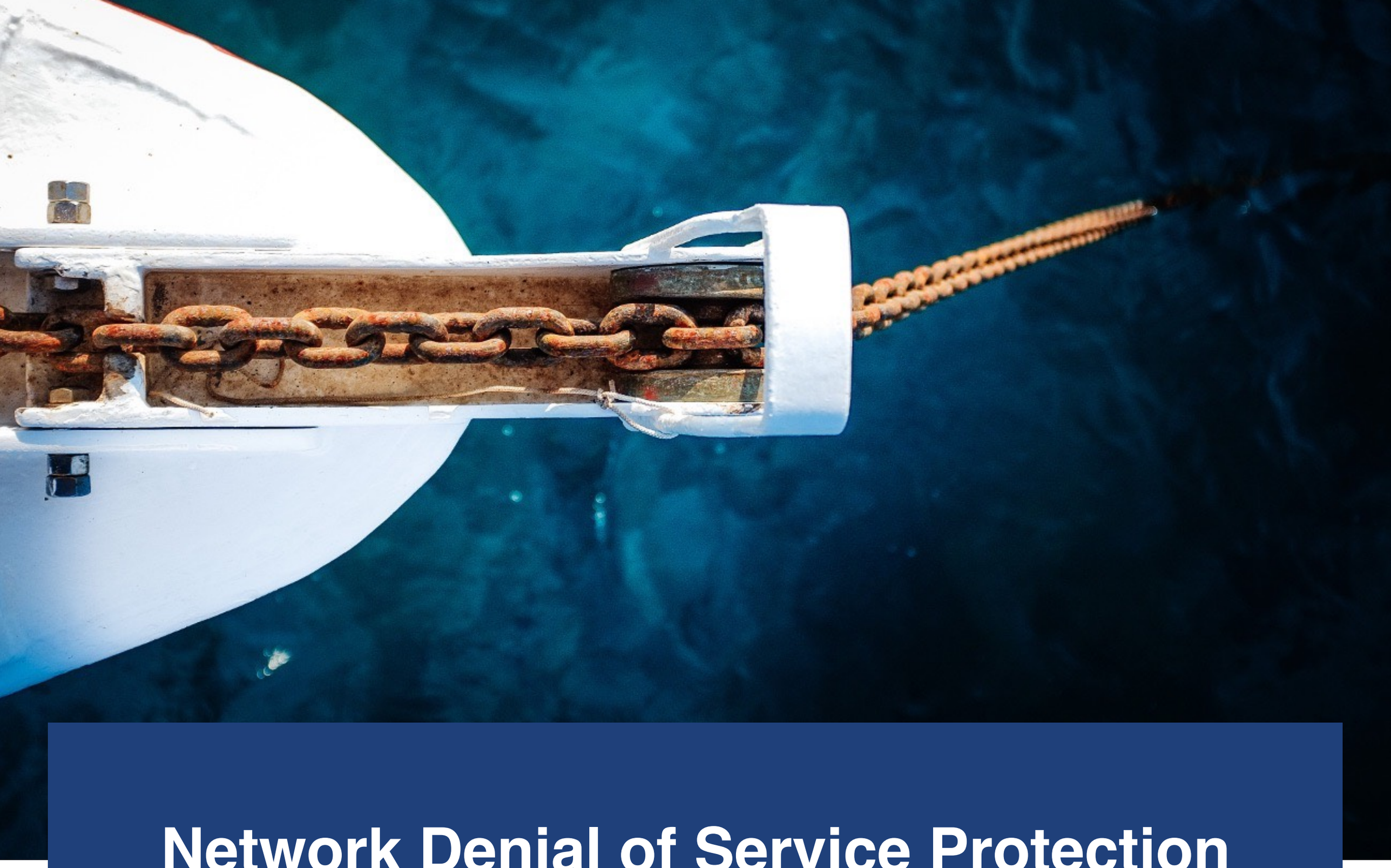


TCP based

- No authentication/encryption

Incoming Packet Validation

- Signature validation
- Consistency, UTXO validation
- Denial of service protections



Network Denial of Service Protection

DoS Protection Mechanism

Sanity checks (lower penalty)

- Size
- Encoding

Critical points (penalty 100)

- Signature validation
- UTXO/double spending validation

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Critical points (penalty 100)

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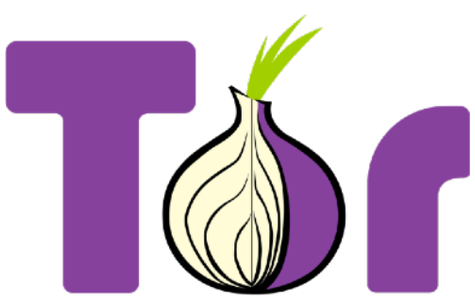
- UTXO/double spending validation

Banned for 24 hours!

DoS Protection Mechanism is a weakness



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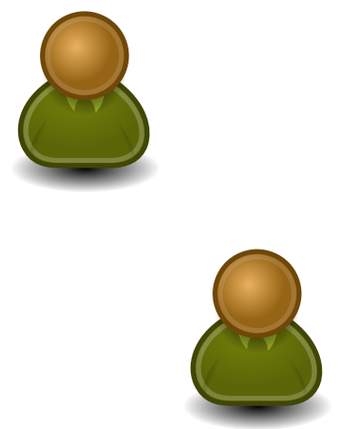

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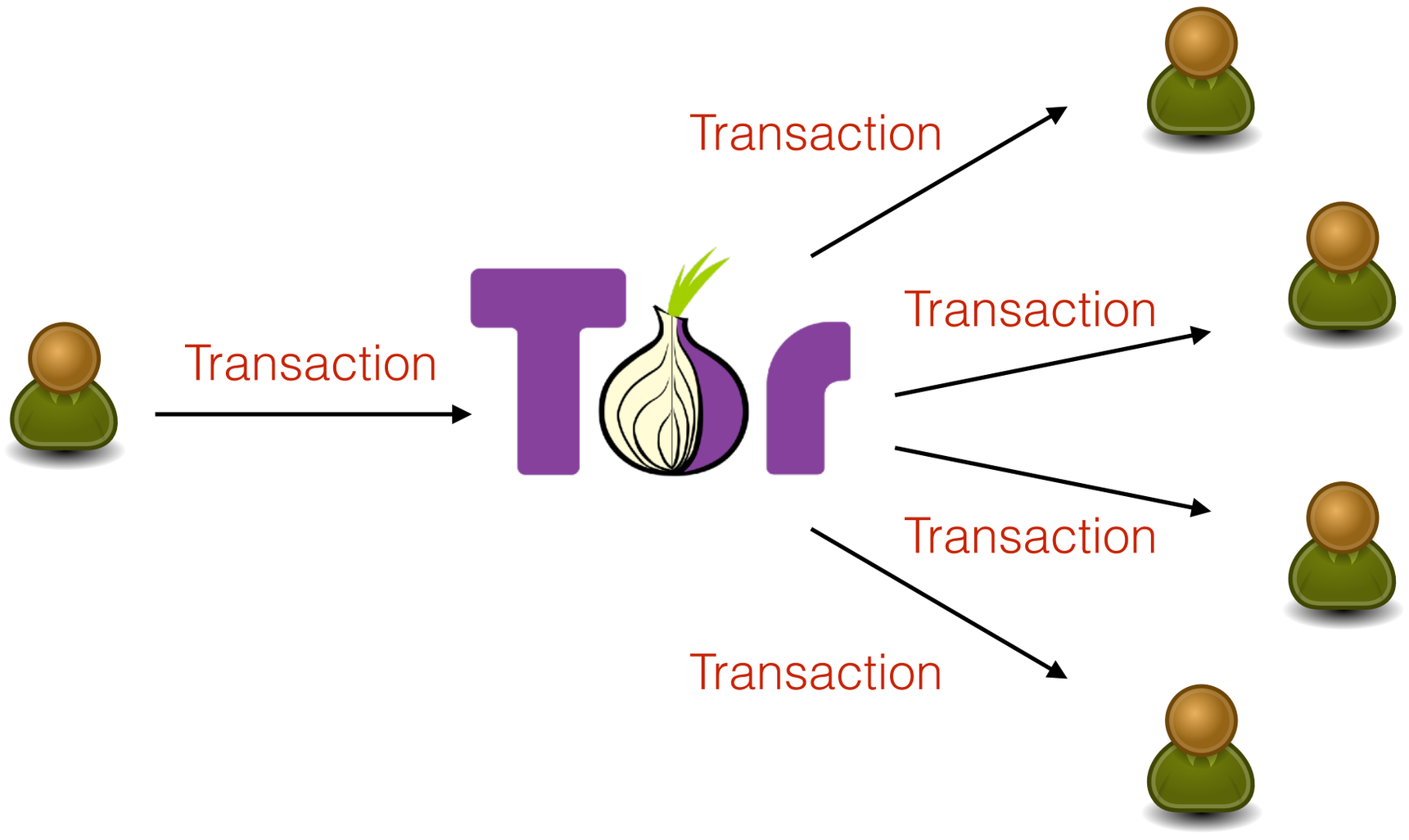

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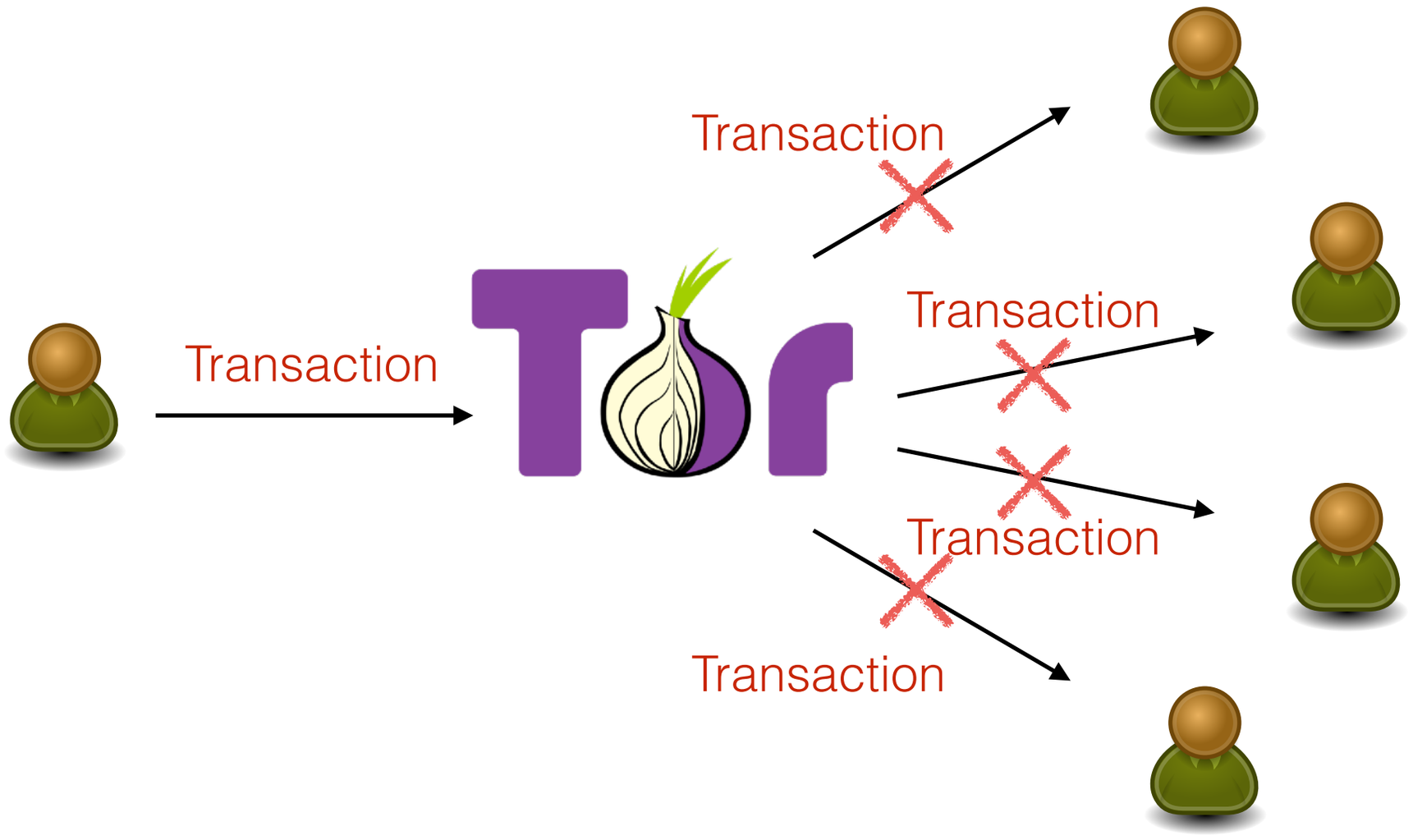

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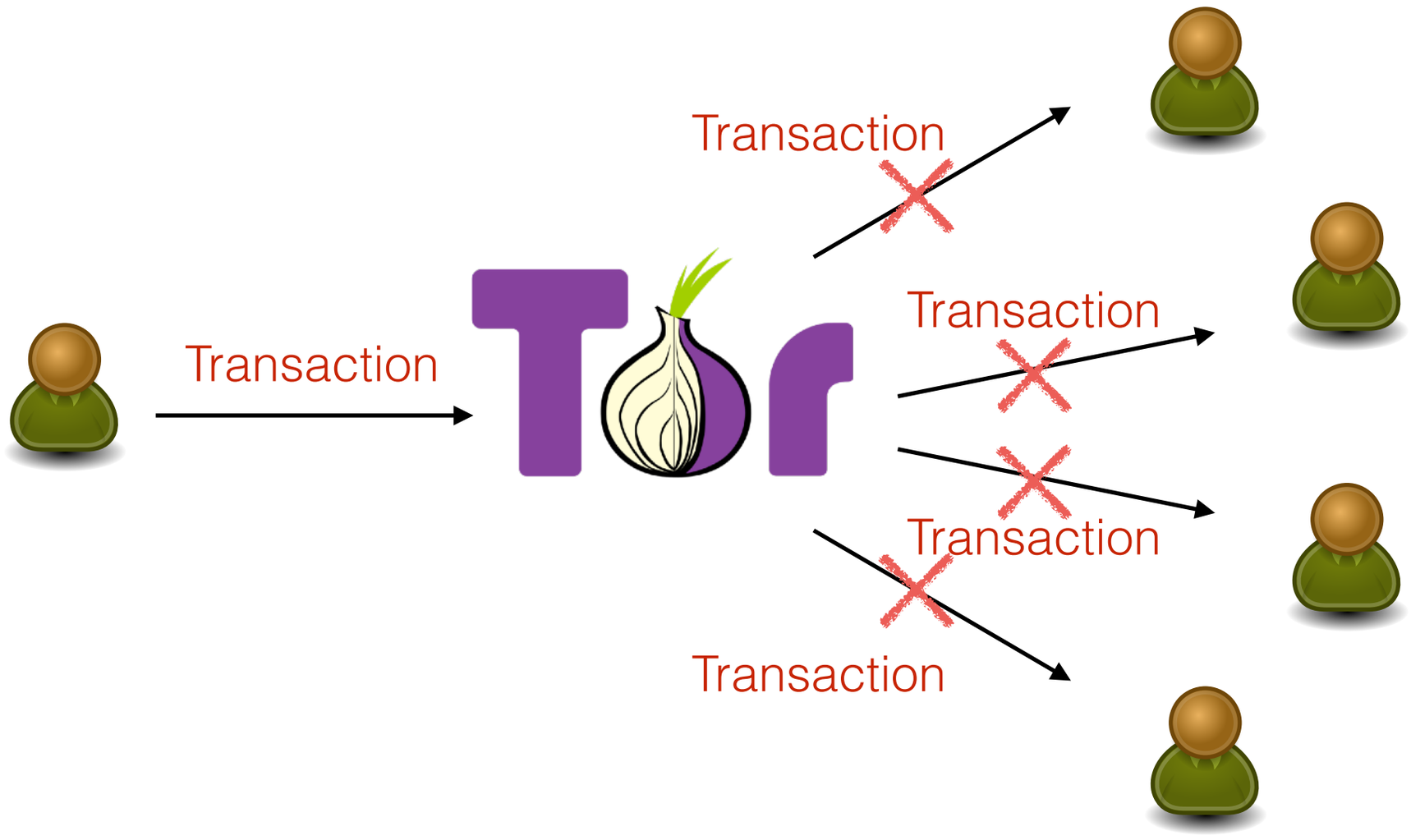
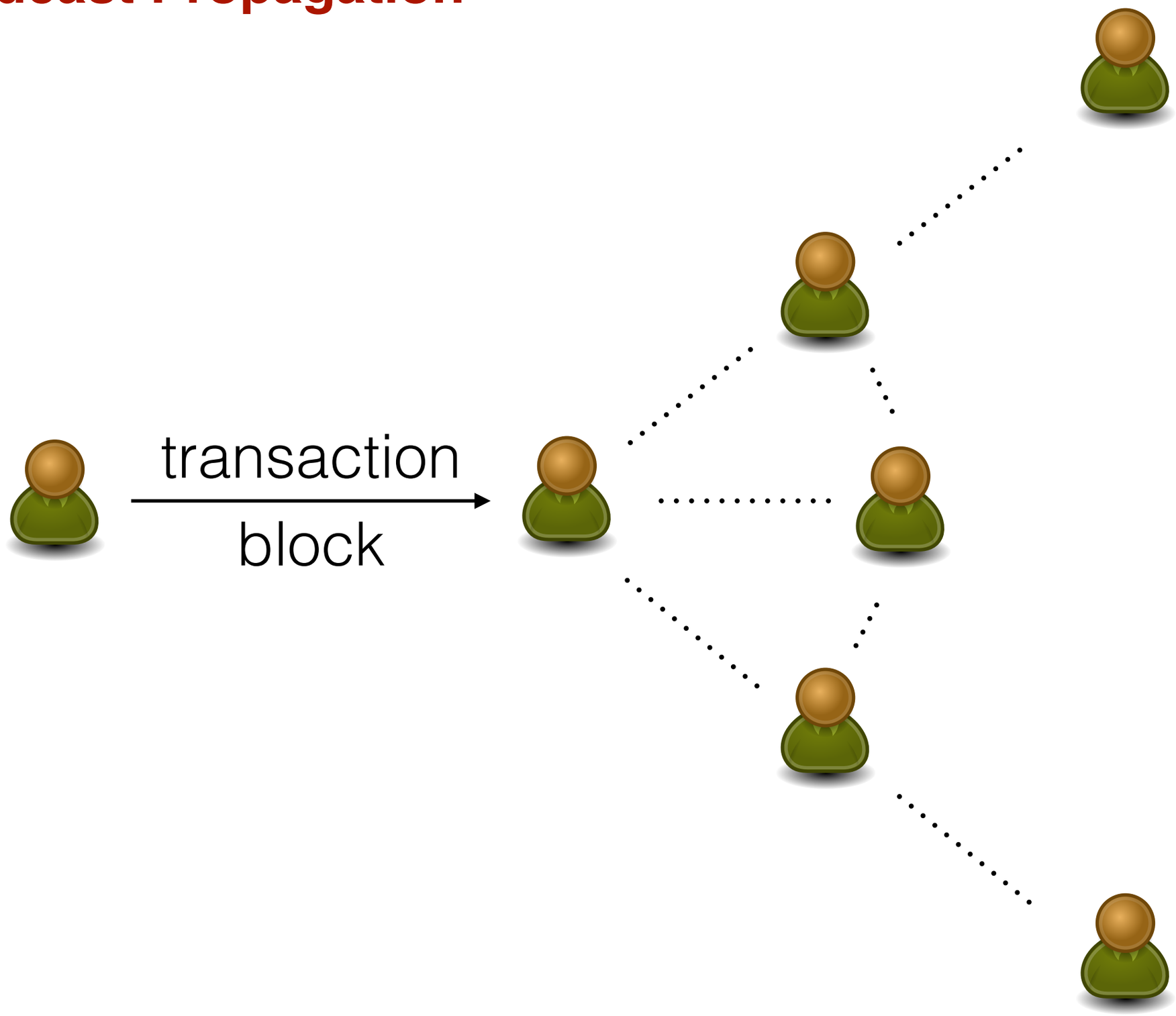


All Tor exit nodes banned through Bitcoin.

Network Gossip Protocol

Broadcast Propagation



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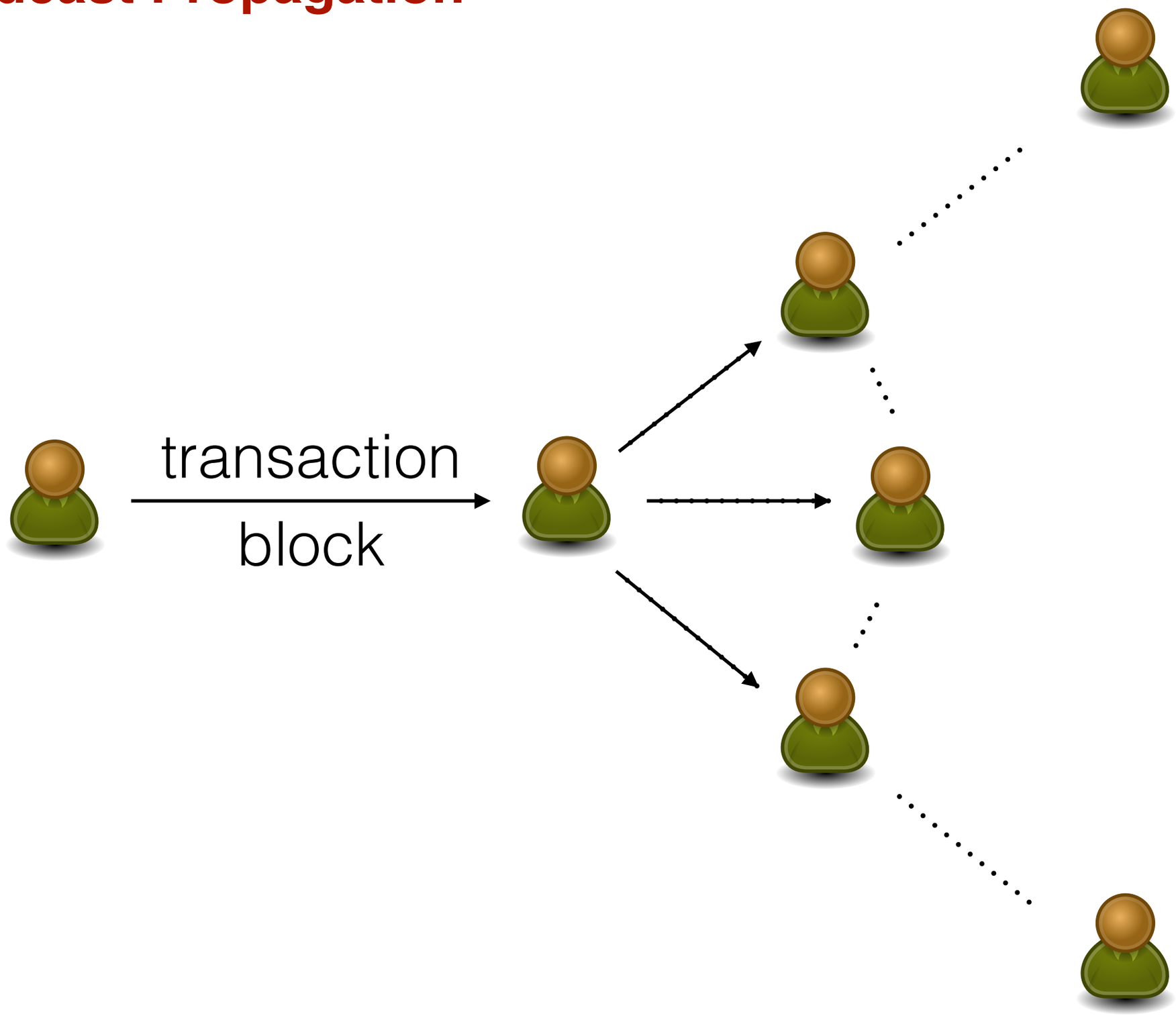

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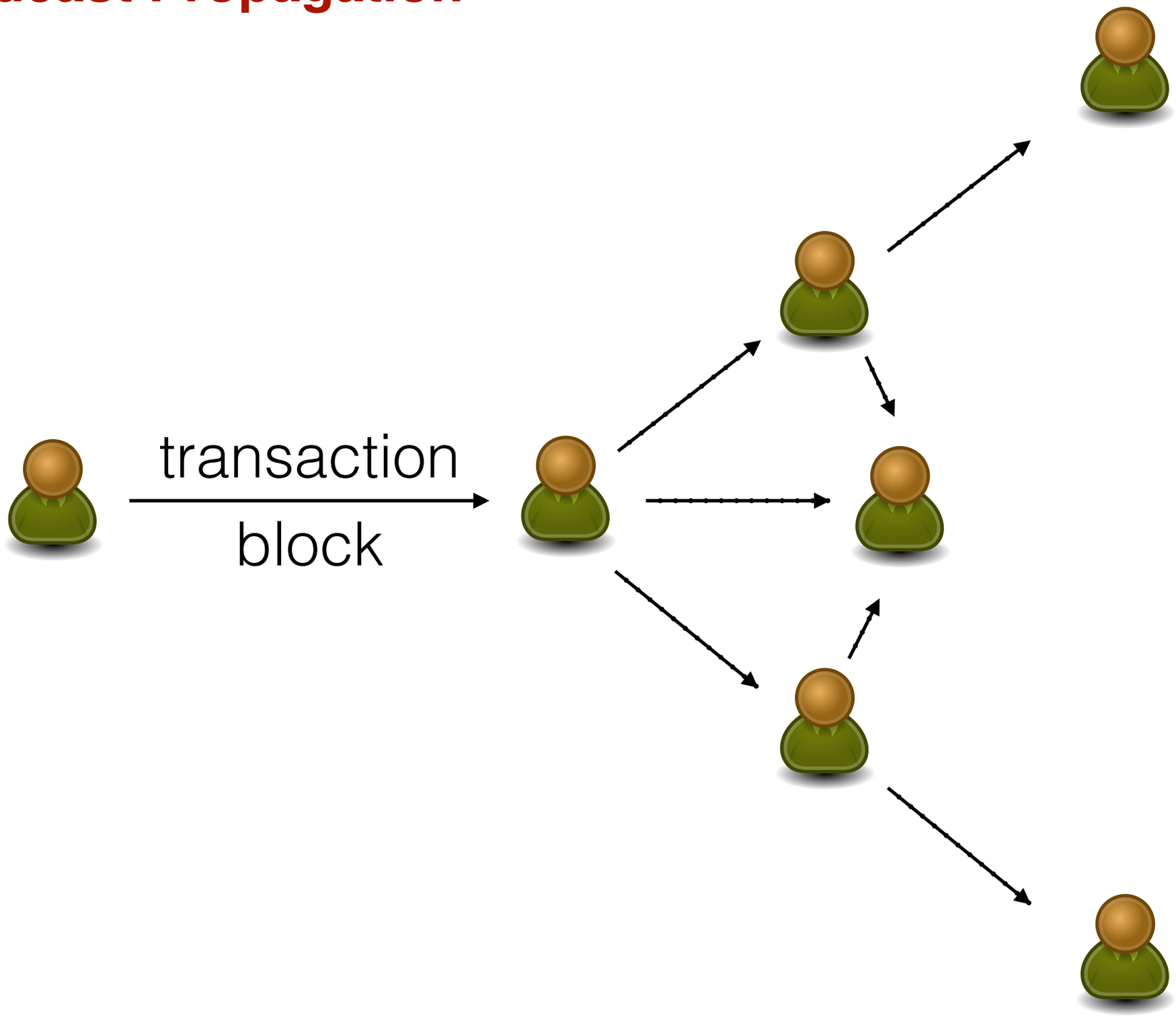

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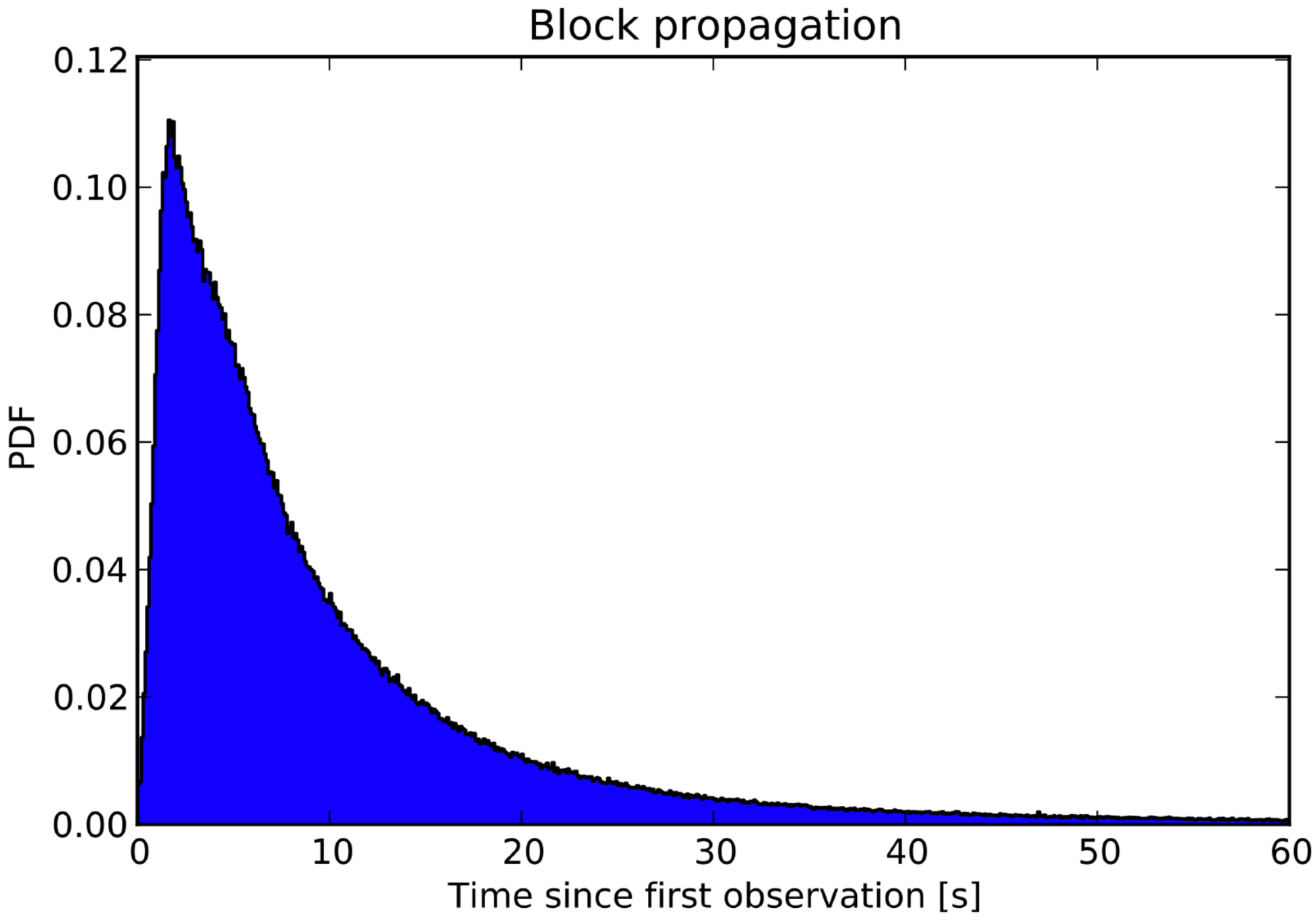
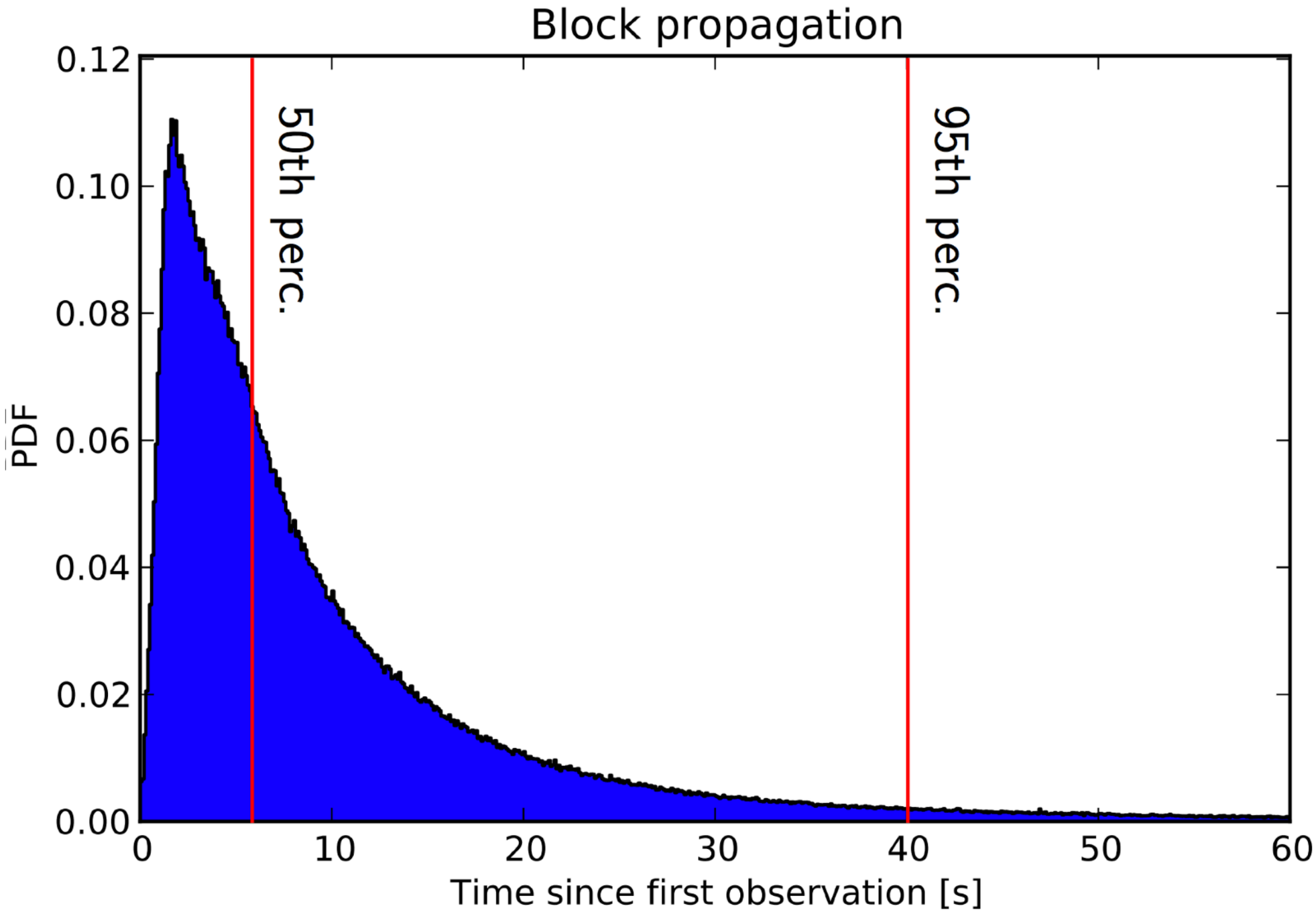


* Christian Decker et al., Information Propagation in the Bitcoin Network

Broadcast Propagation



* Christian Decker et al., Information Propagation in the Bitcoin Network

Propagation Methods

Standard

- Send first the hash of an object, transaction/block
- Recipient requests the object
- Sender transmits the object

Send Headers

- Send first the block header (no more block hash)
- Then block

Unsolicited Block Push

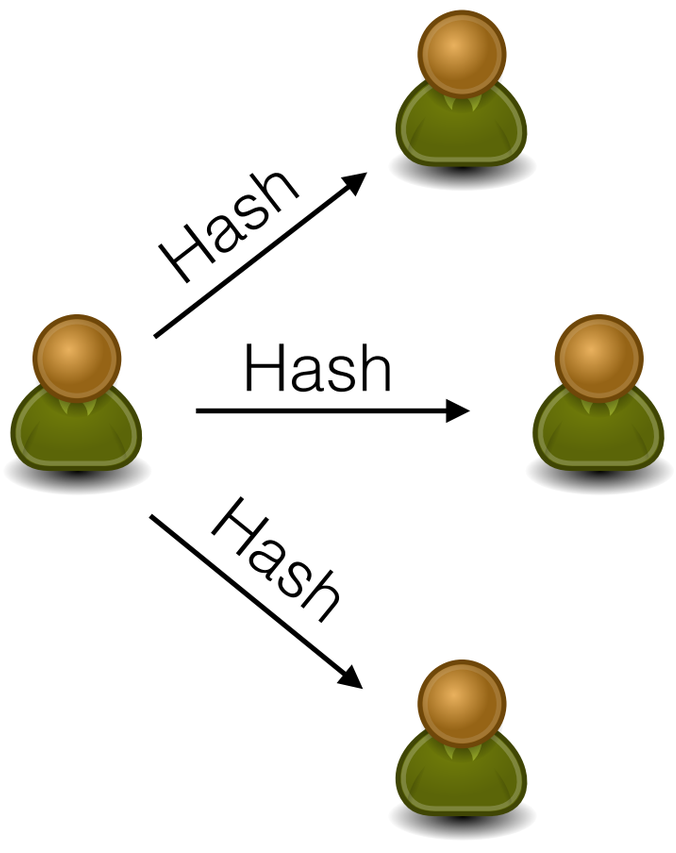
- Miners can push a block directly, without pushing the header

Fibre (Fast Internet Bitcoin Relay Engine) Network

- Optimized network for miners

Standard Transaction/Block advertisement

1. Transaction/Block
   hash broadcast



Broadcast

Standard Transaction/Block advertisement

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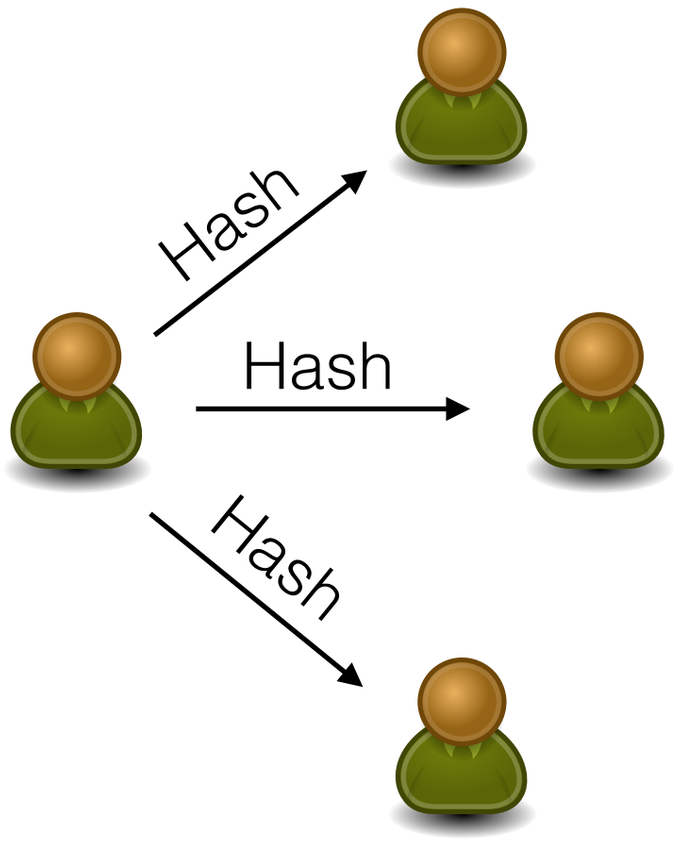
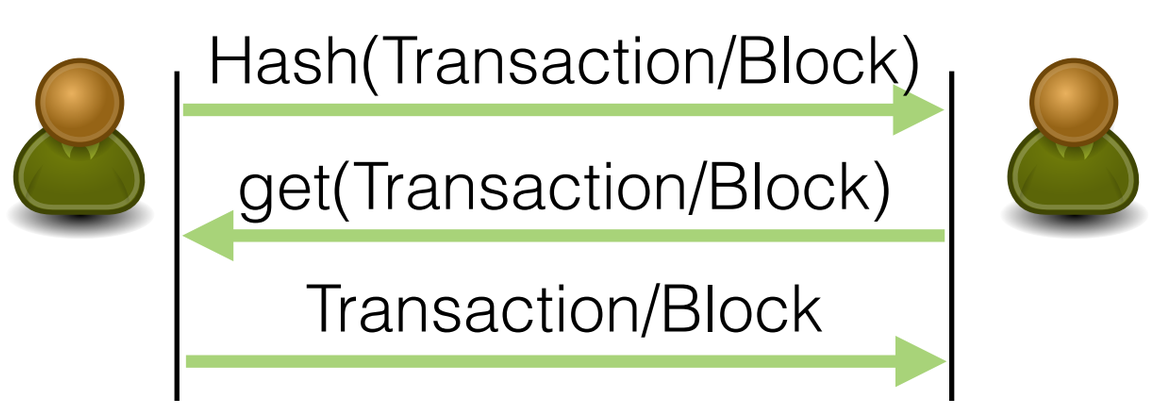


Broadcast

2. Transaction/Block request

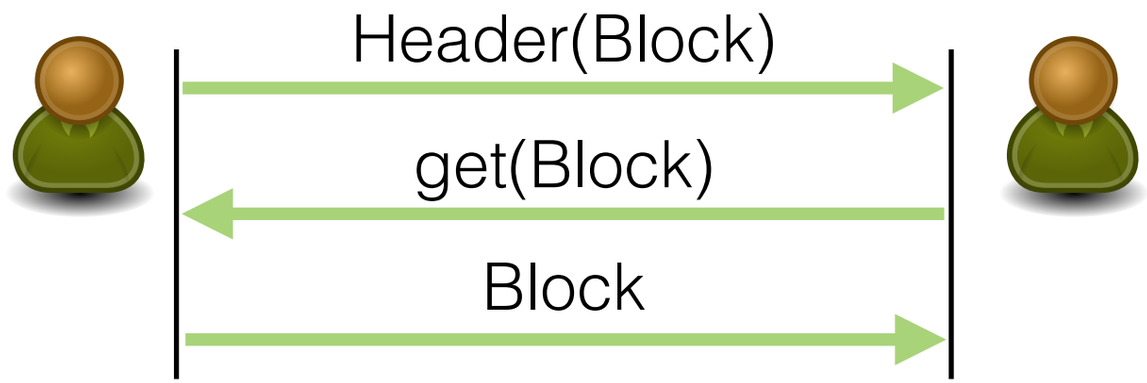


Request from only 1 peer!

Send Headers Block advertisement

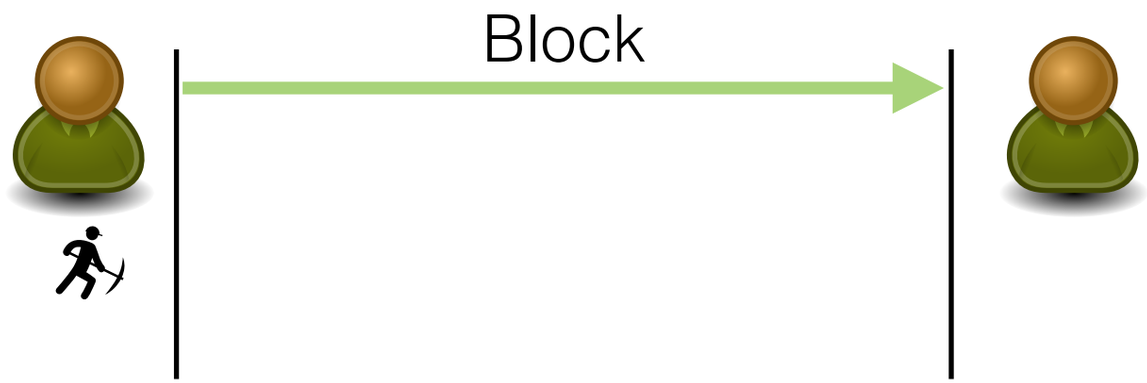
Header in Bitcoin about 80 bytes,
hash about 36 bytes

Send Headers Block advertisement

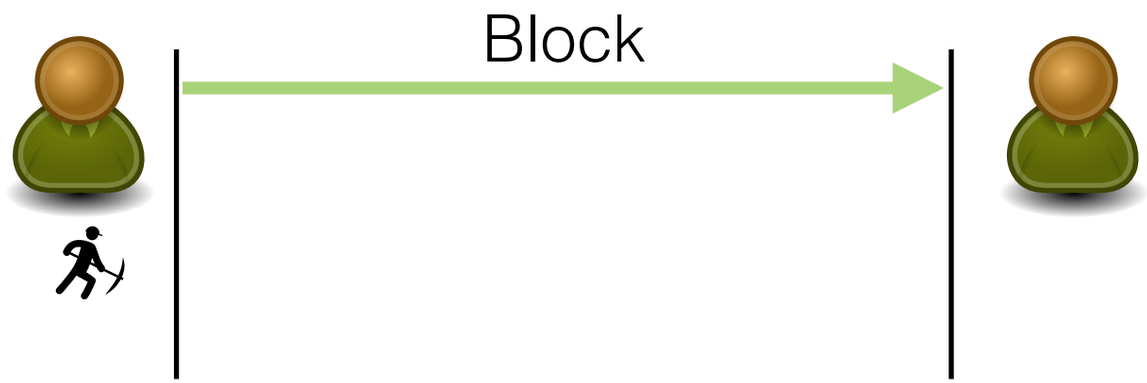


Header in Bitcoin about 80 bytes,
hash about 36 bytes

Unsolicited Block Push



Unsolicited Block Push



Nobody else knows about the block

Bitcoin Fibre

- Fibre node sends a short block sketch
  - List of short hashes, lengths

- Receiver can reconstruct block based on memory pool and construct a block with holes

- Fibre sender breaks block into chunks and sends error correction data
  - Receiver can reconstruct block, without the sender knowing what's missing.

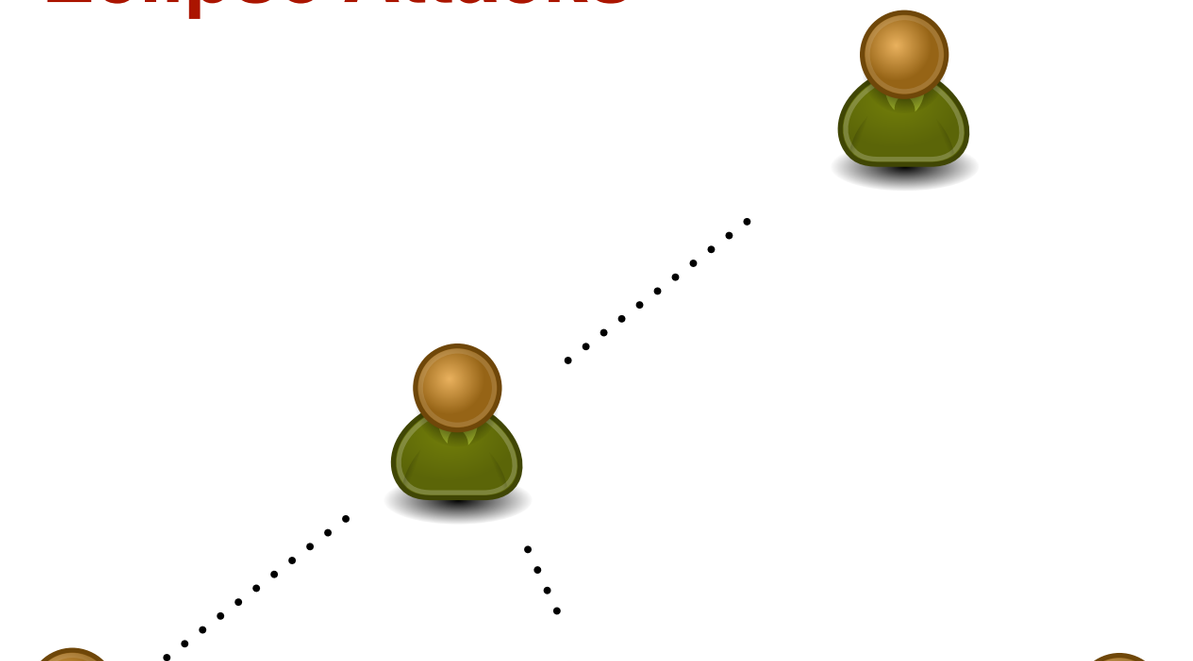
- Once received and reconstructed the block, the fibre node emits novel chunks —> no redundancy.

- UDP based —> no ramp up

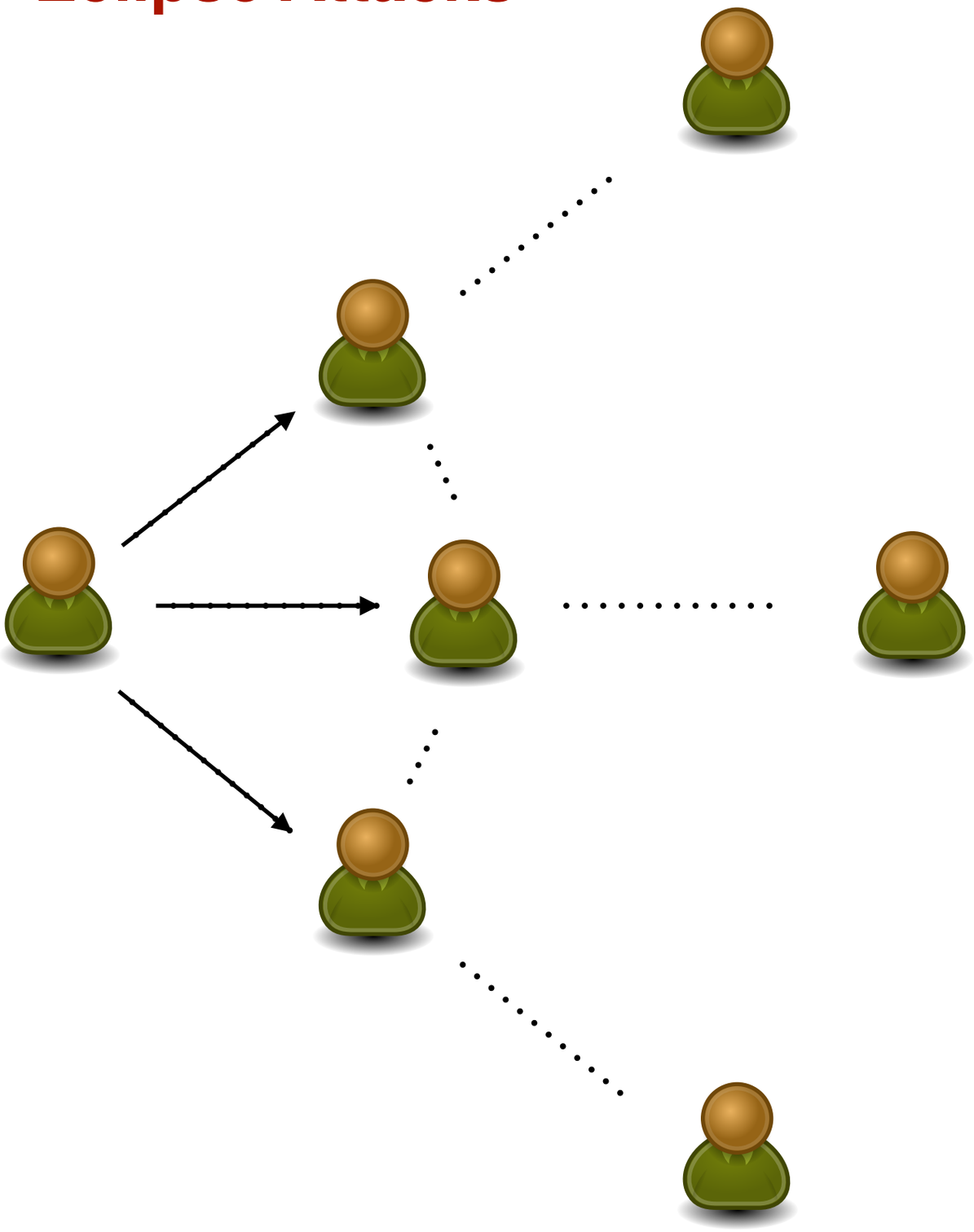
https://github.com/bitcoin/bips/blob/master/bip-0152.mediawiki

Network Security - Eclipse Attacks

Eclipse Attacks



Eclipse Attacks



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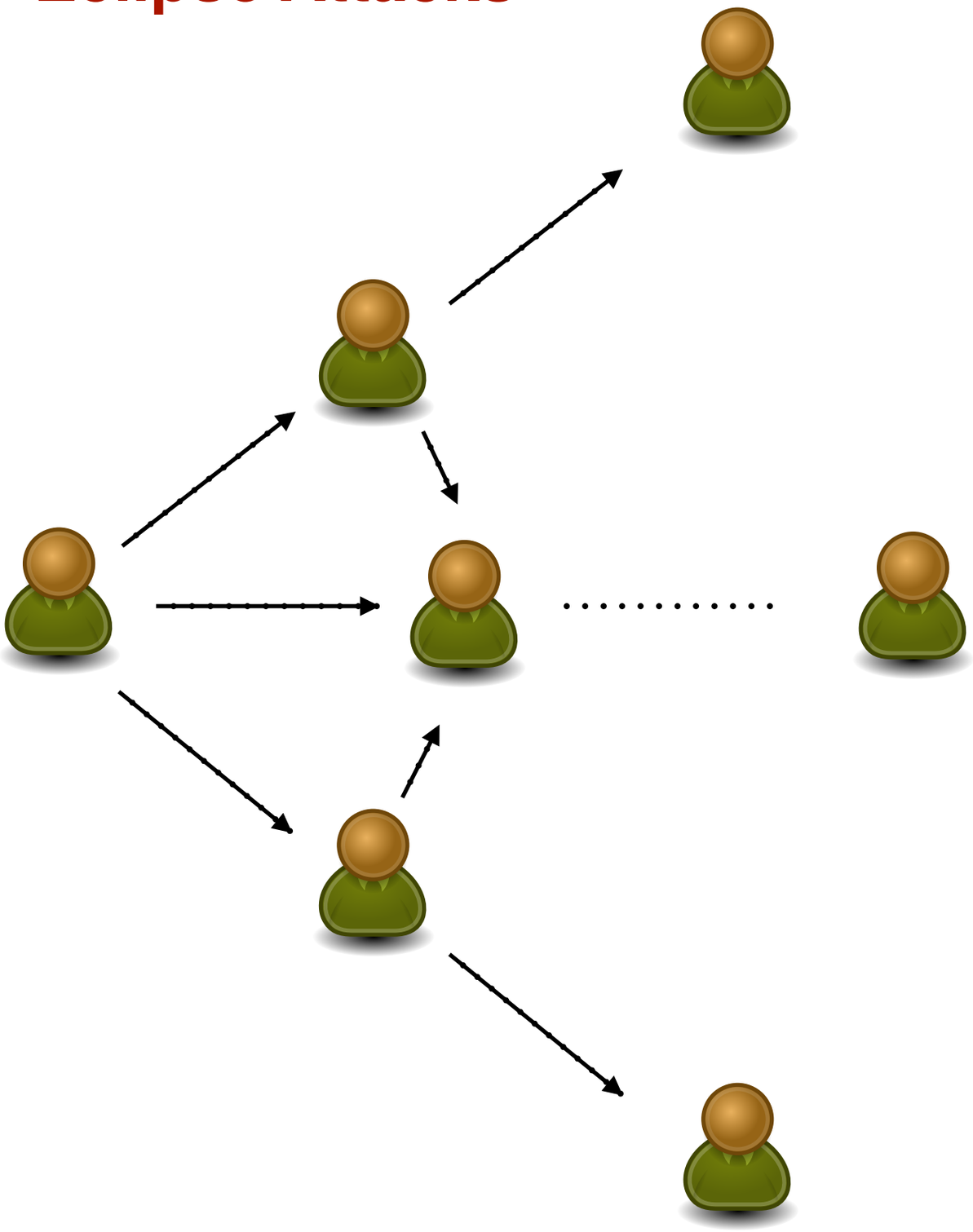

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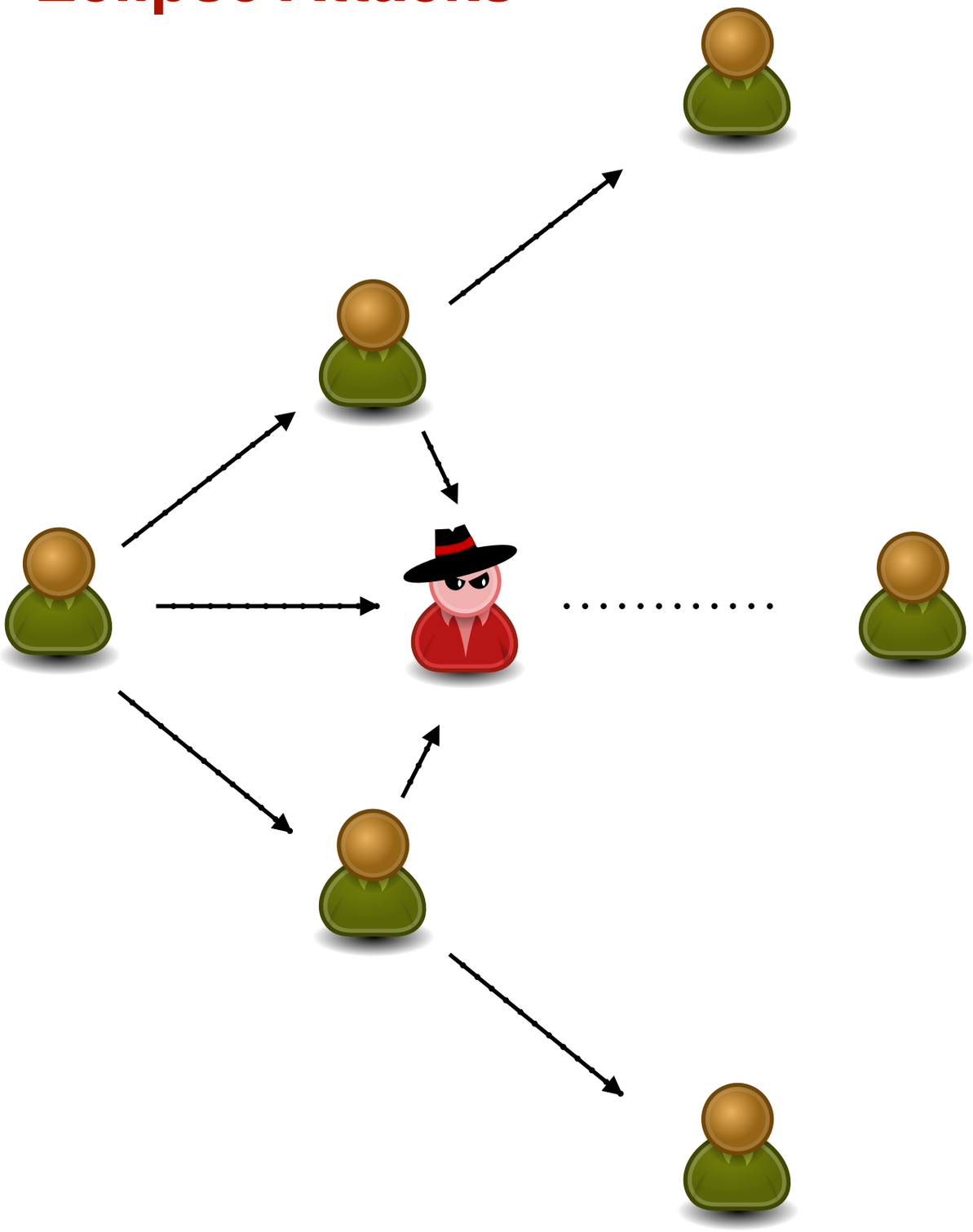

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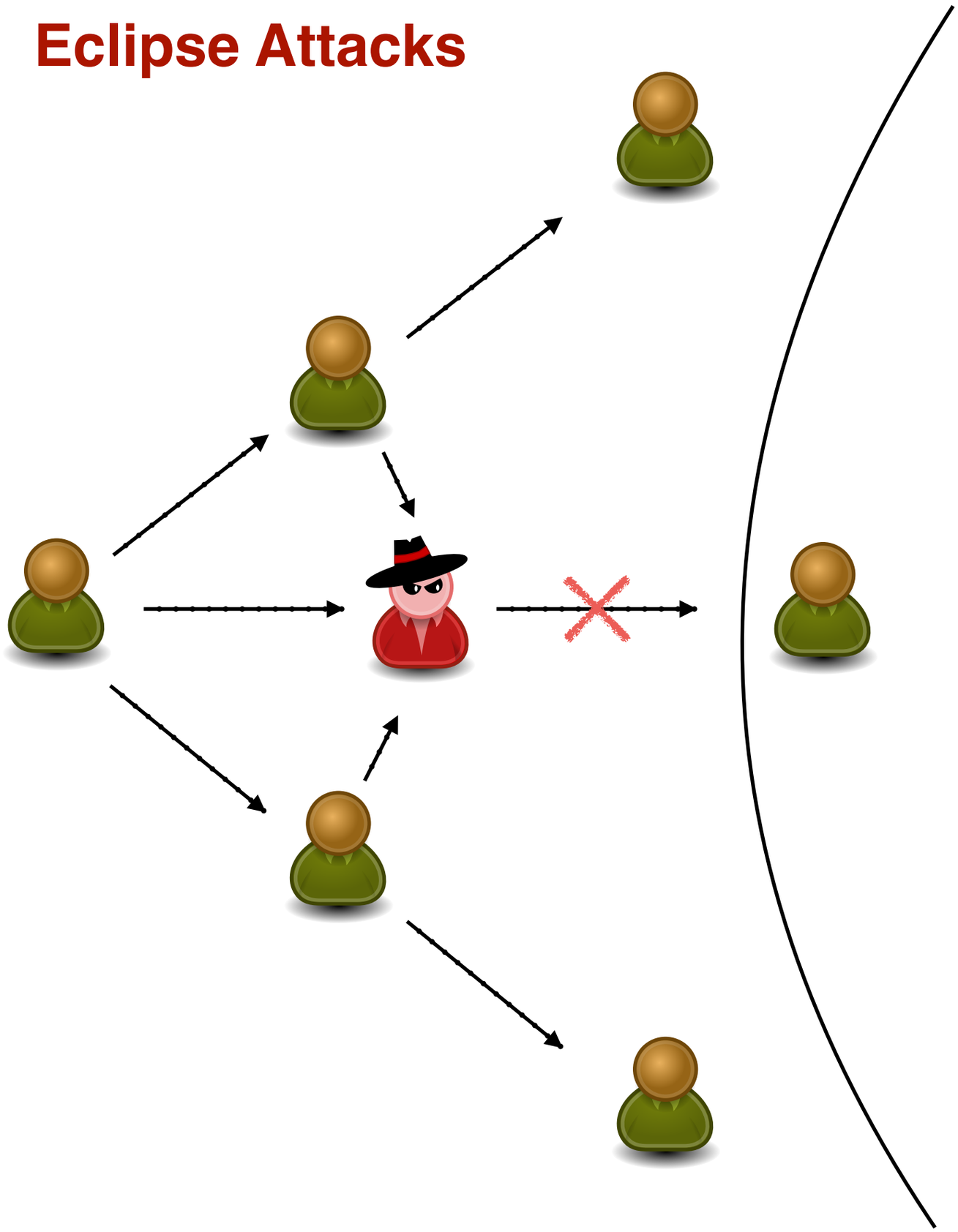

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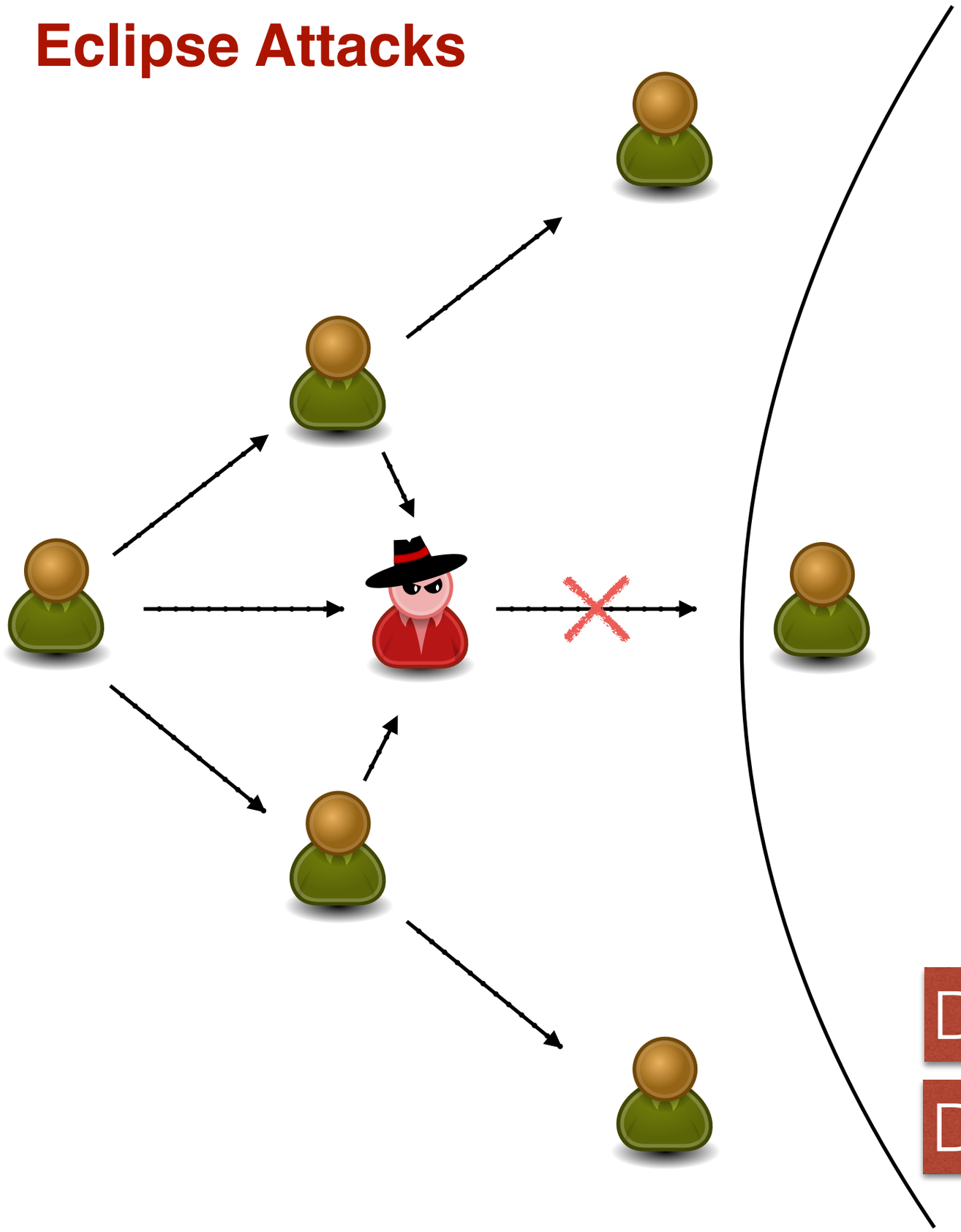
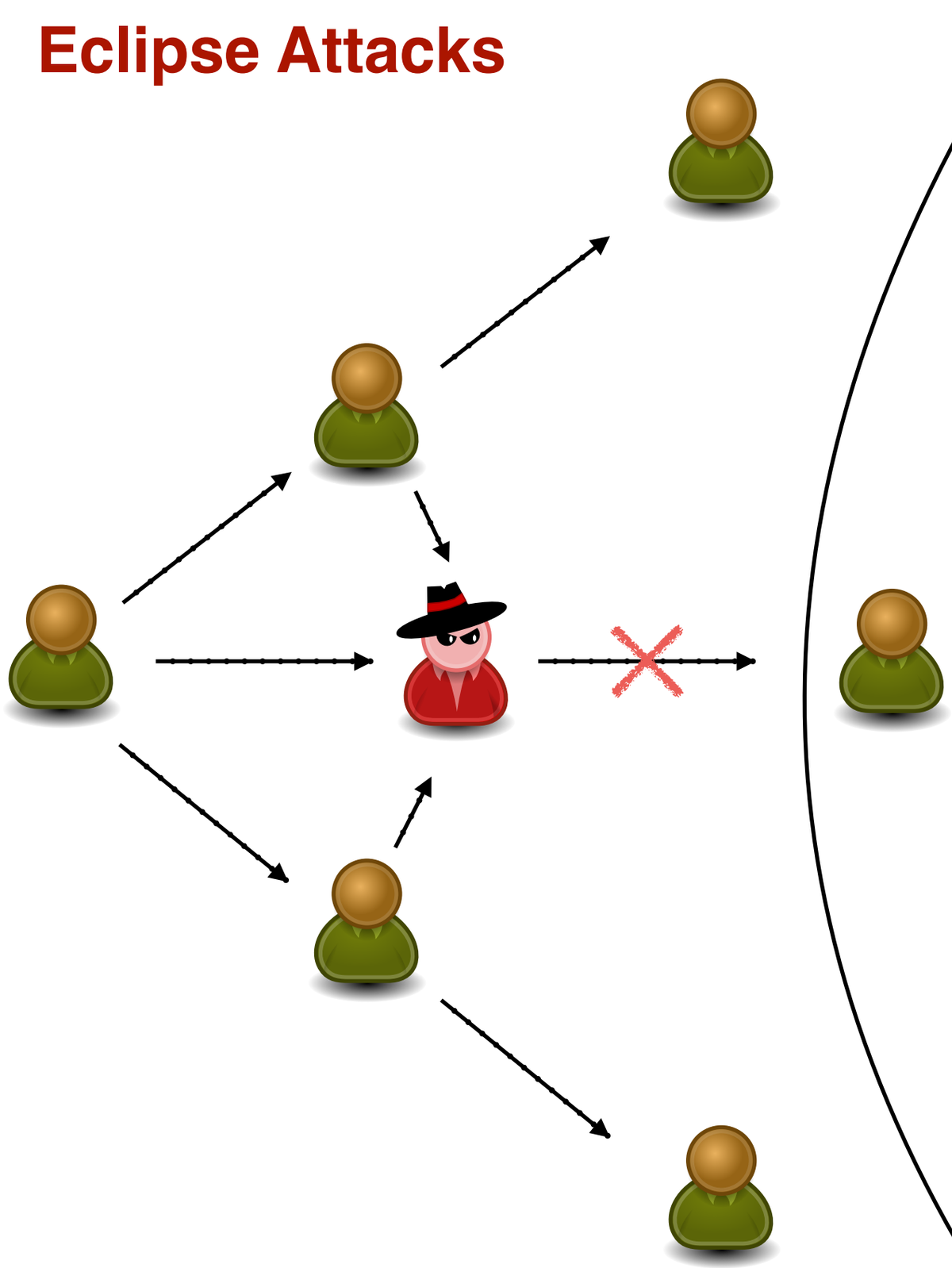


Denial of Service

Double Spending

Eclipse Attacks

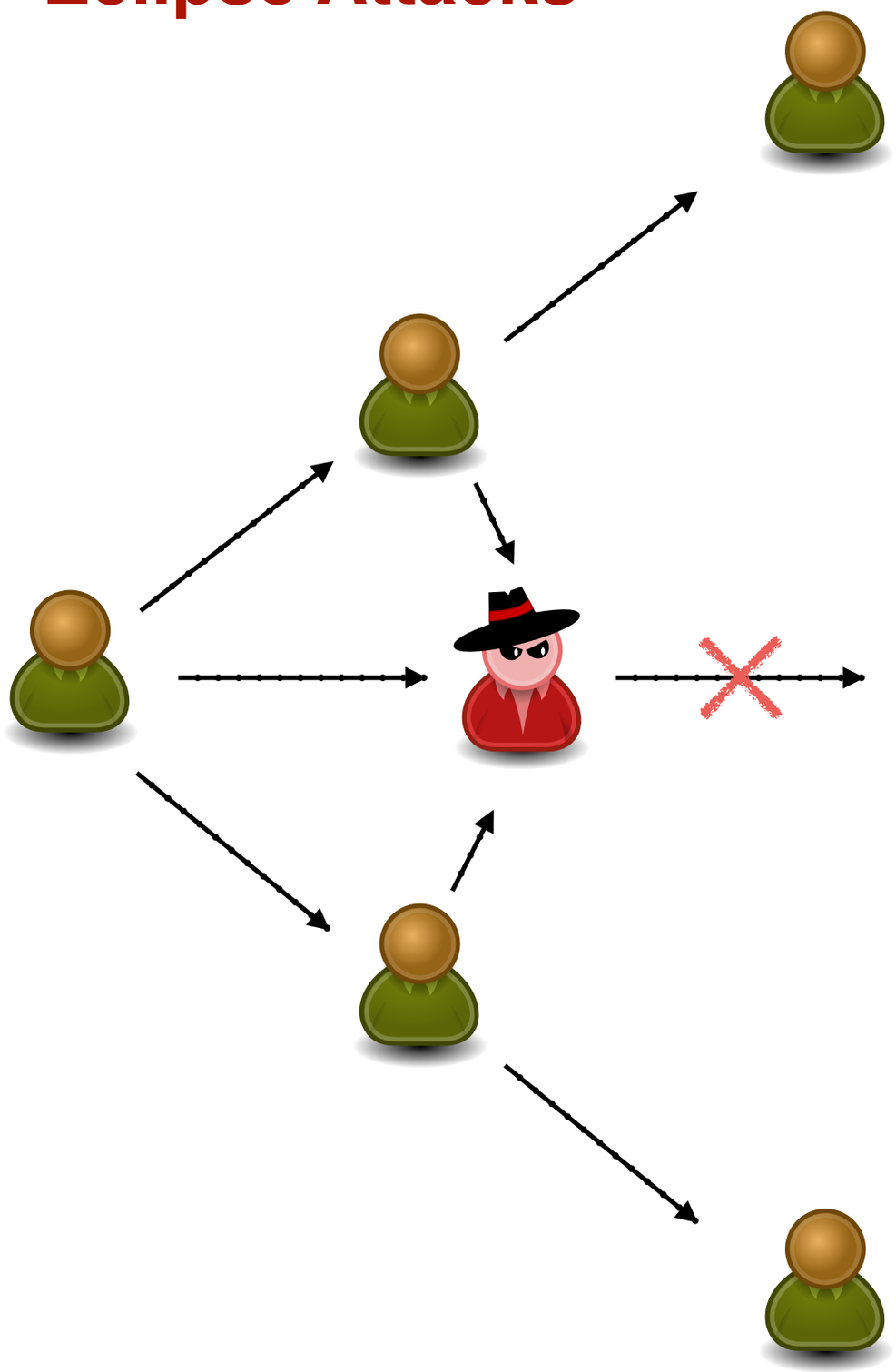


Eclipse attacks
Heilman et al., Usenix ’15

Denial of Service

Double Spending

Eclipse Attacks



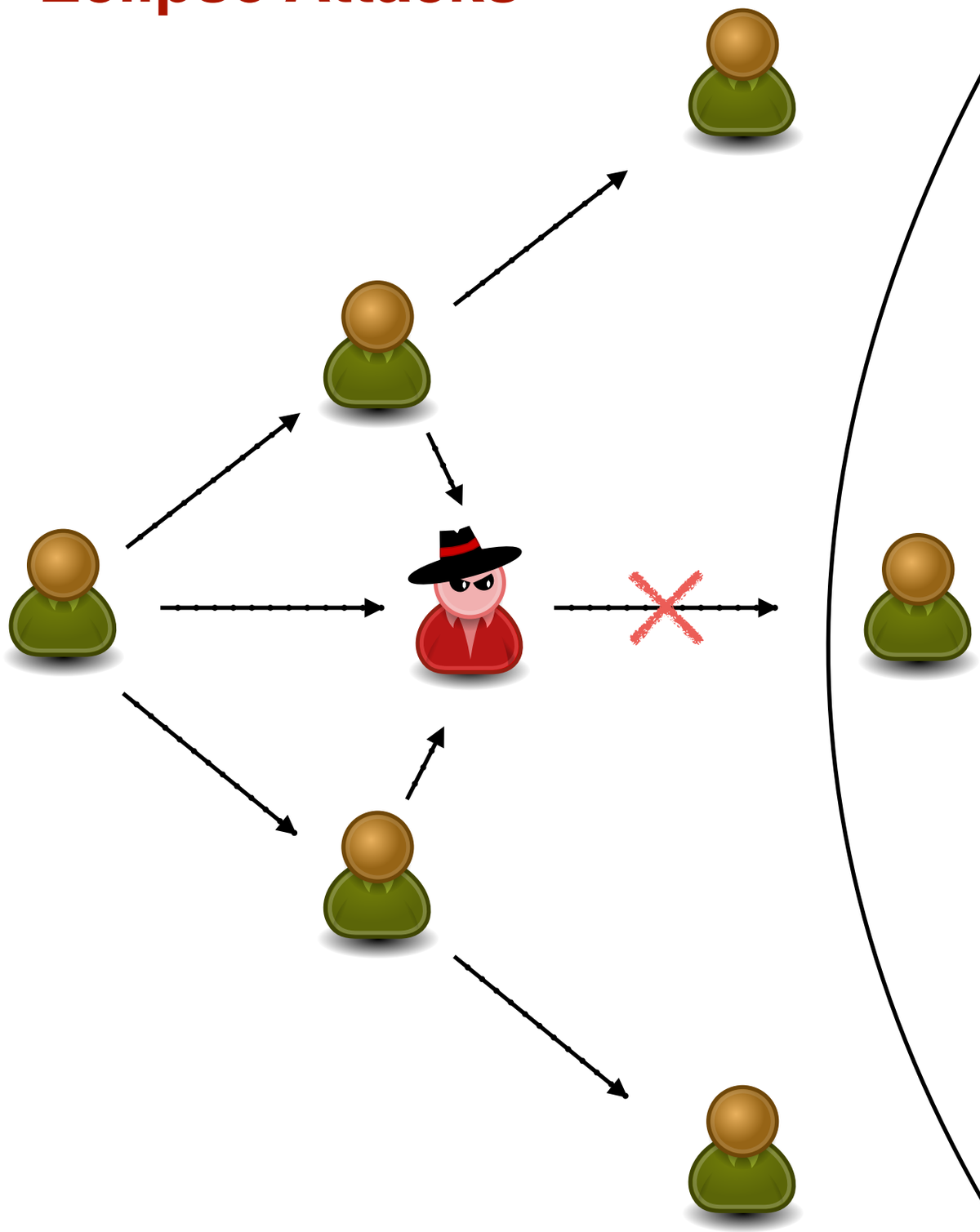
Eclipse attacks
Heilman et al., Usenix ’15

Monopolize connections
Spamming addresses
Forcing node restart
Requires many bots

Denial of Service

Double Spending

Eclipse Attacks



1 connection sufficient
No victim restart necessary

Eclipse attacks
Heilman et al., Usenix ’15

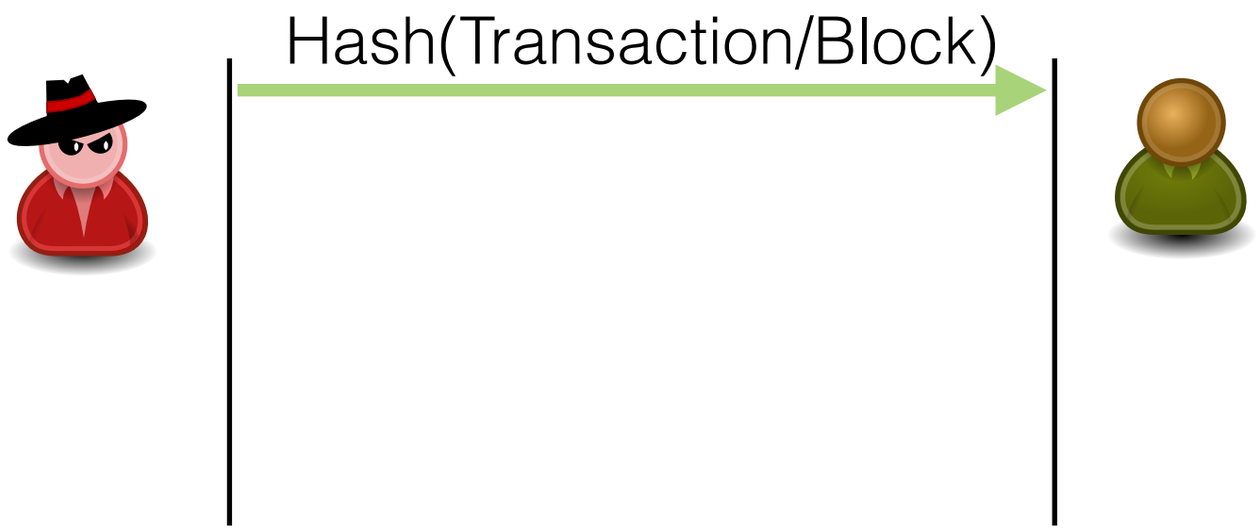
Monopolize connections
Spamming addresses
Forcing node restart
Requires many bots

Denial of Service

Double Spending

Request timeouts

Request timeouts



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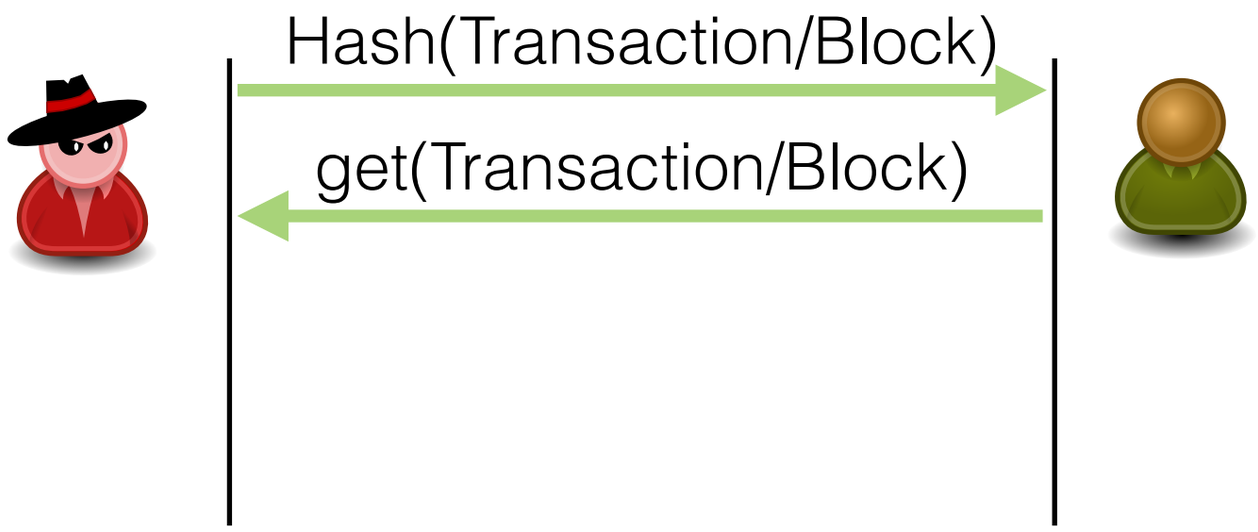

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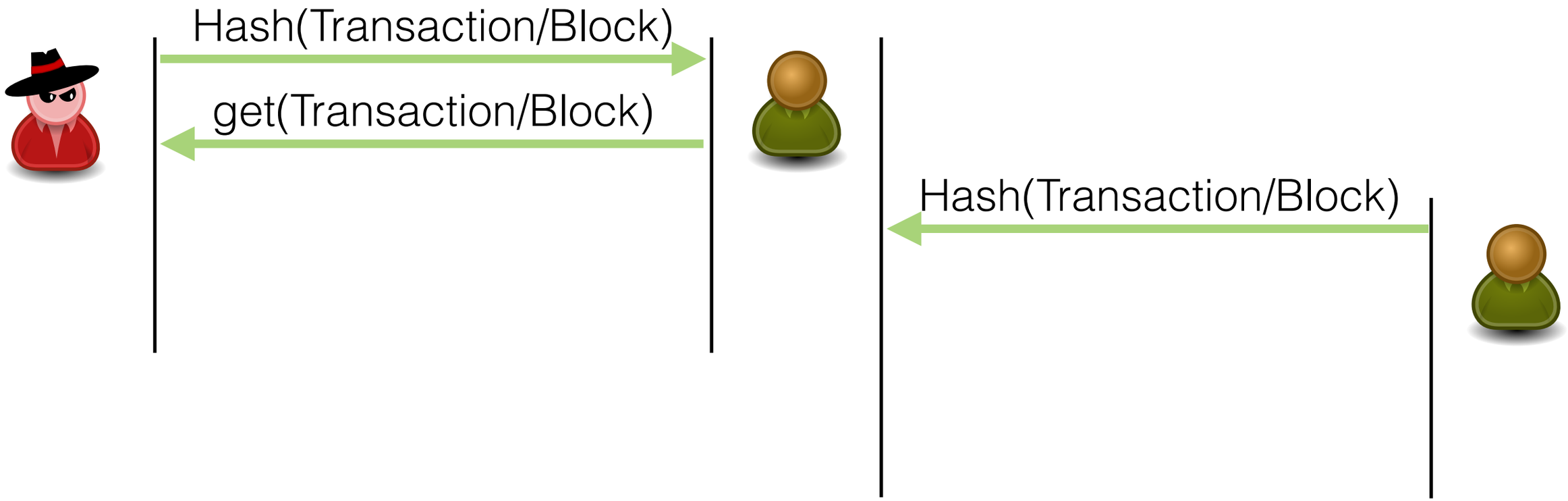

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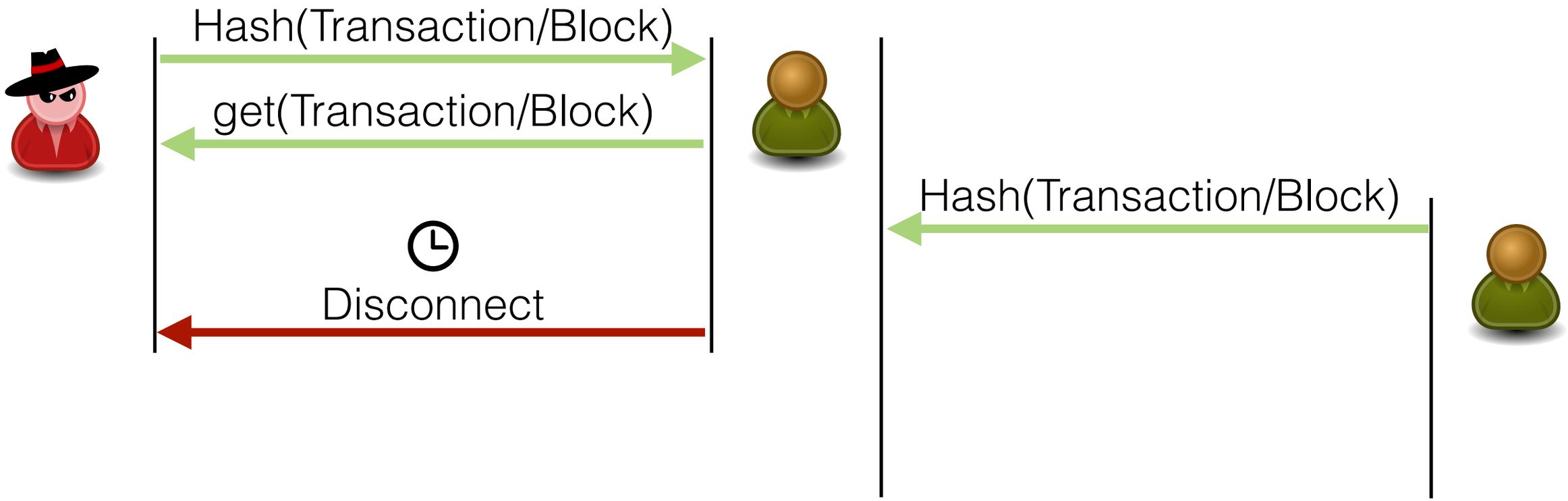

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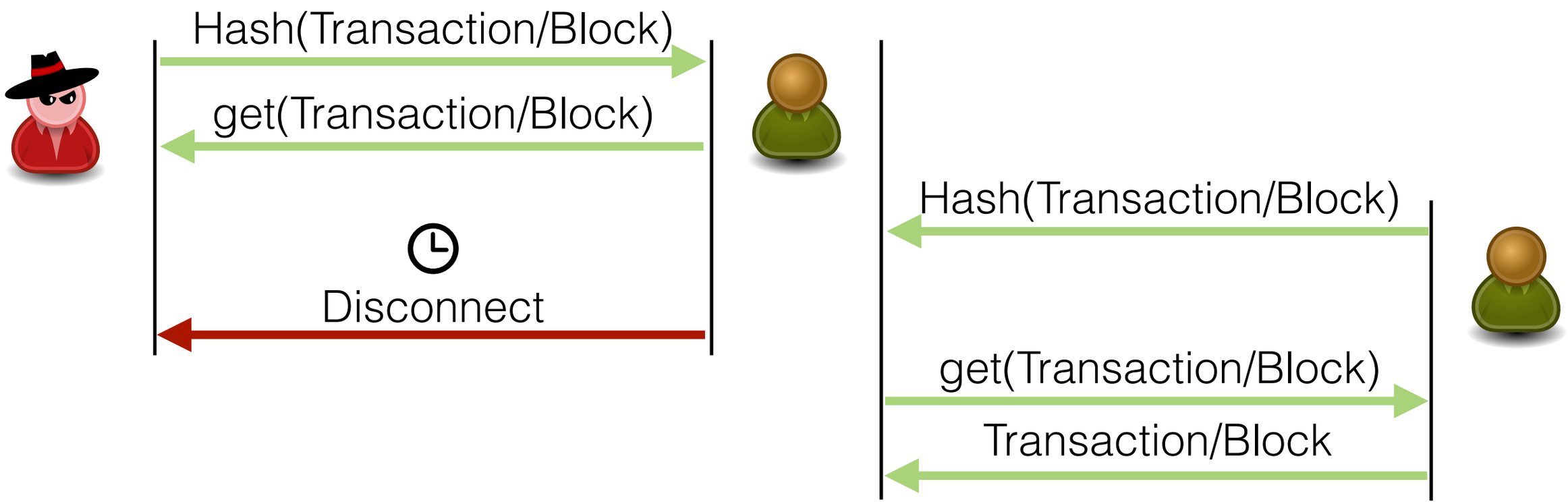

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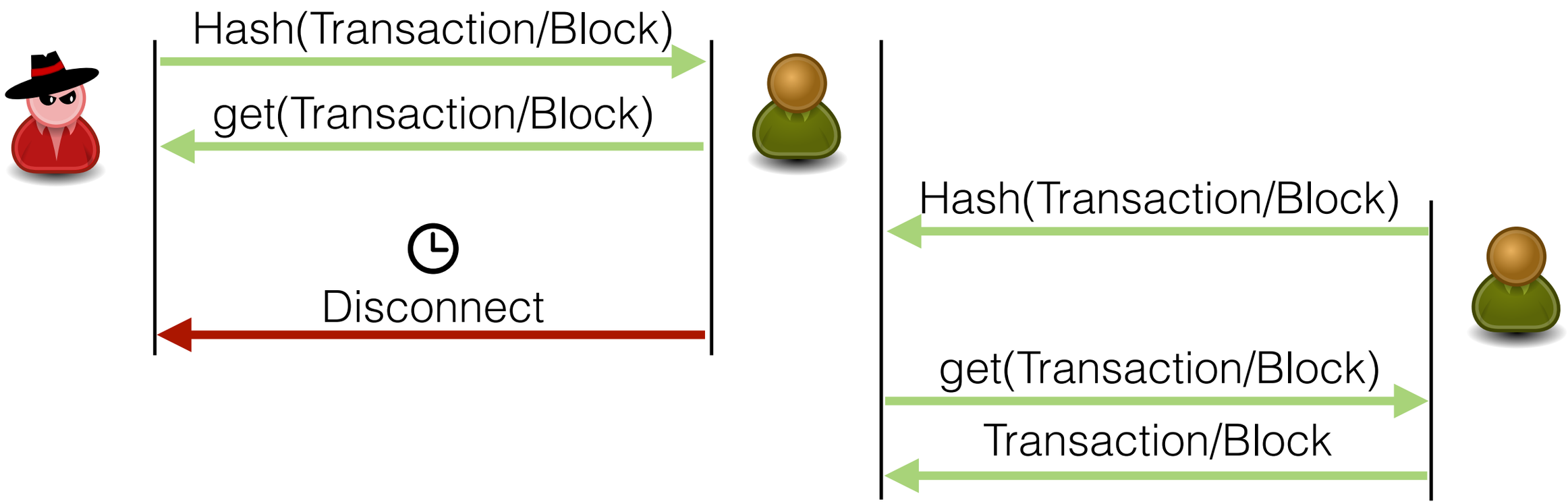


Block timeout: 20 minutes
Transaction timeout: 2 minutes

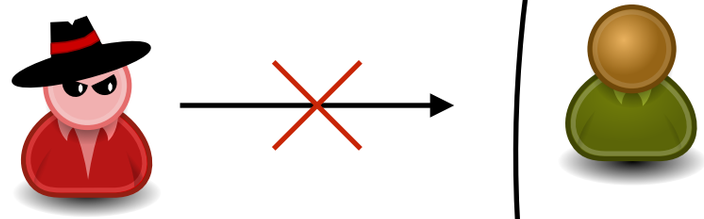
Implications

Adversary

- Blinds victim from blocks and transaction > 20 min
- Experimental validation

Impact

- **Double spend transactions**
- Aggravated selfish mining
- **Network wide Denial of Service**

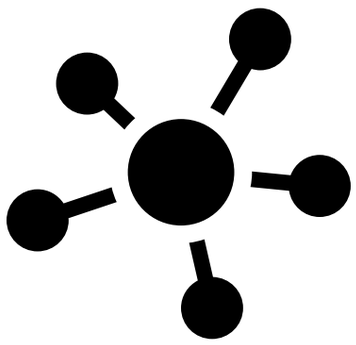


Mitigations

- **Hardening measures**
- Estimate waiting time for secure transactions

Necessary requirements

1. Must be **first** peer to advertise Transaction/Block



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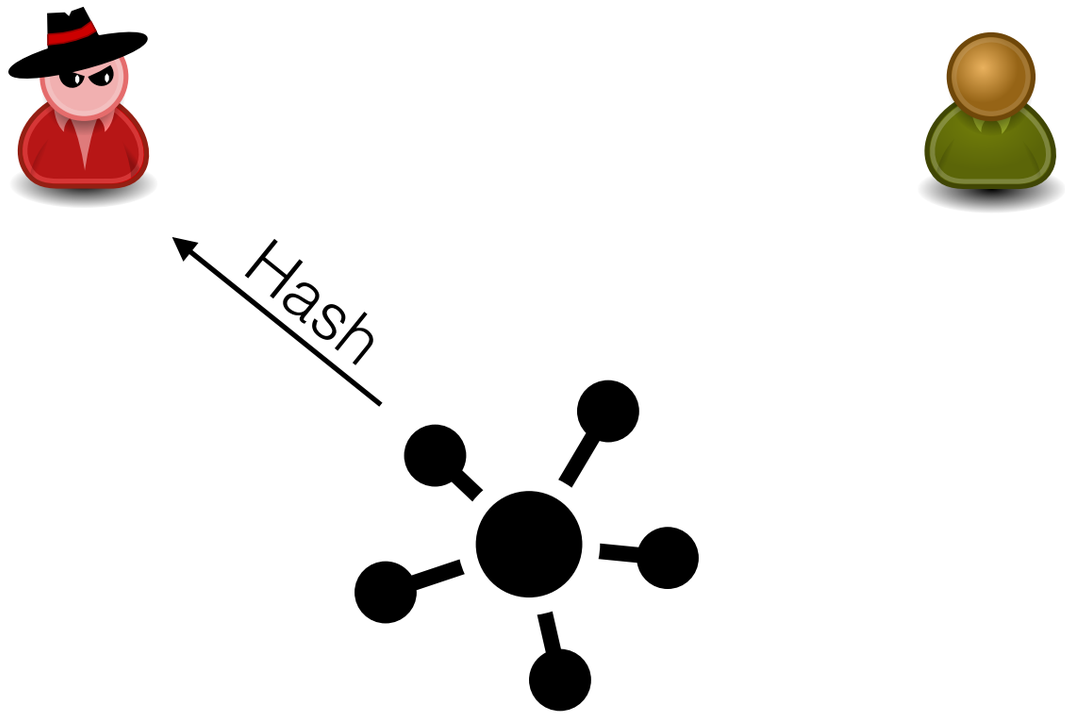

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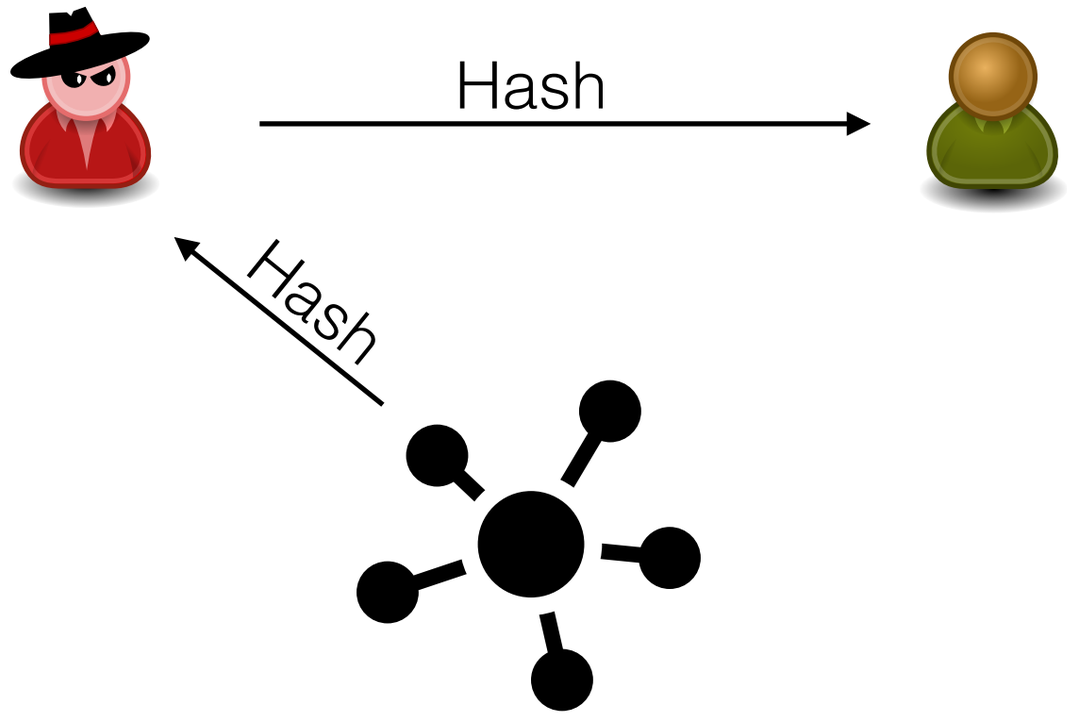

Necessary requirements

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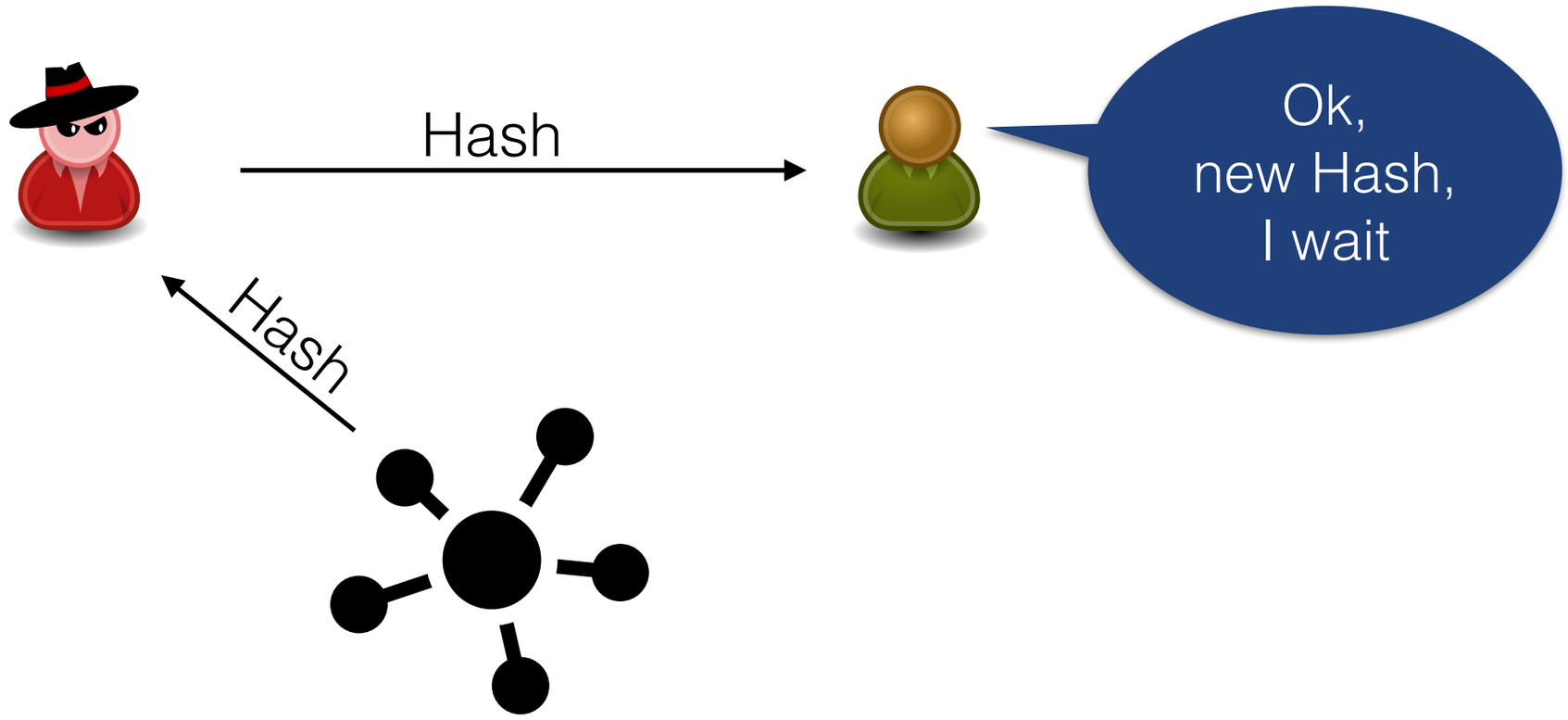

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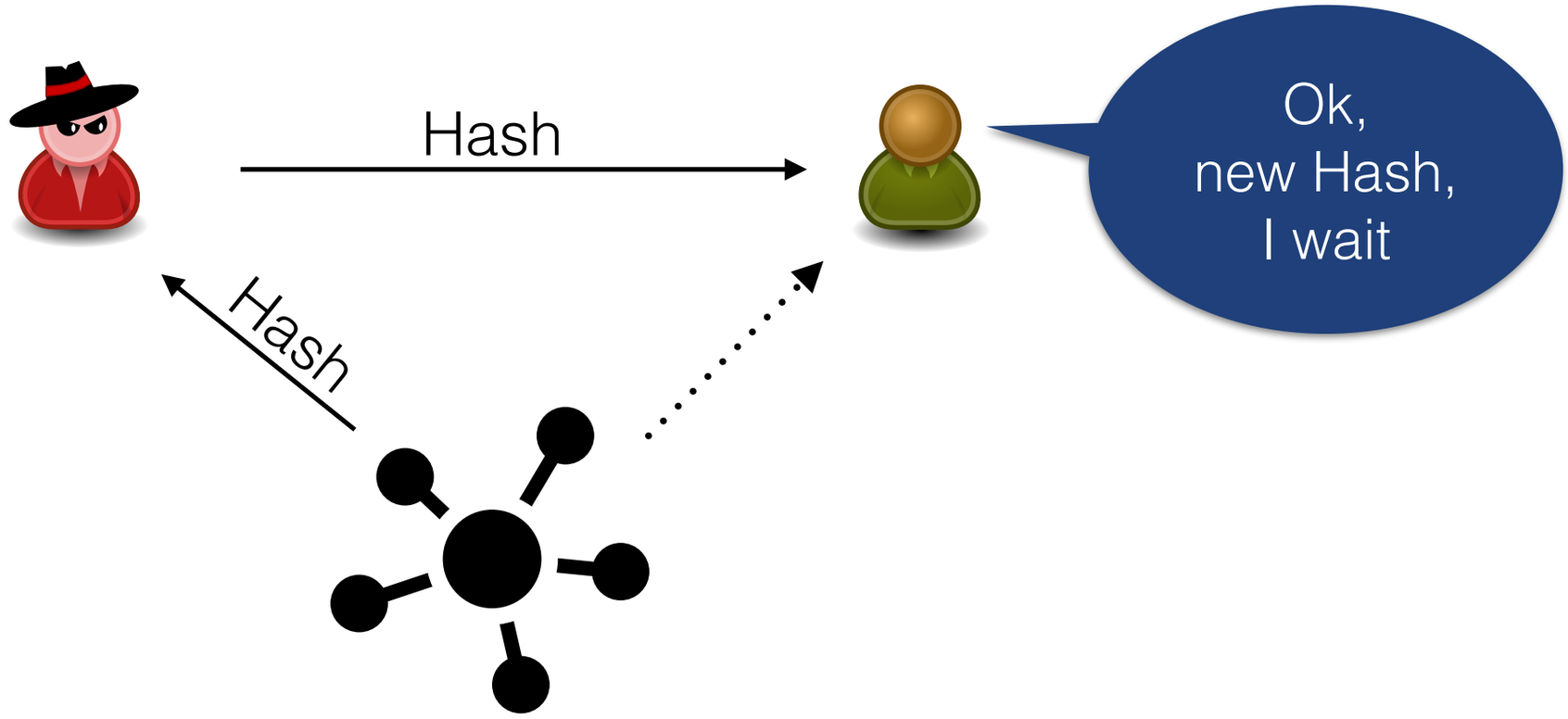

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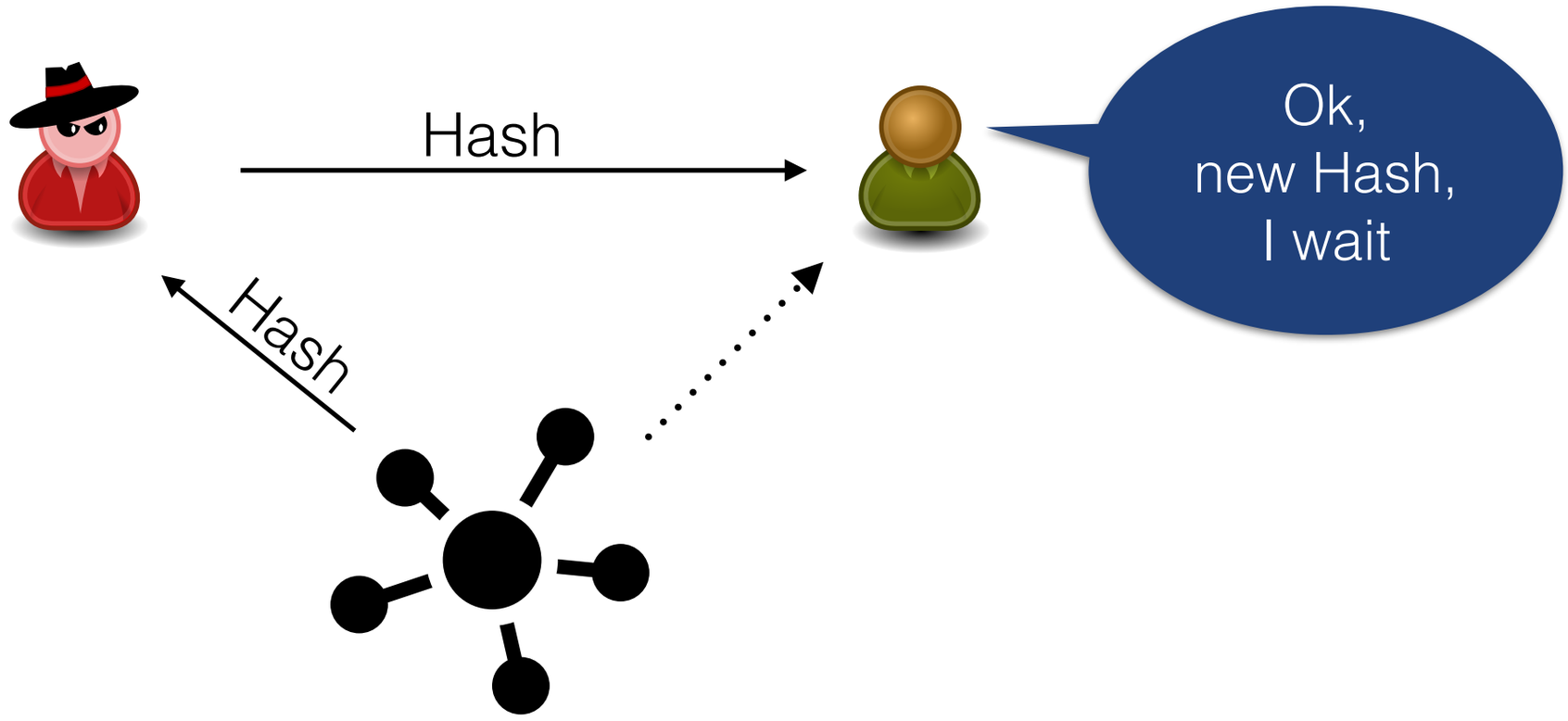
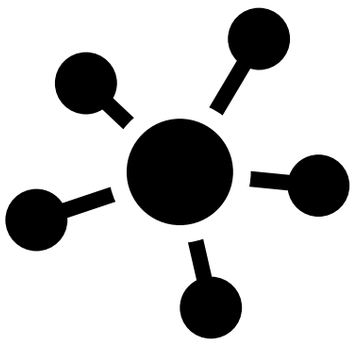


2. Victim should wait
   - Block timeout: 20 minutes
   - Transaction timeout: 2 minutes

Being First

Zurich



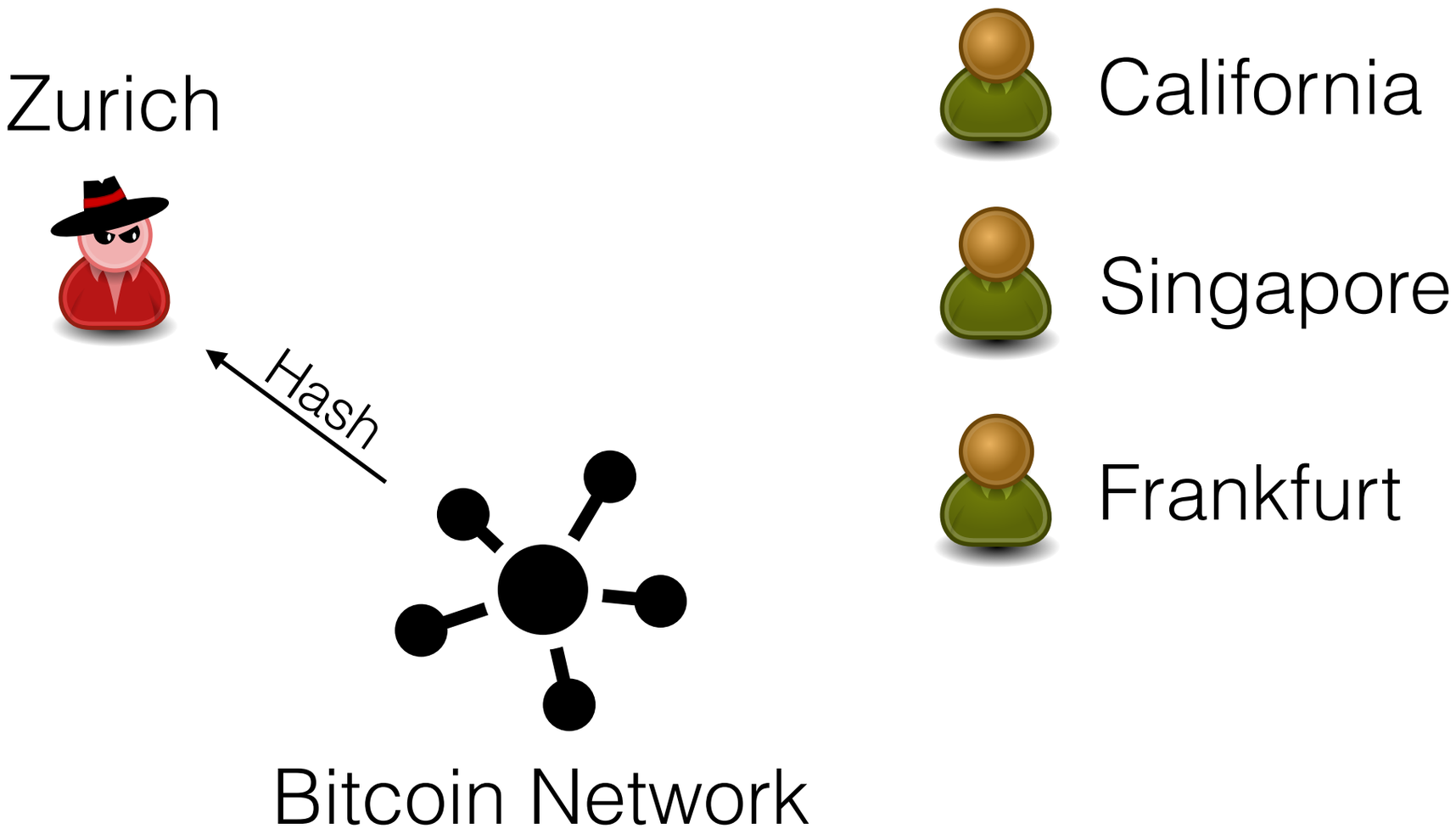
Bitcoin Network

California

Singapore

Frankfurt

Being First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Hash
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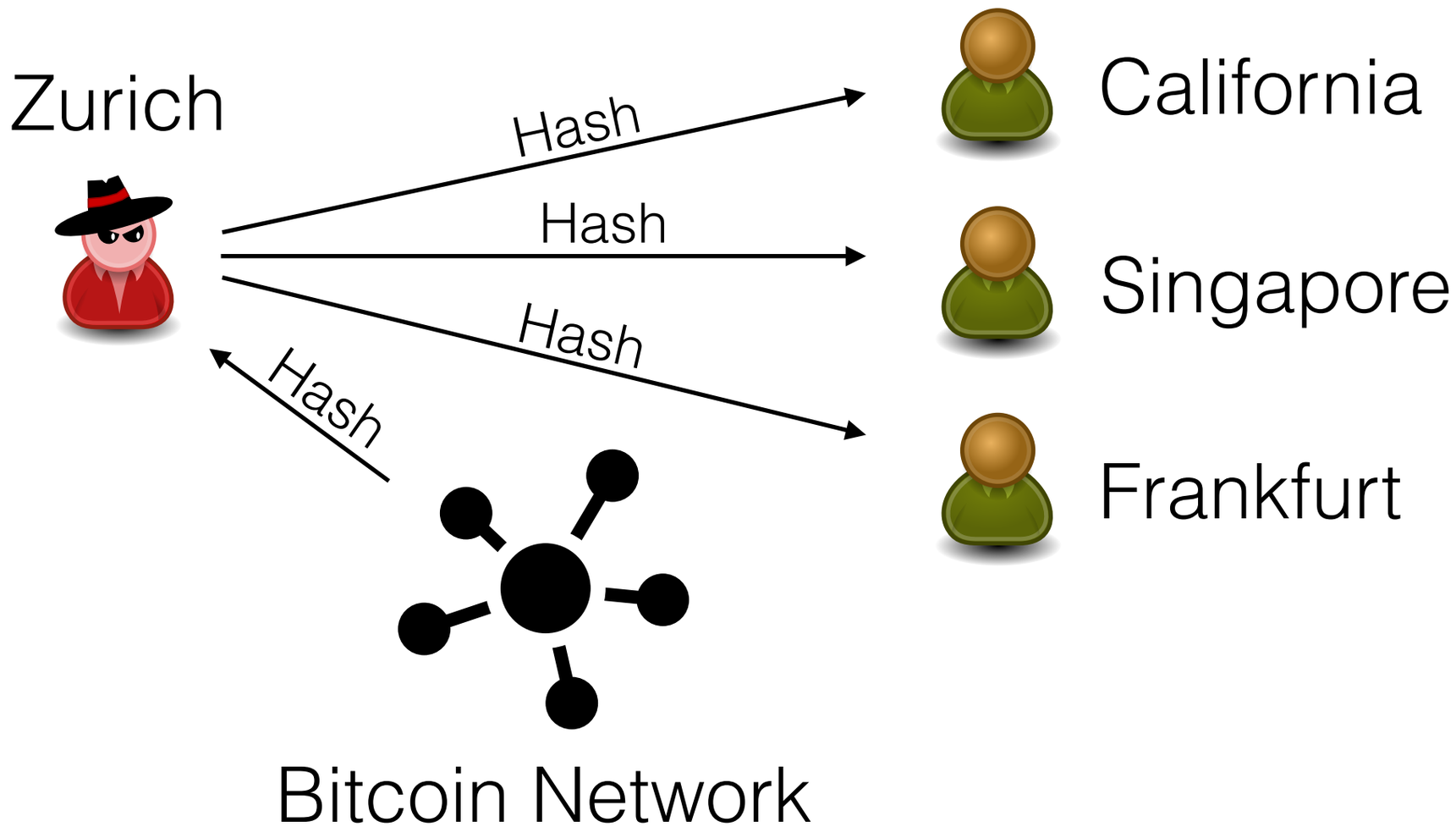
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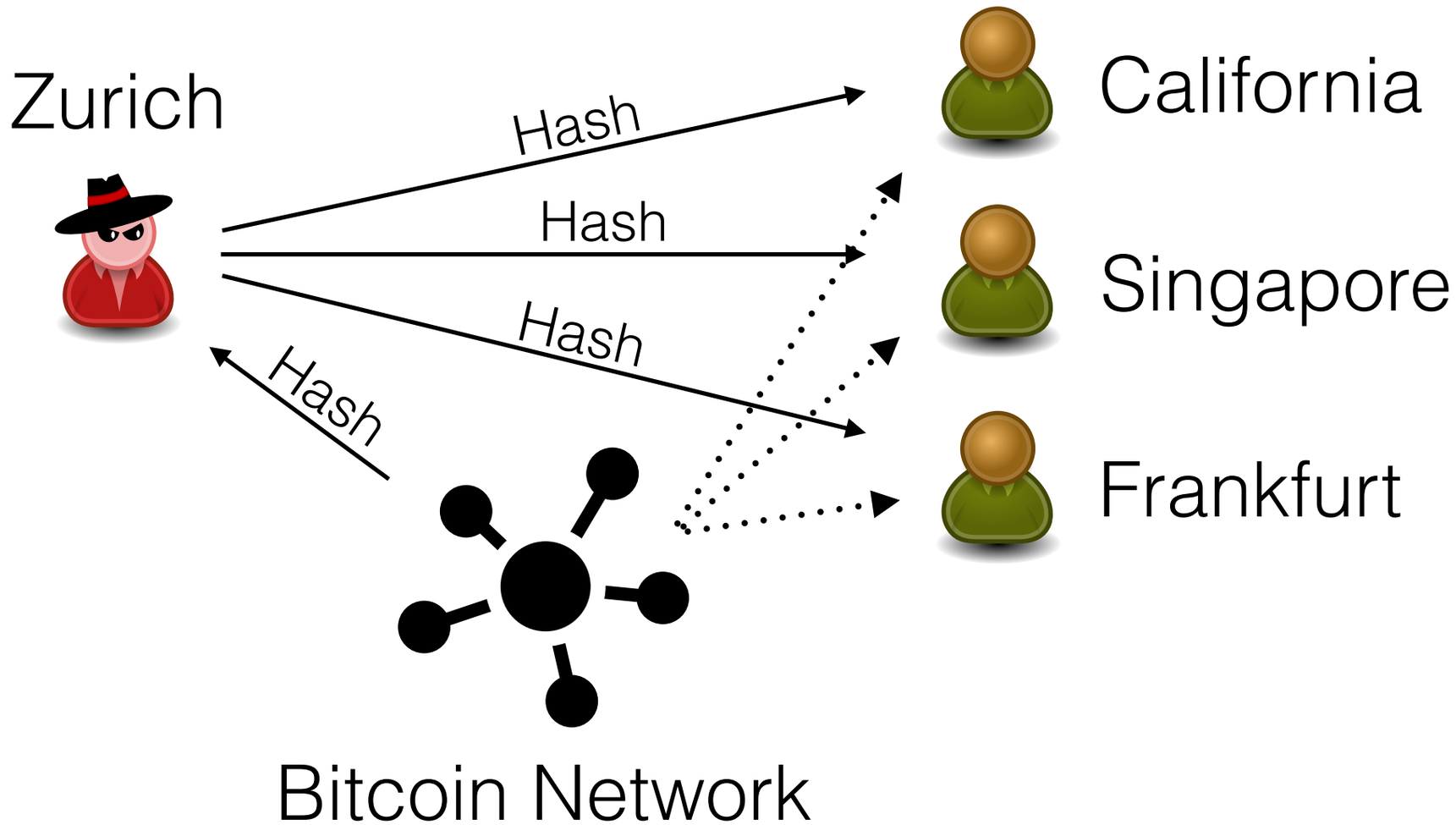
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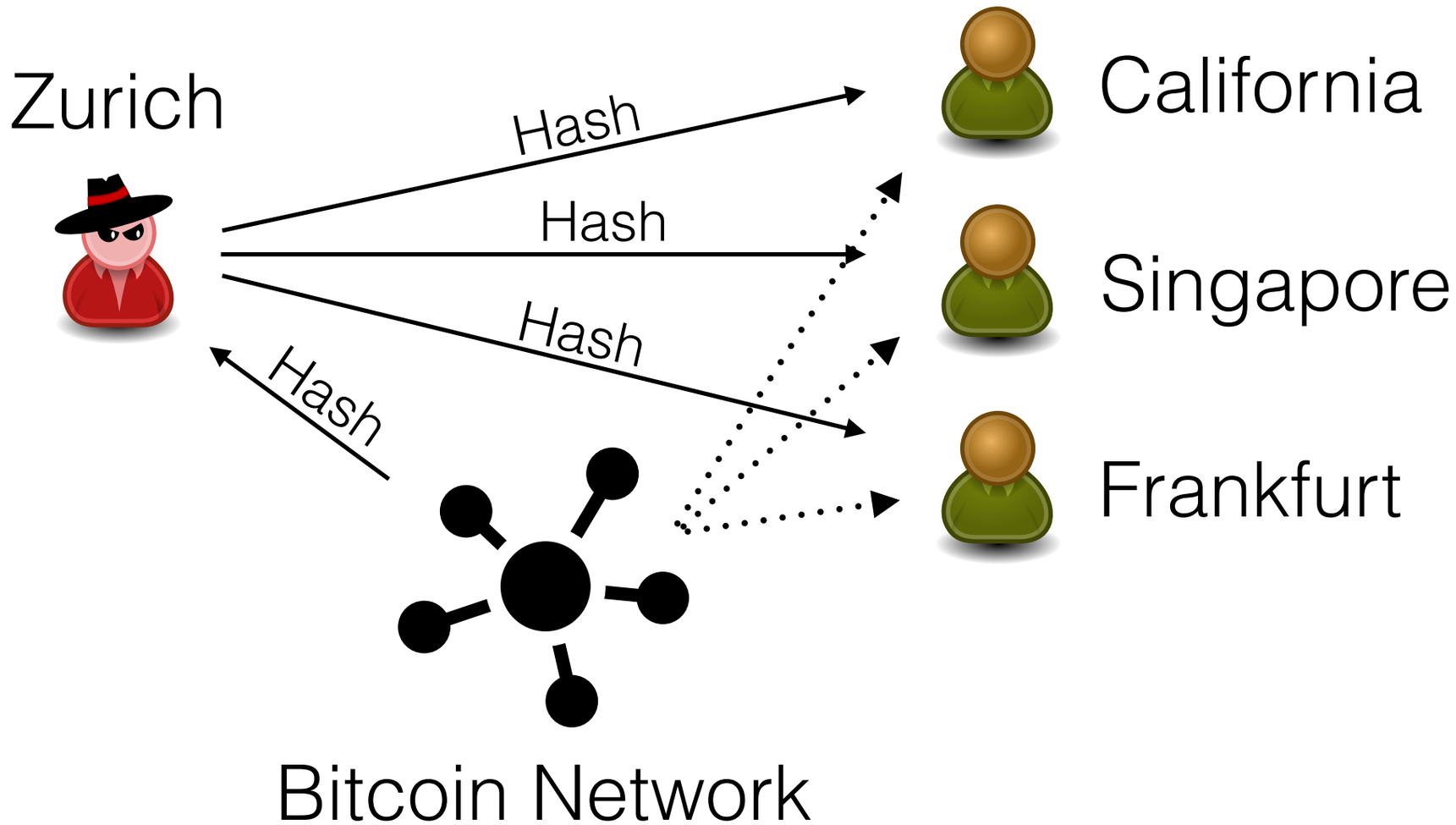

Connections of Adversary	40	80	200	800
Connections of Victim	40	40	40	40
Average success in being first	0.44± 0.14	0.57± 0.20	0.80± 0.14	**0.89± 0.07**

Waiting

Transactions

- After 2 minutes request from other peer (FIFO)

Waiting

Transactions

- After 2 minutes request from other peer (FIFO)

FIFO queue

Waiting

Transactions

- After 2 minutes request from other peer (FIFO)

Waiting

Transactions

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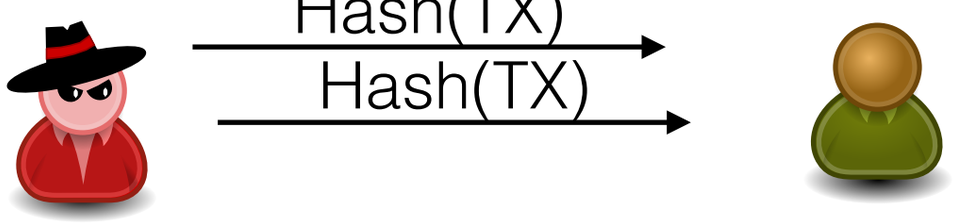

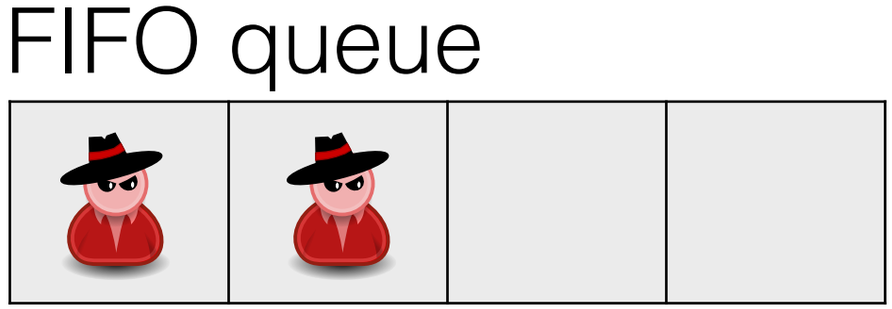

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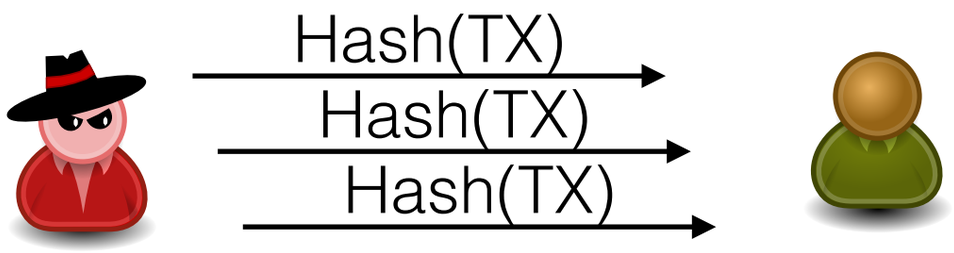

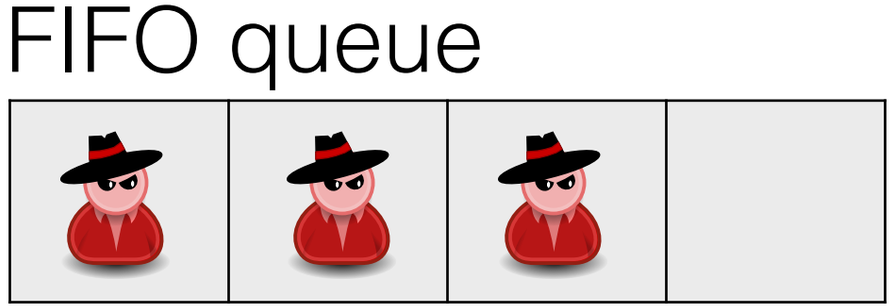

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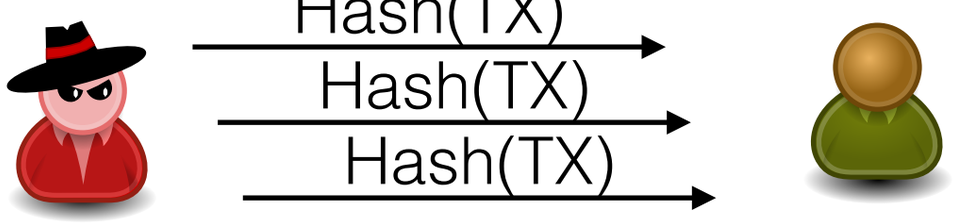

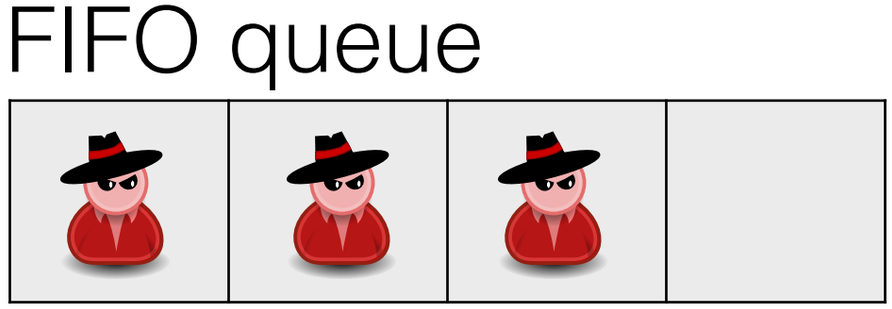

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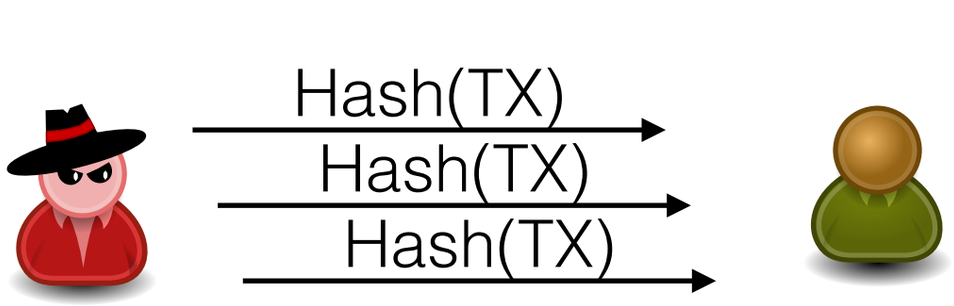
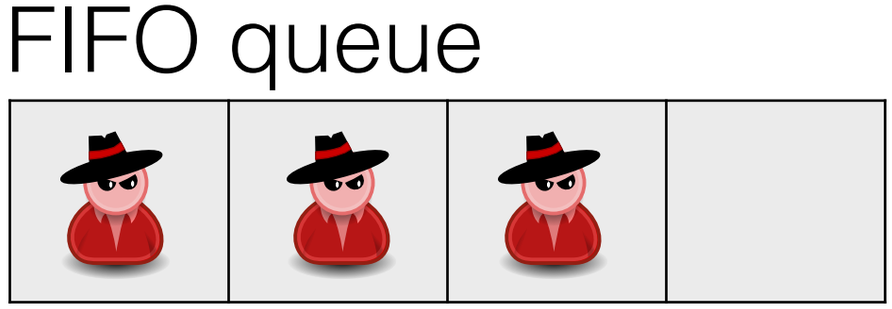




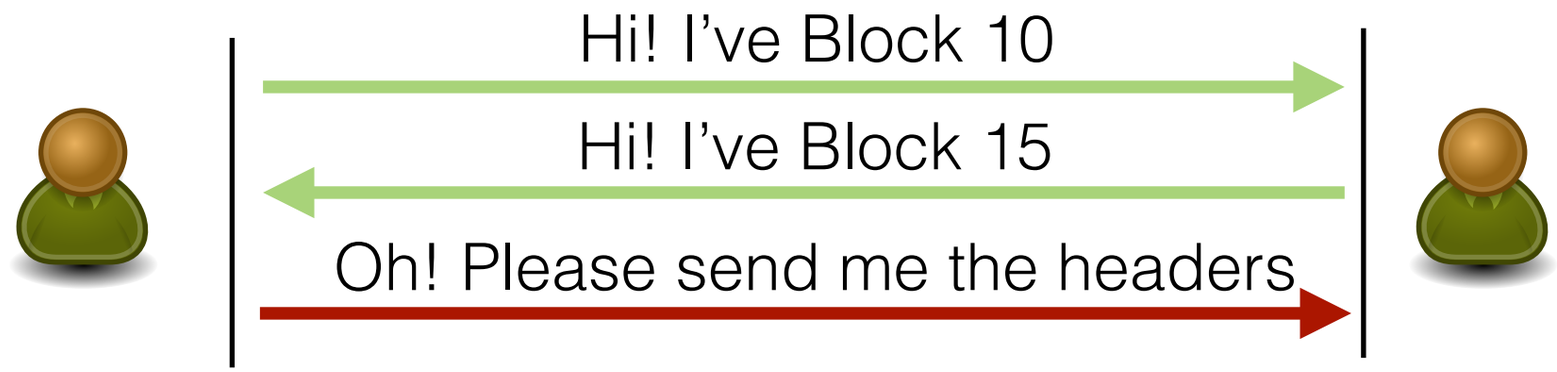
Blocks

- After 20 minutes disconnect and do nothing
- If received header, disconnect and request block from another peer

Eclipse Attacks - Delaying Blocks

Block delivery time > 20 min

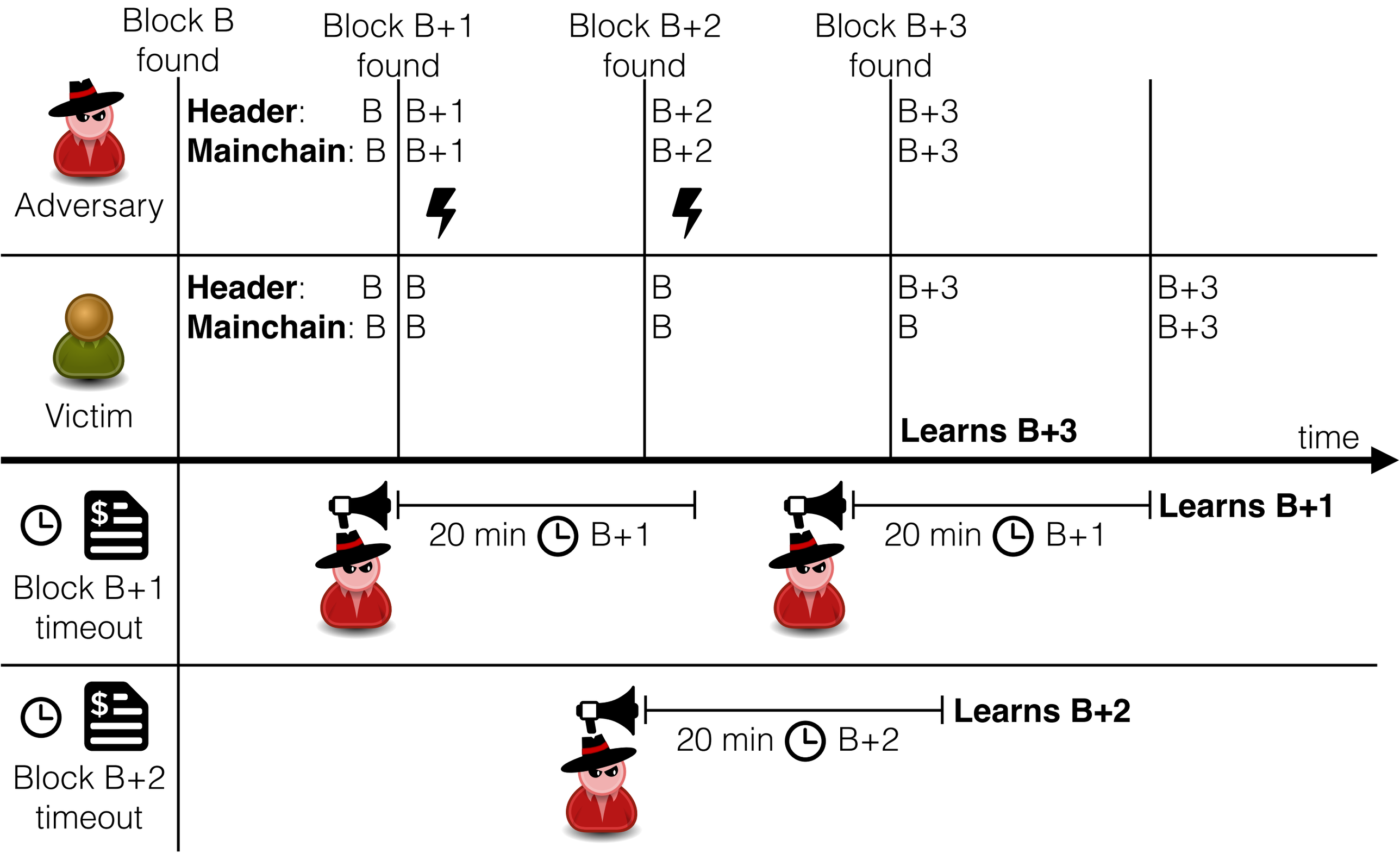
Version message exchange
on connection initiation



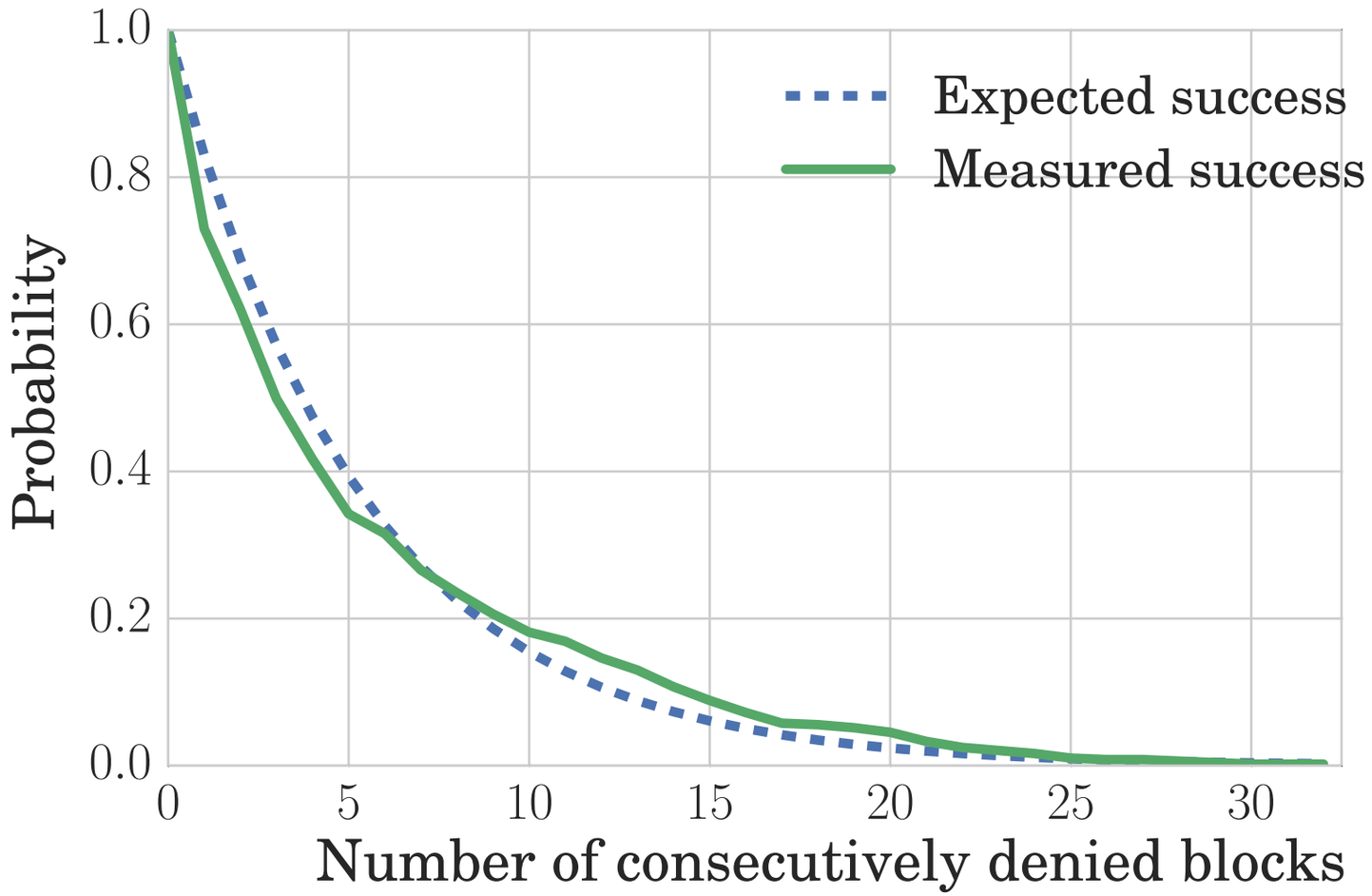
Occupy all open connection slots
No new connections

- Should perform connection depletion

Extending the block delivery time - Example



Experimental validation - Continuous block denial



Probability for N blocks = P^N

based on P = 0.83

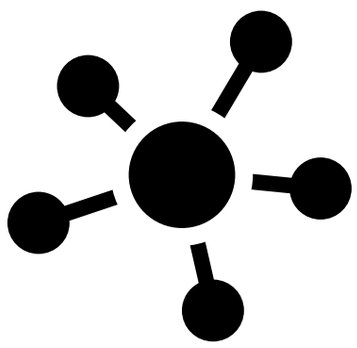
Eclipse Attacks - Double Spending

What is Double Spending?

Spending money more than once

$TX_{legitimate}$ - Pays the vendor

$TX_{doublespend}$ - Pays the adversary



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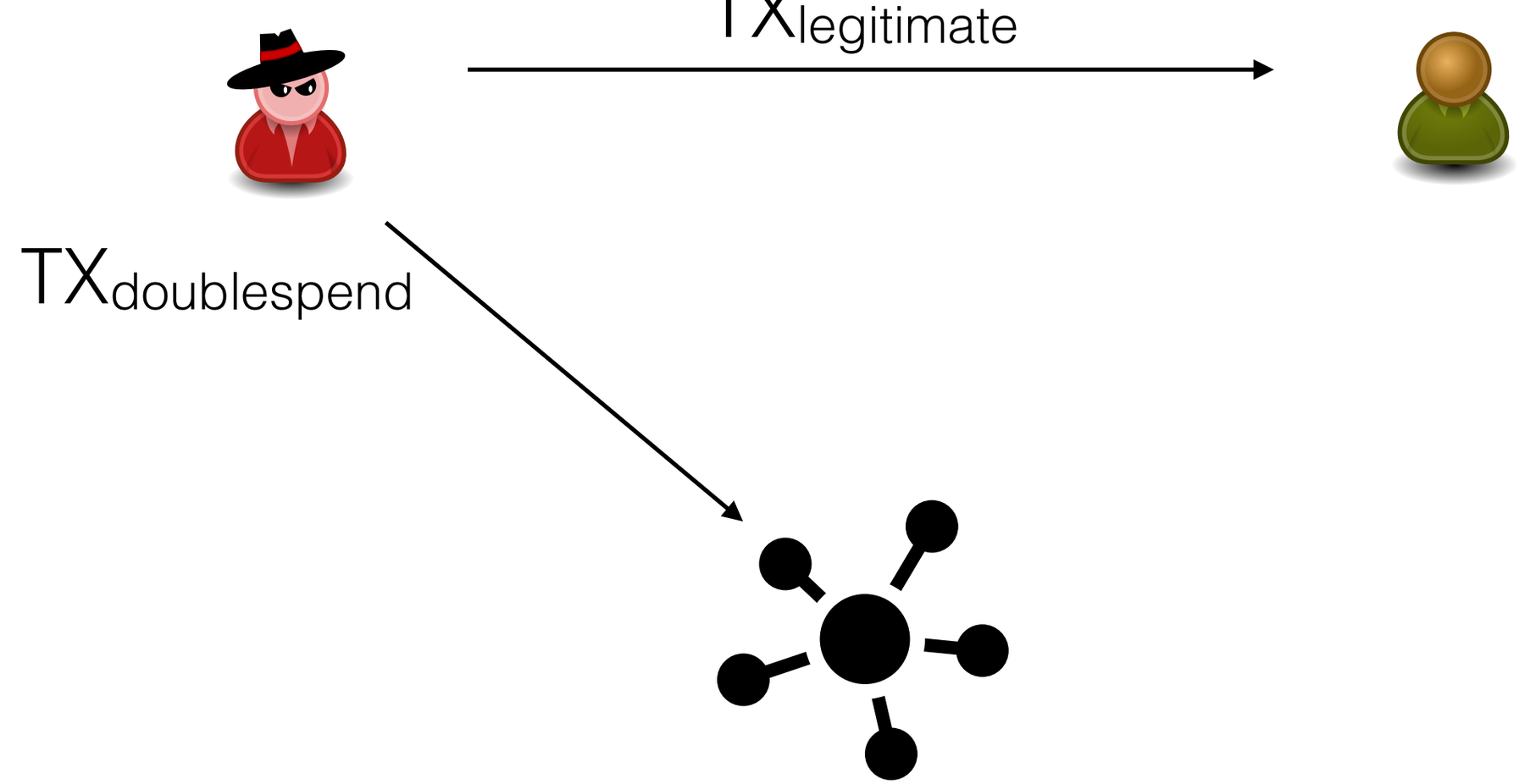

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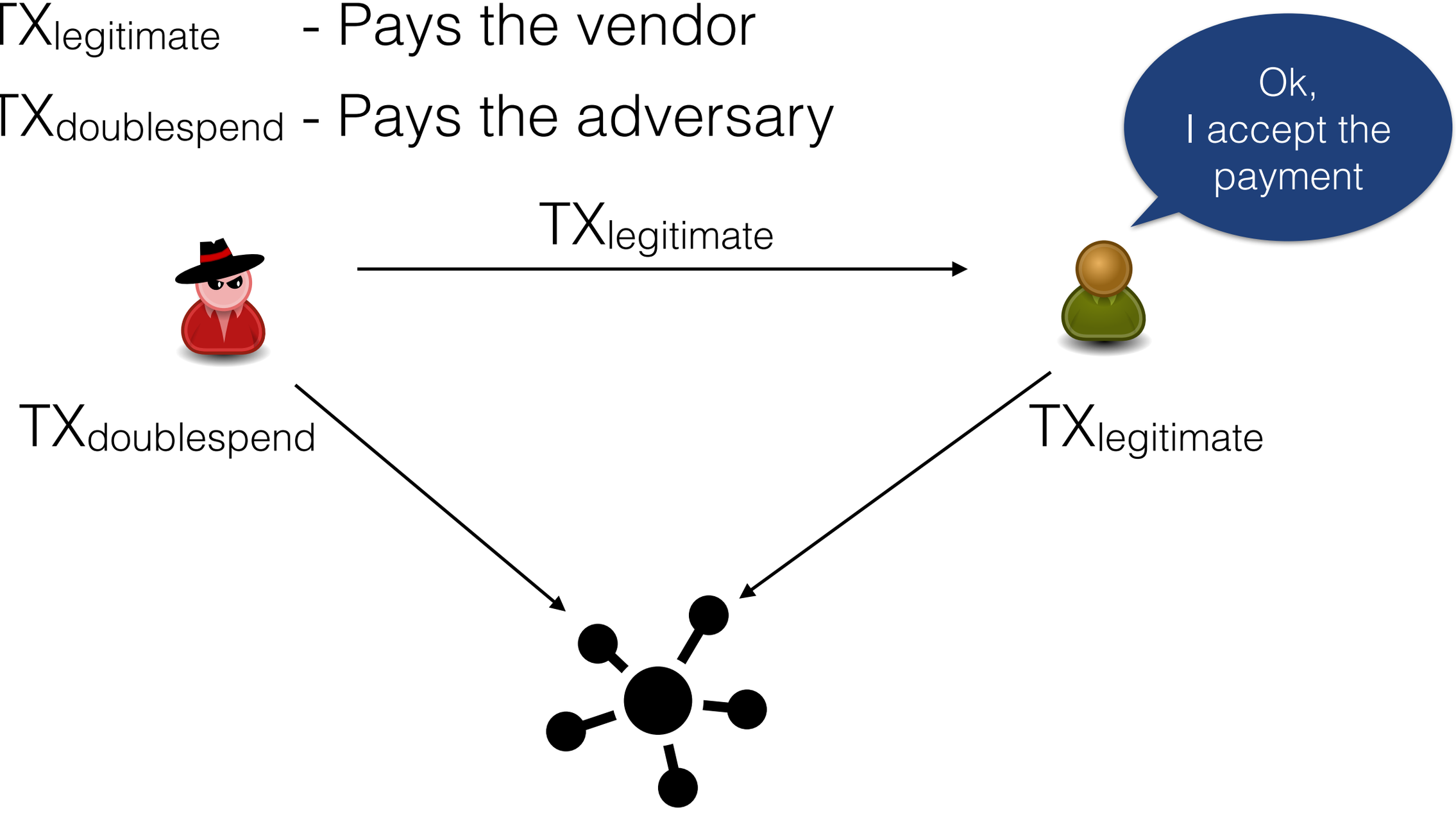

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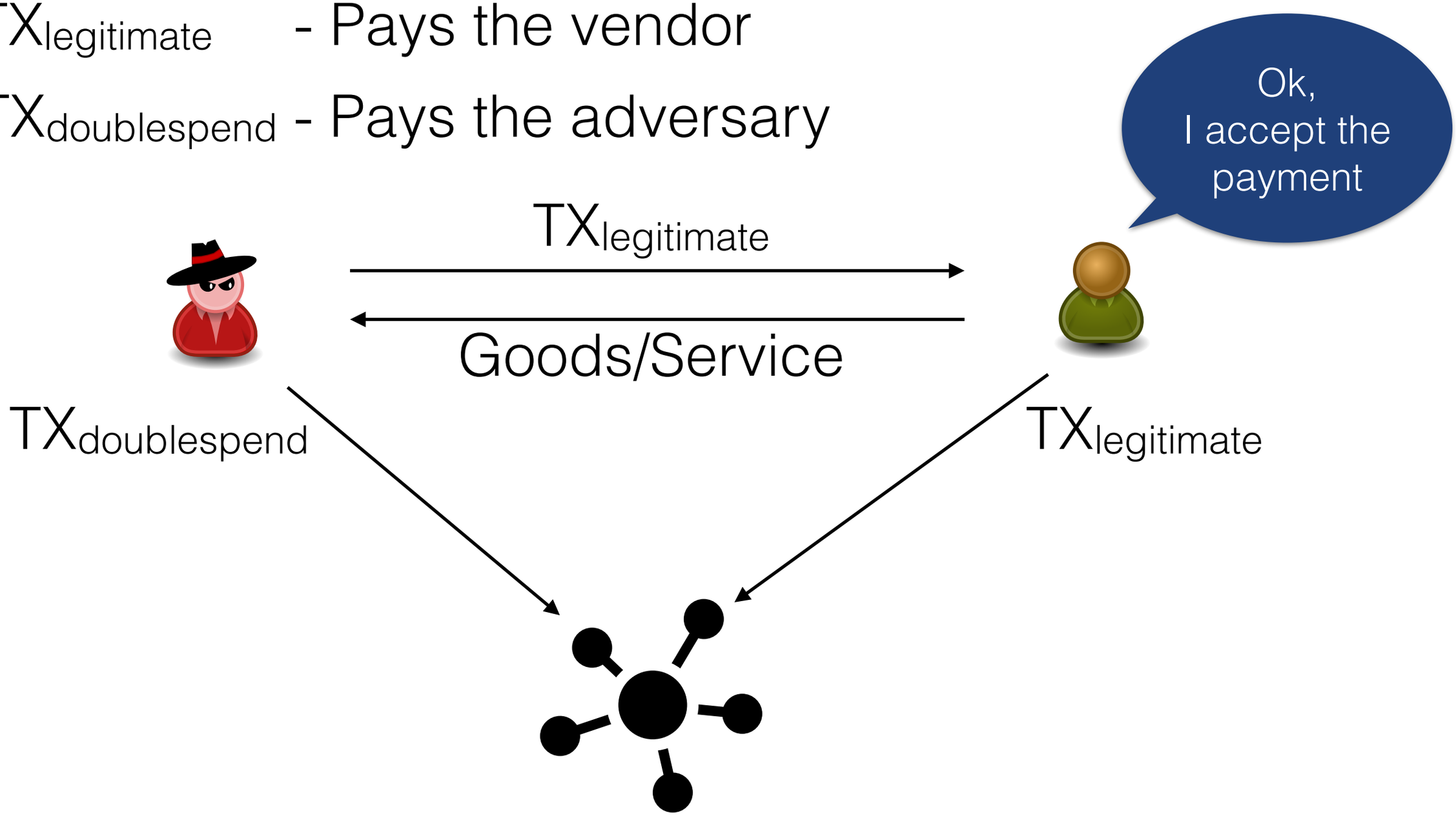

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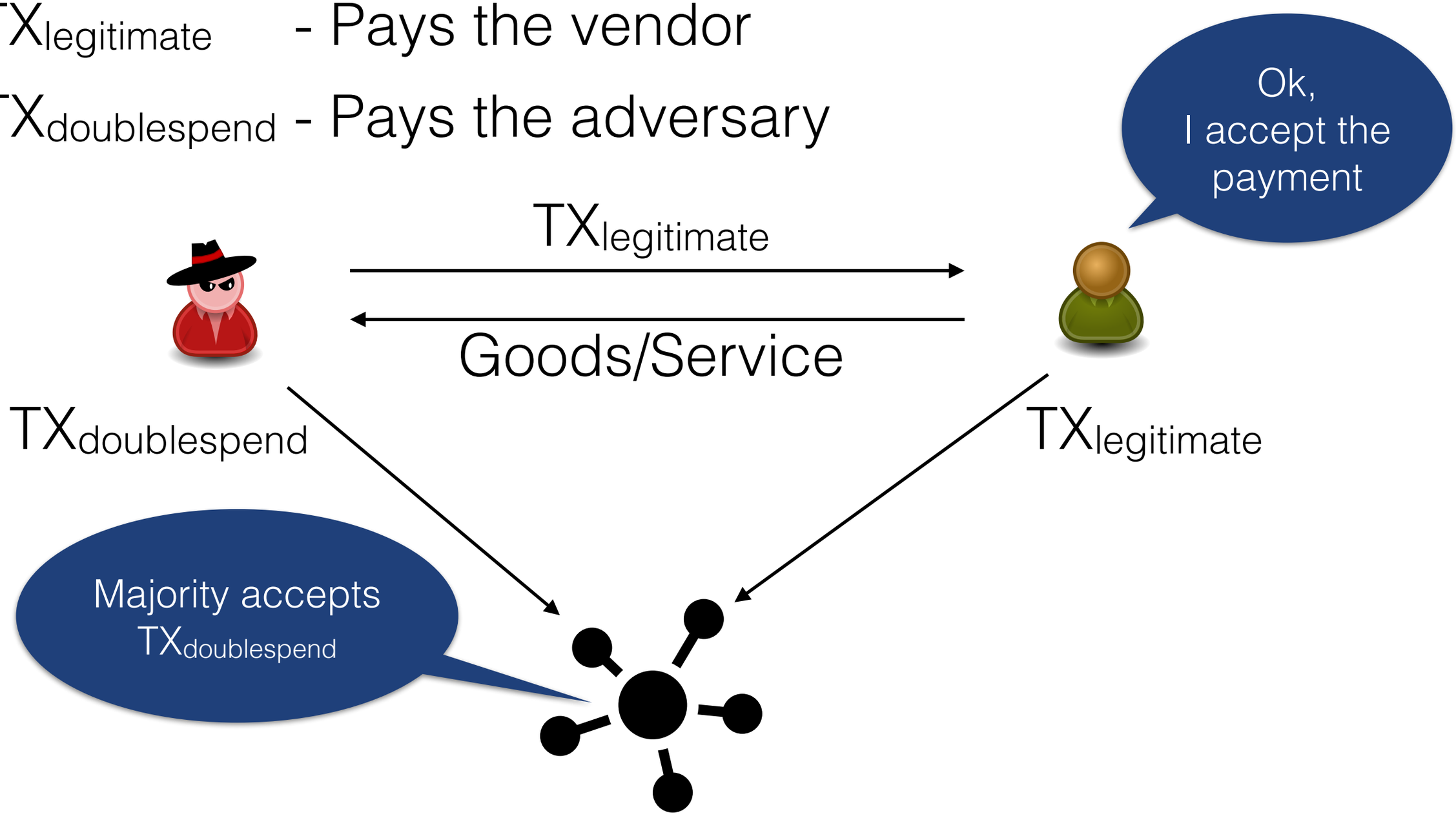

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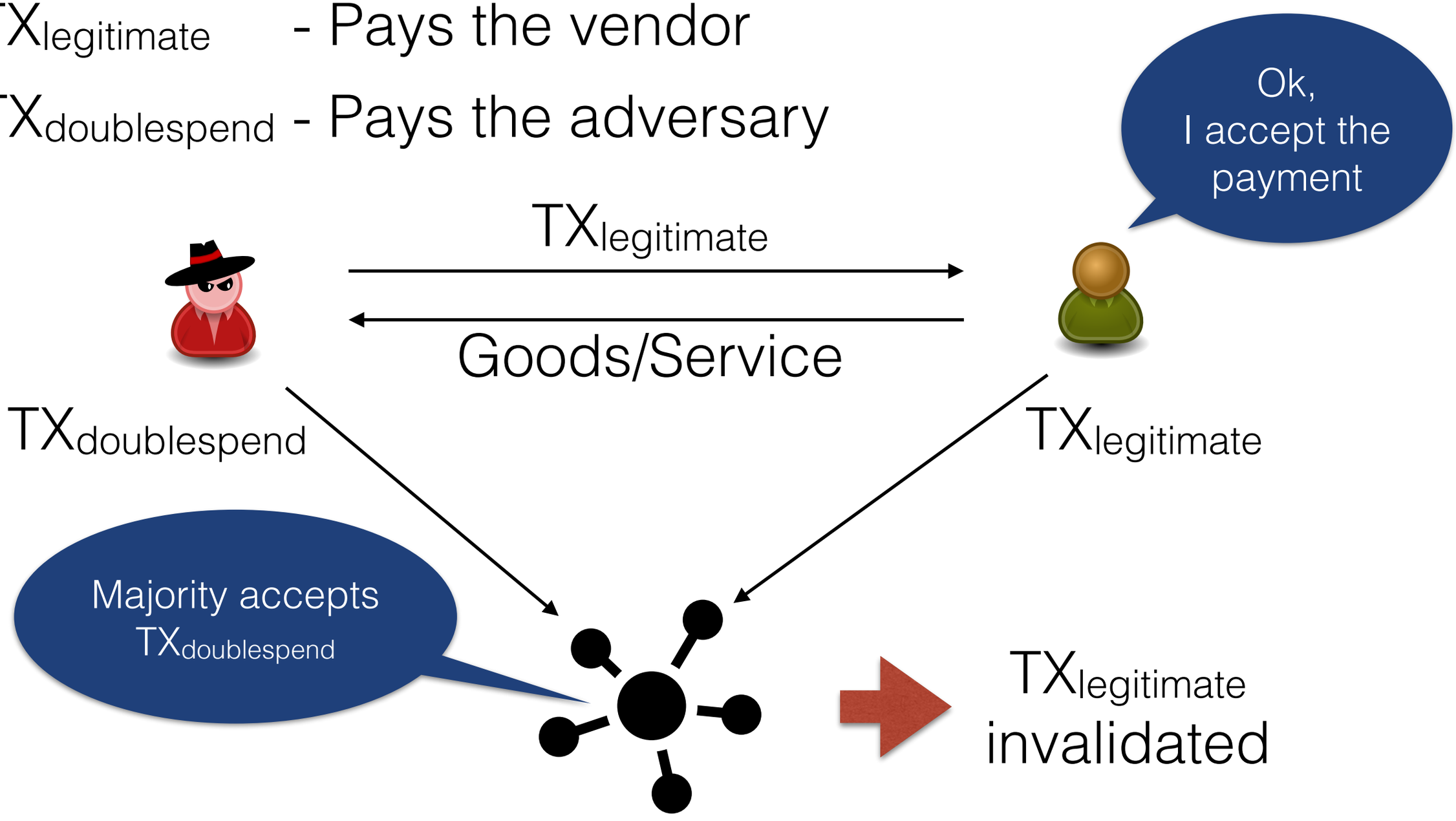
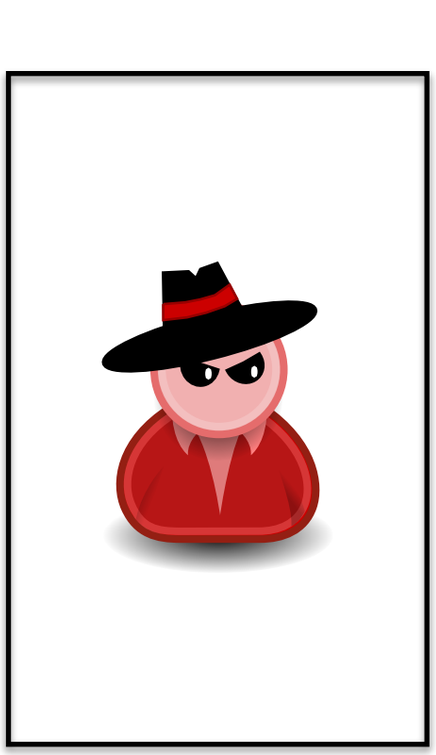
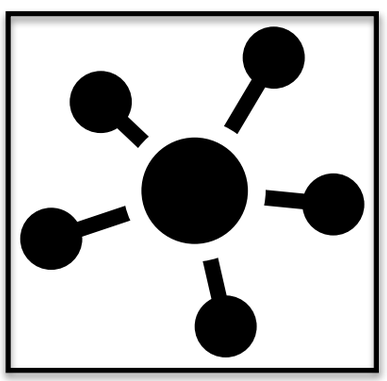


Double Spending 0 Confirmation Transactions

- Very reliable attack
- Regardless of protection (double spend relay)



Vendor



Bitcoin Network

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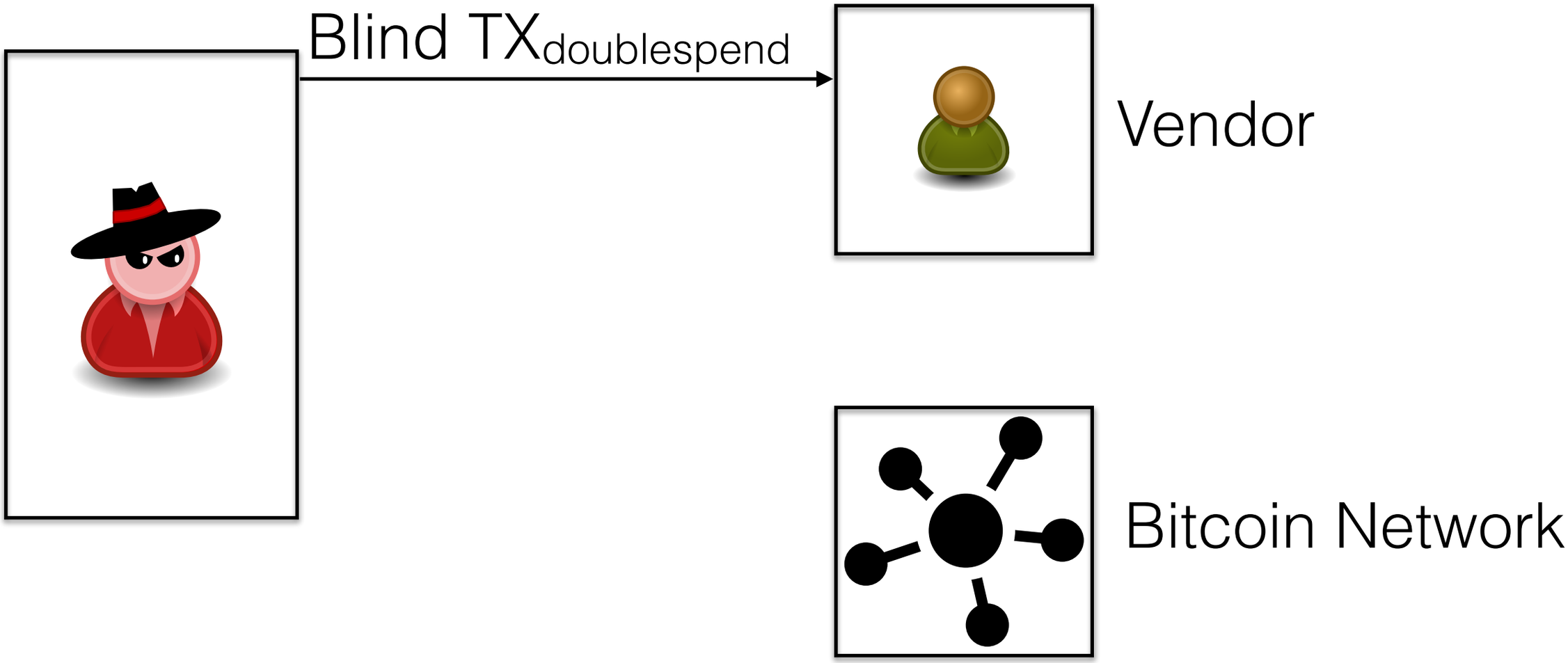

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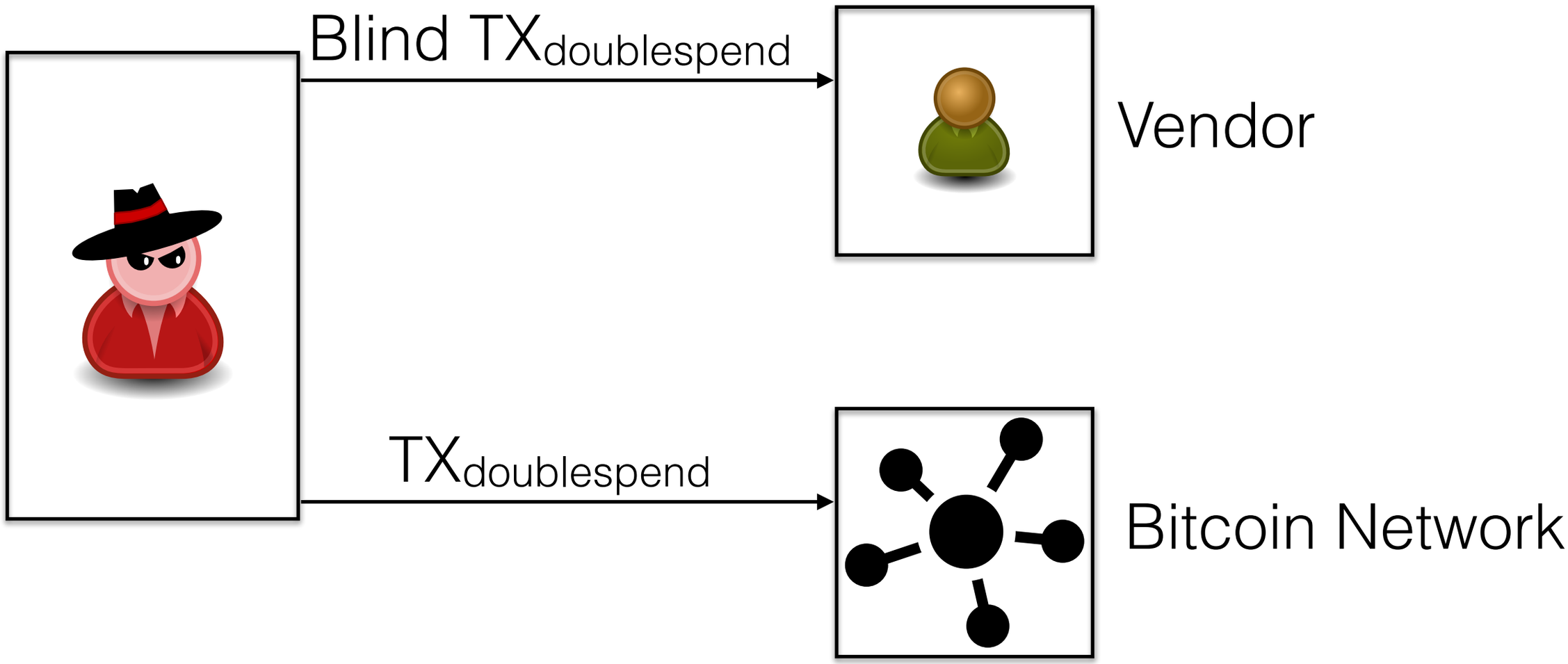

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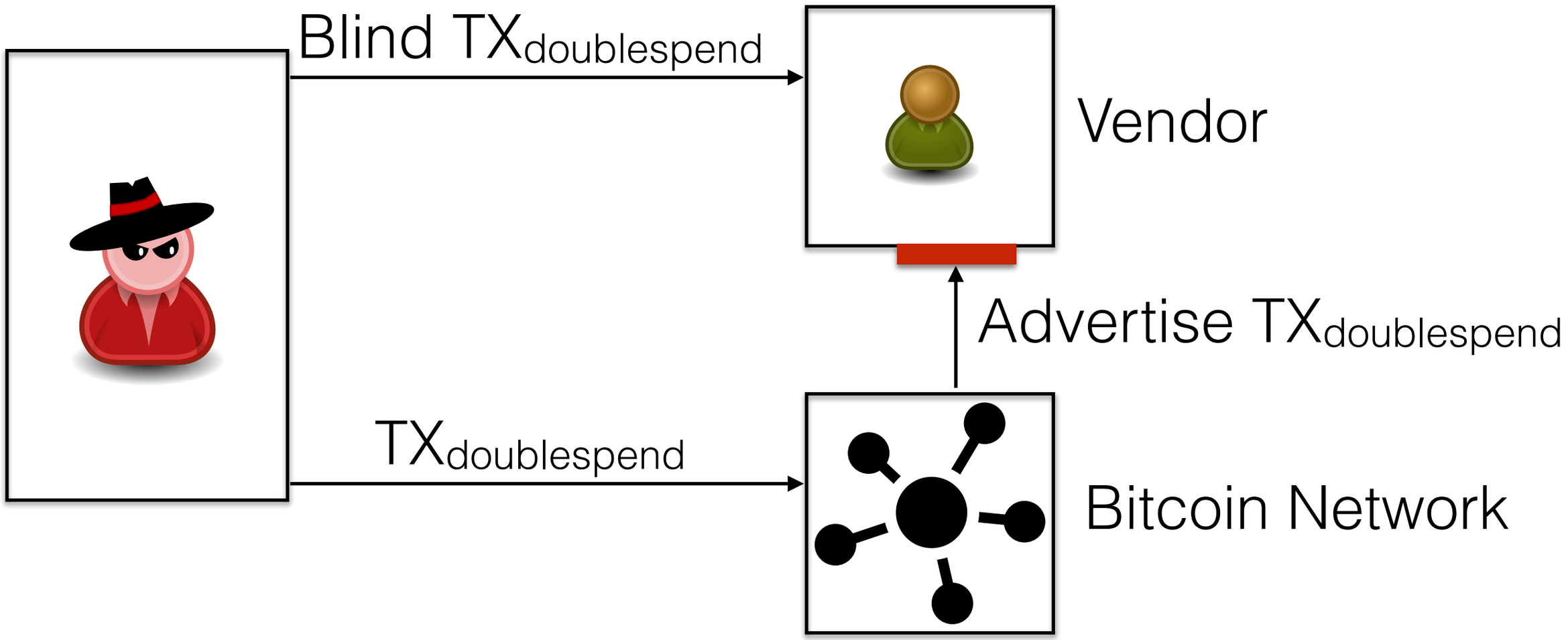

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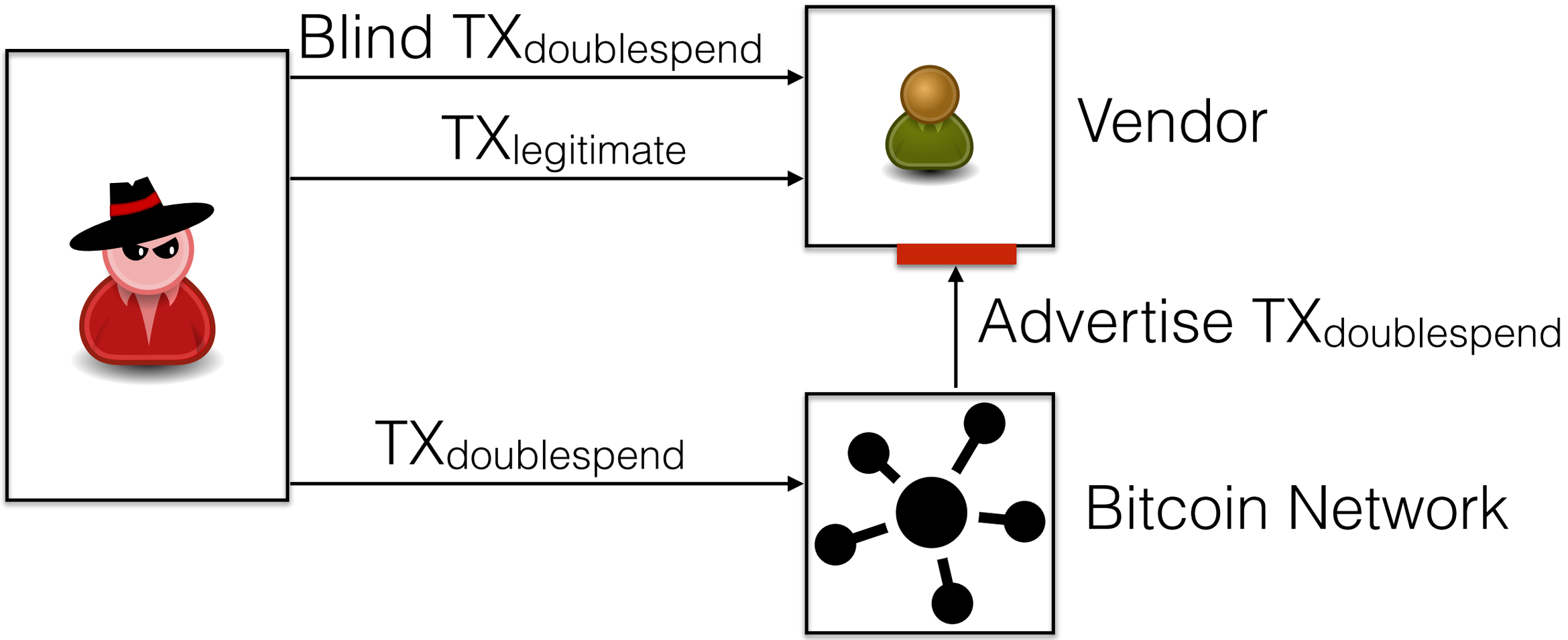

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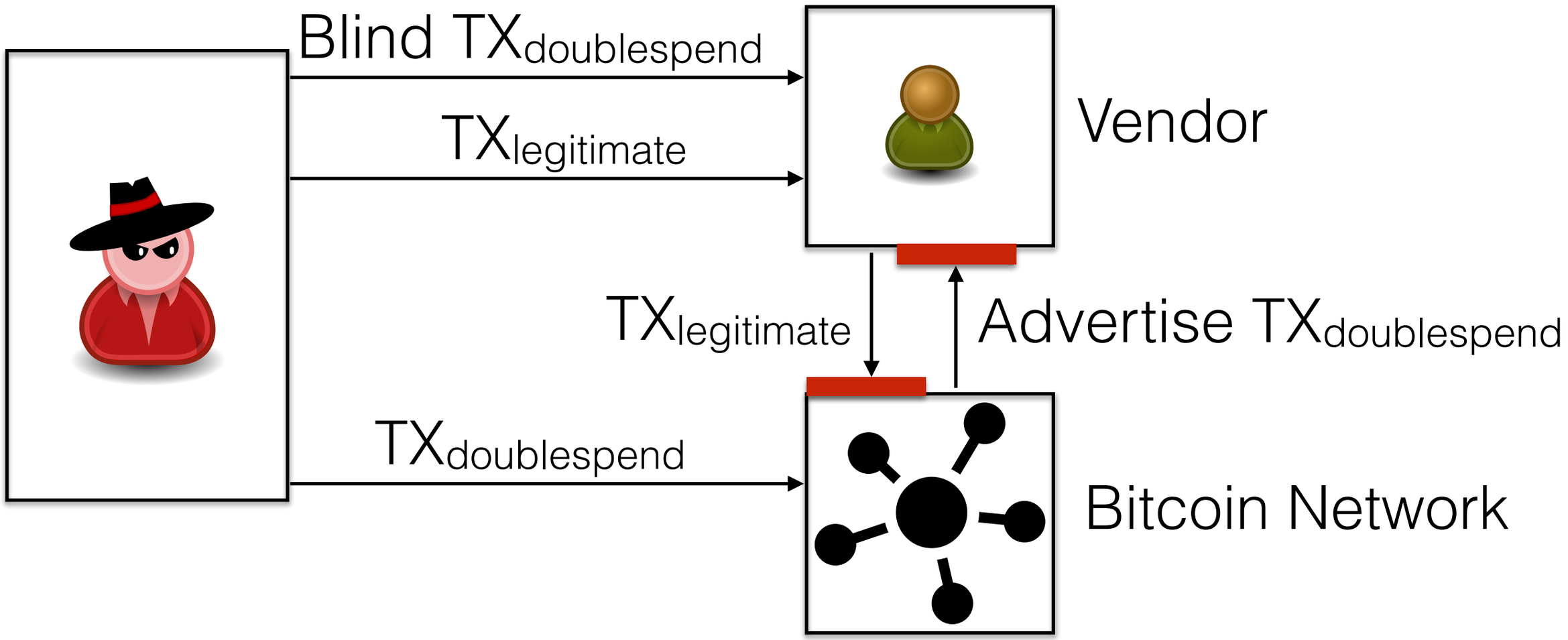
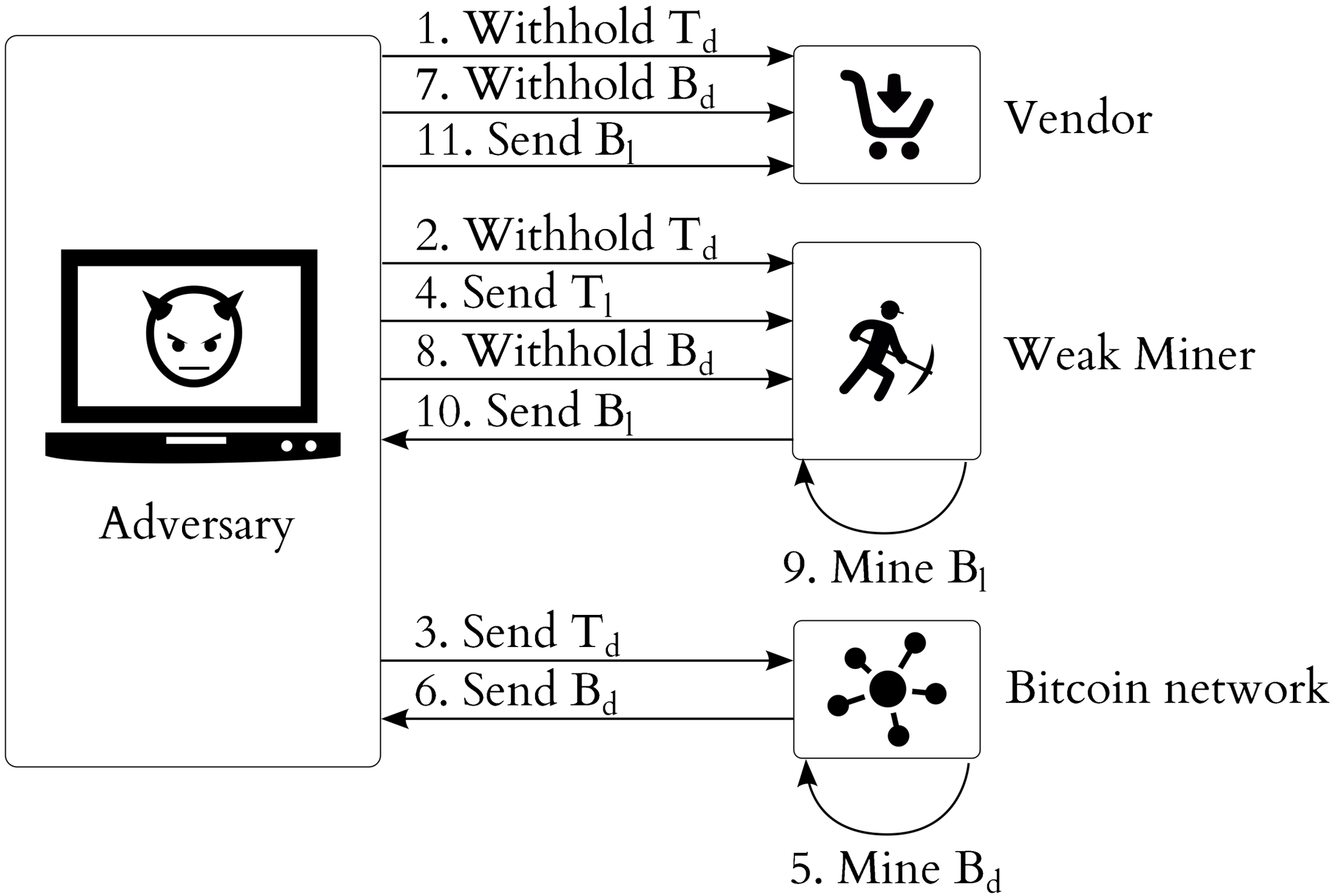
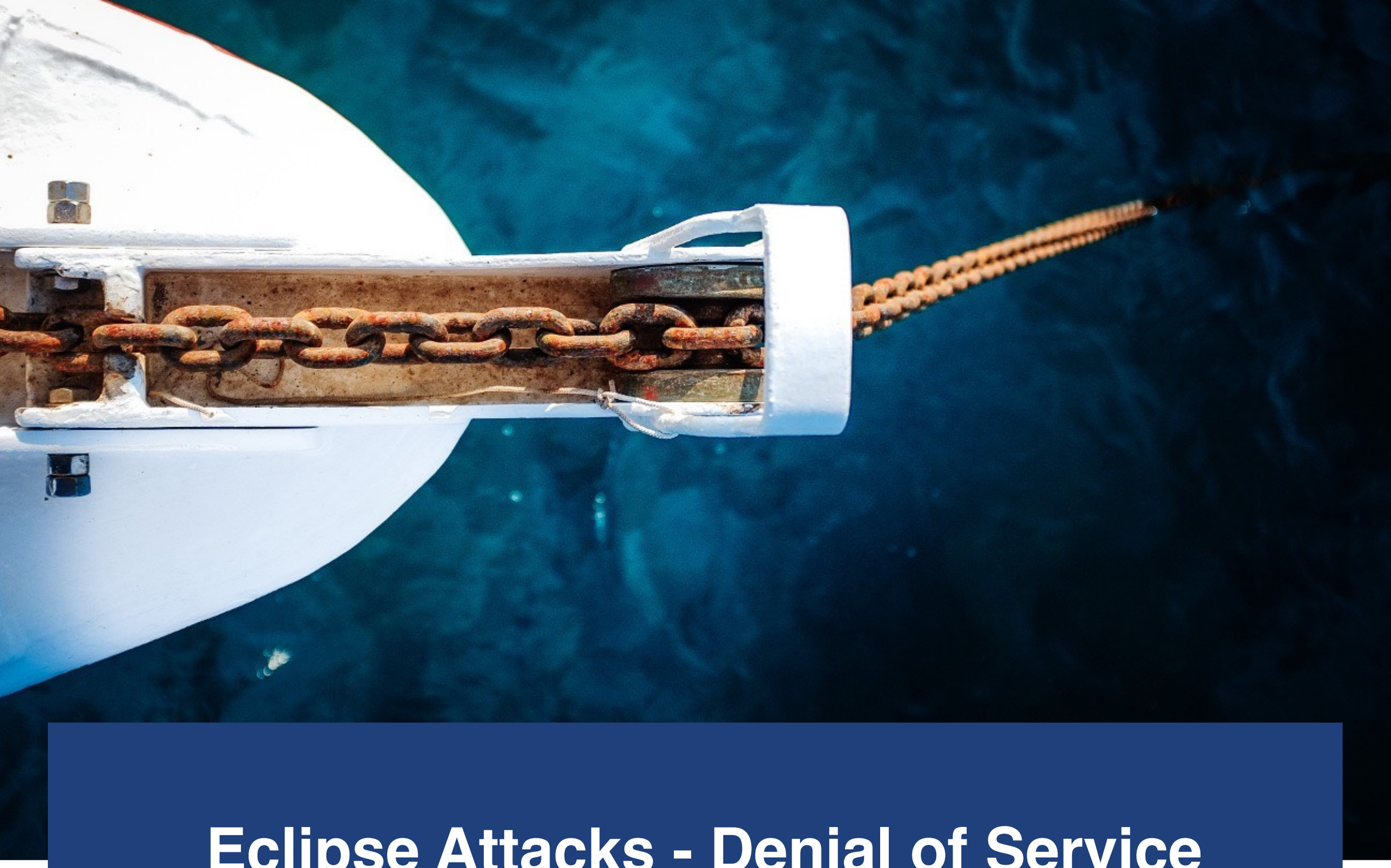


Implications - Double Spending 1 Confirmation Transactions



X**l** = legitimate
X**d** = double spend attempt



Eclipse Attacks - Denial of Service

Denial of Service

6000 reachable Bitcoin nodes

Preventing the delivery of blocks to these

- 450 000 TCP connections required
- 600 KB of advertisement / block / 20 min

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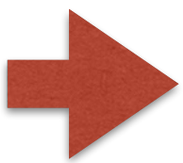


Network wide Denial of Service

Eclipse Attacks - Hardening the P2P Layer

Hardening the P2P overlay network

1. Why not smaller static timeouts?

2. Why not requesting from multiple peers?

3. What about alternative relay networks?

Security vs Scalability tradeoffs

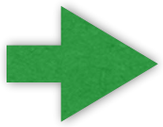
Hardening the P2P overlay network

1. Dynamic timeouts

Hardening the P2P overlay network

1. Dynamic timeouts

2. Handling Transaction Advertisements
   - **Filtering by IP address**
   - Randomly choosing sender



First request from one peer, then two, then three…

Hardening the P2P overlay network

1. Dynamic timeouts

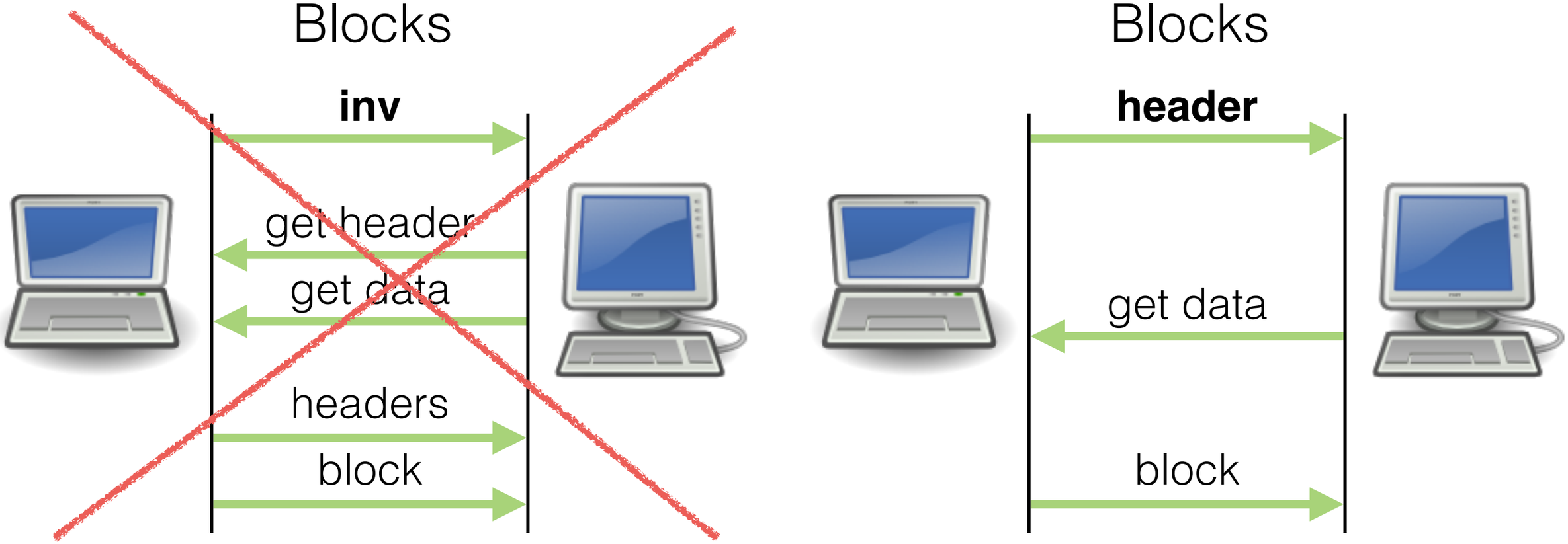
2. Handling Transaction Advertisements
   - **Filtering by IP address**
   - Randomly choosing sender

   First request from one peer, then two, then three…

3. Updating Block Advertisements:
   - **Broadcast header instead of hash**
   - Keep track of block advertisers

Hardening the P2P overlay network

Better Block request management



size(inv) = 36 bytes
size(header) = 80 bytes

Hardening the P2P overlay network

1. Dynamic timeouts

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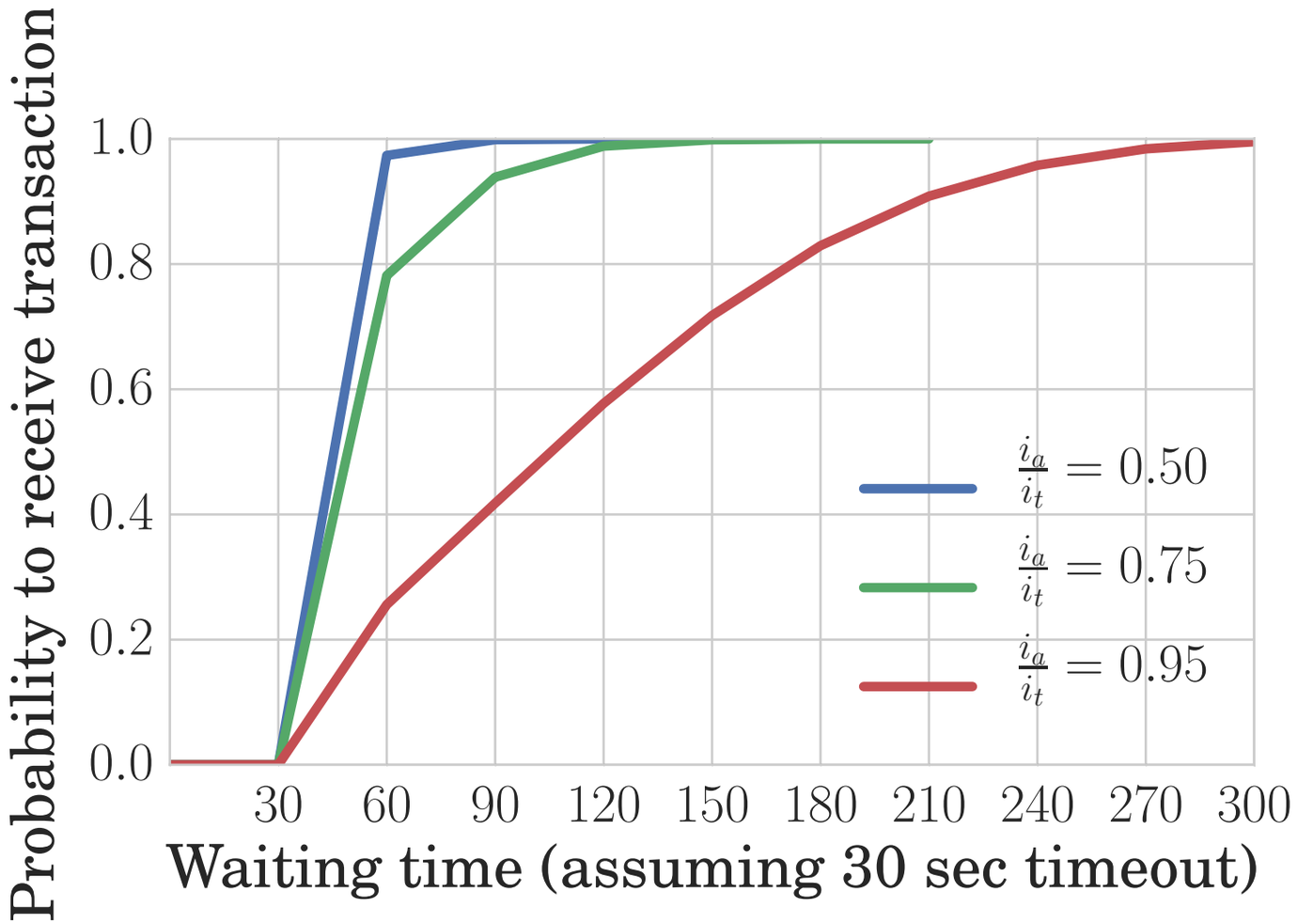


i_a = **inv** messages sent by adversary

i_t = total **inv** messages

After 5 minutes, transaction is received, even if the adversary controls 95% of the inv

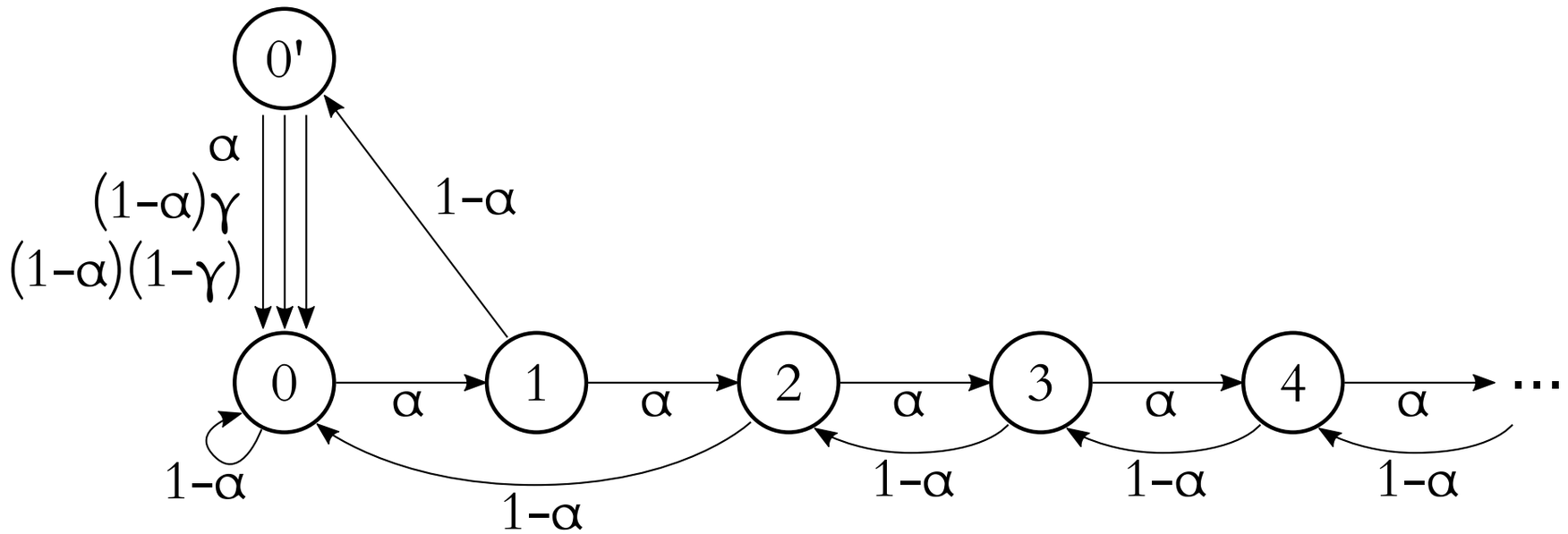
Selfish Mining and Eclipse Attacks

Implications - Increasing Mining Advantage

Idea from Eyal et. al:

- Instead of publishing, keep a block private

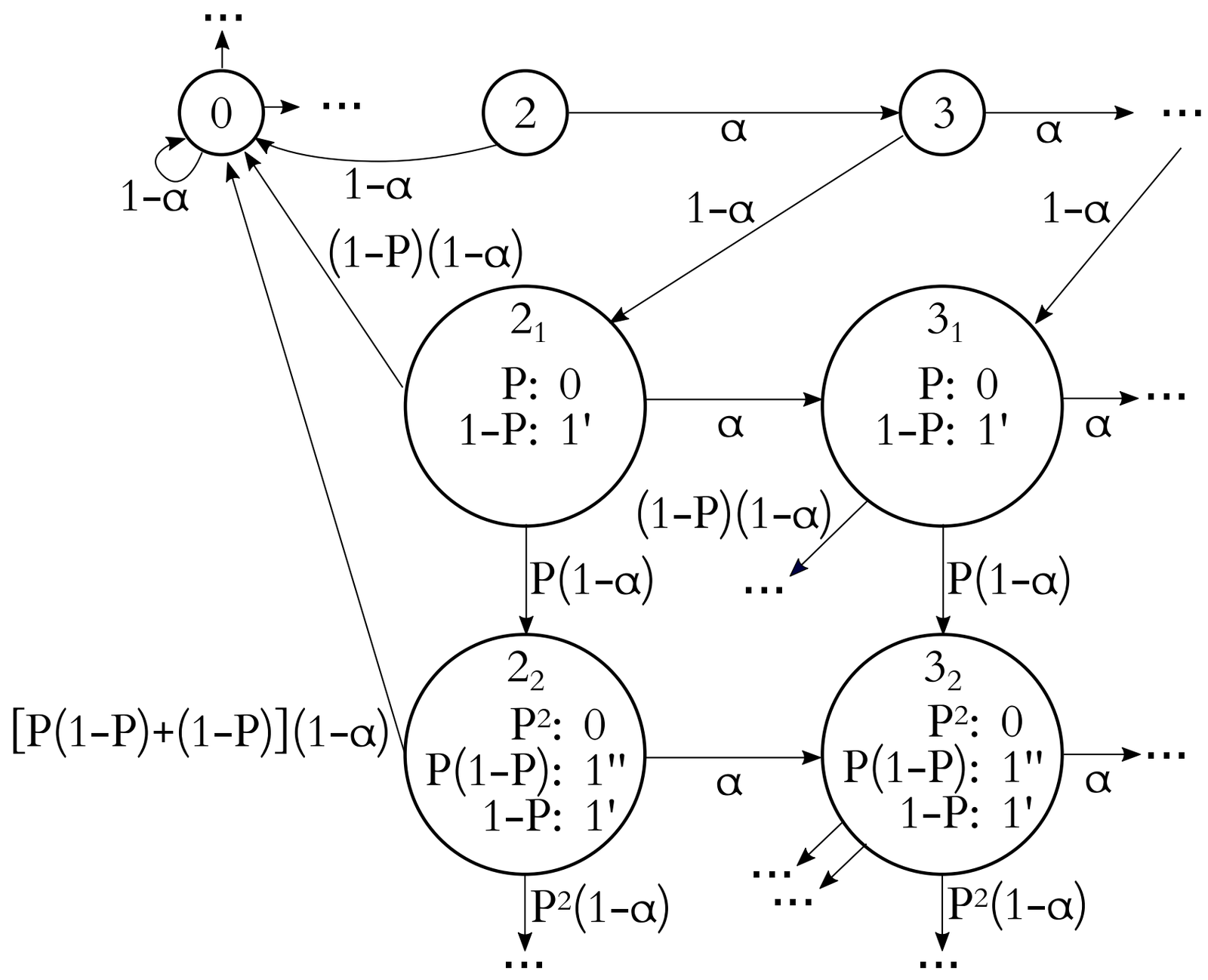
➡ Other miners will perform wasteful computations



α : hashing power of adversary

γ : propagation parameter

Implications - Increasing Mining Advantage



P: probability to deny a block to a miner

Implications - Increasing Mining Advantage