Eclipse Attacks on Bitcoin's Peer-to-Peer Network

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Presented by Joonhyuk Lee
(*slides adapted from Heilman*)

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1. Introduction

- Bitcoin is thought to be secure if 51% of the mining power is honest.
- Assuming that all miners see all Blocks/transactions: Perfect Information
- Bitcoin relies on its P2P network to deliver this information
- Controlling the network ➔ Controlling the blockchain

Can attacker manipulate node's view on the Bitcoin Network?

1. Introduction - Outline

- **Eclipse Attacks & Implications** — chapter 2
- **How to eclipse a Bitcoin node** — chapter 3
- **How many IPs does the attacker need?** — chapter 4
- **Countermeasures** — chapter 5
- **Eclipse Attack on Ethereum** — chapter 6

Chapter 2

: Eclipse Attacks & Implications

Outline

- **Eclipse Attacks & Implications**
  - Explanation about eclipse attack
  - 51% attack, Selfish Mining
  - N-confirmation double spending
- How to eclipse a Bitcoin node
- How many IPs does the attacker need?
- Countermeasures
- Eclipse Attack on Ethereum

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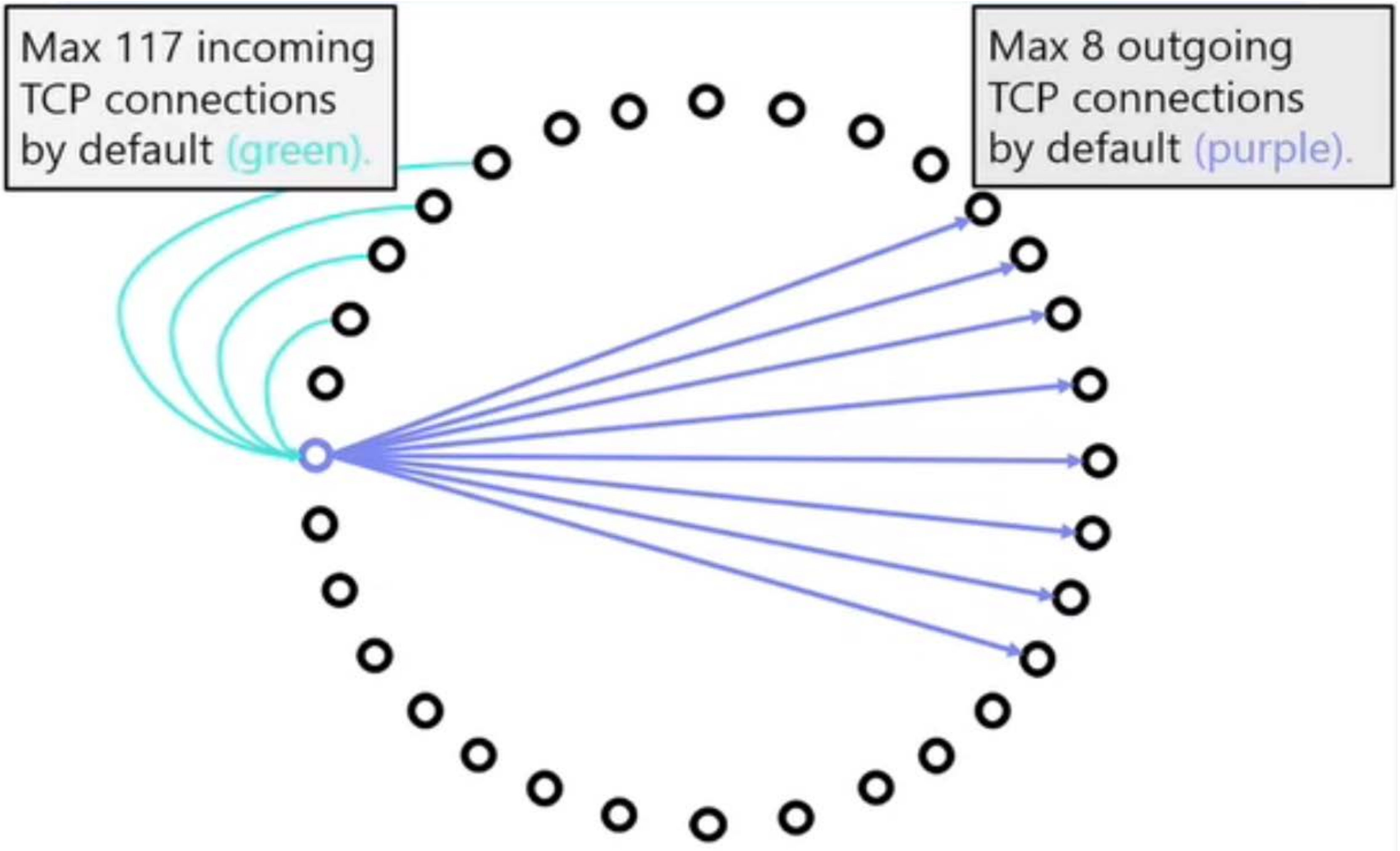
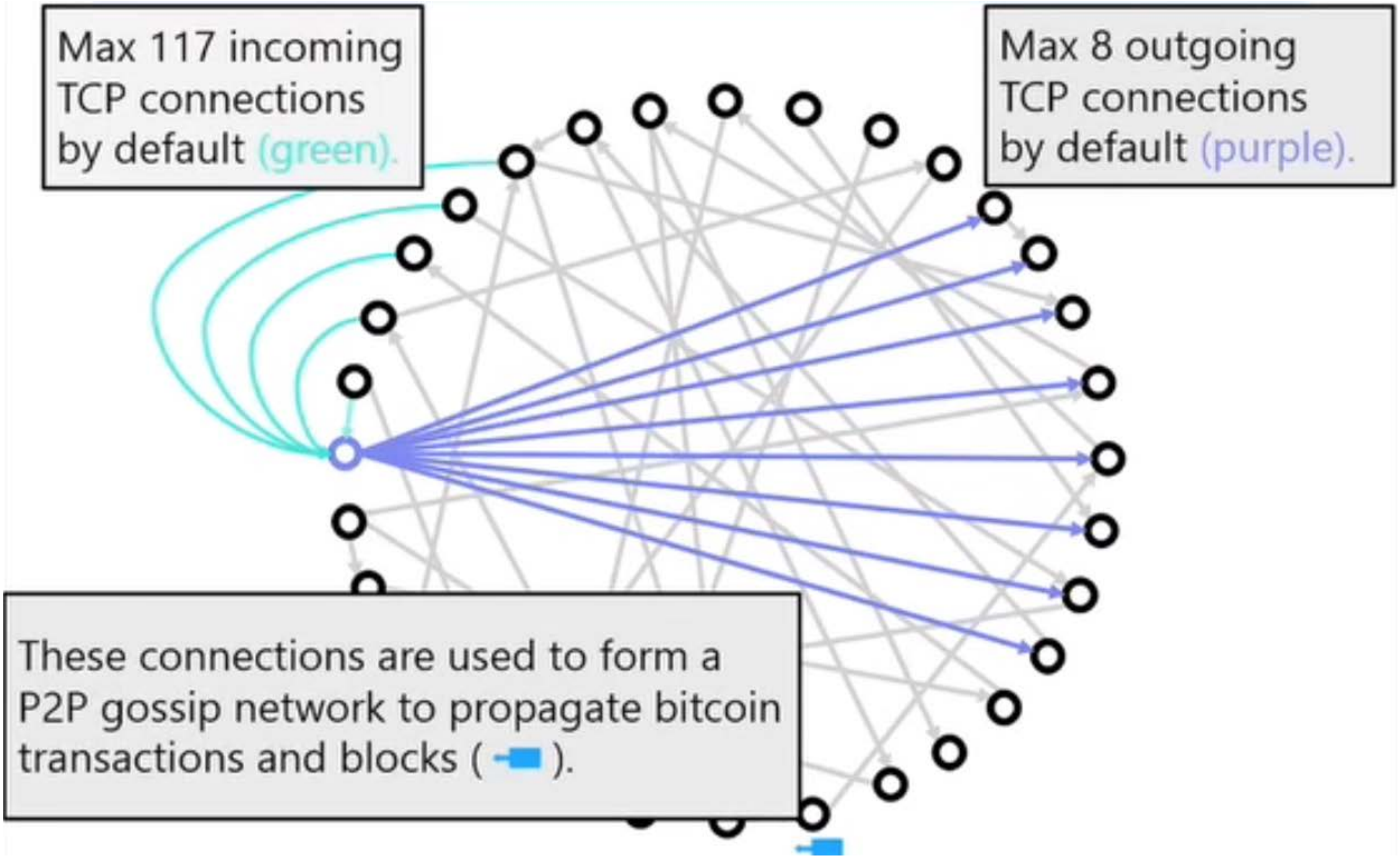
2. Eclipse Attacks & Implications – Bitcoin networking



2. Eclipse Attacks & Implications – Bitcoin networking



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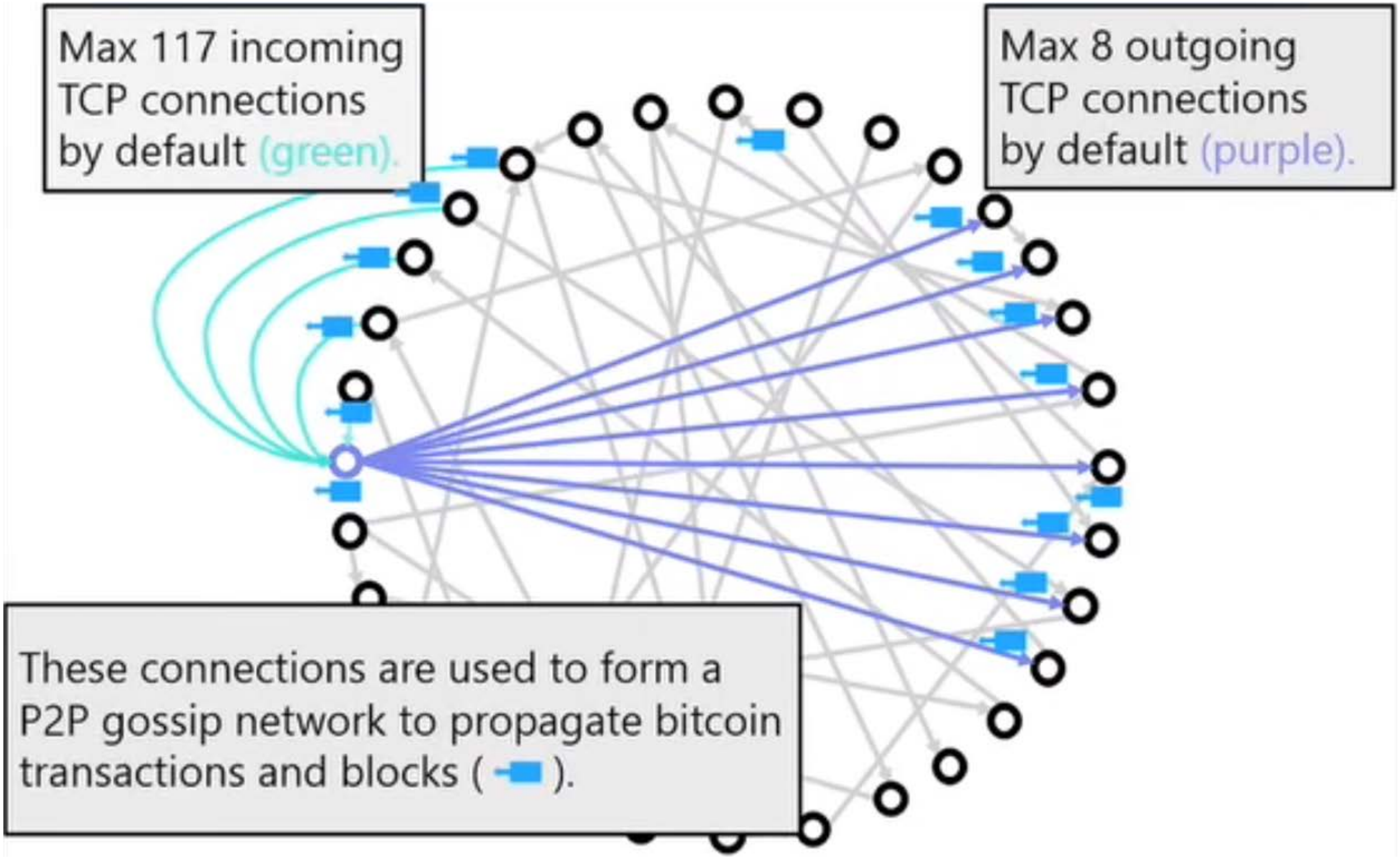

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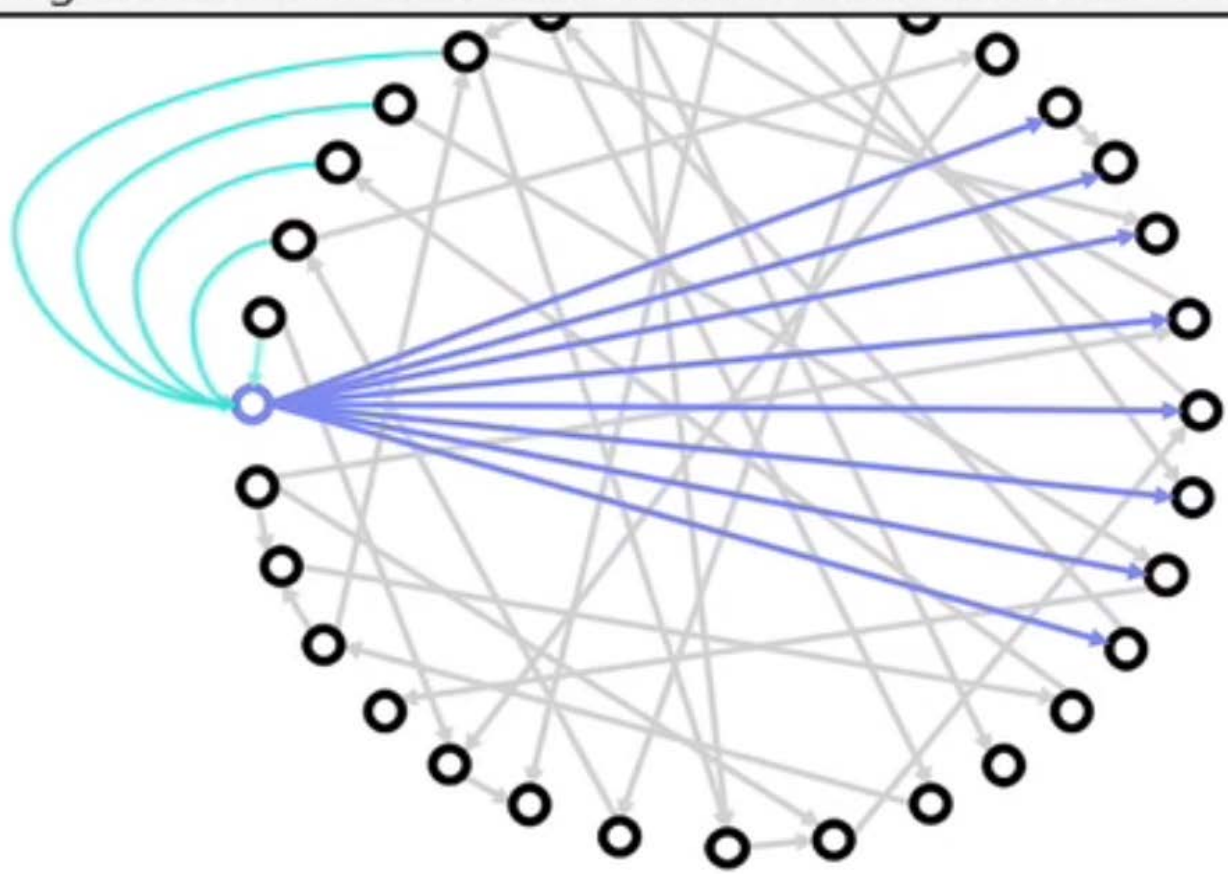
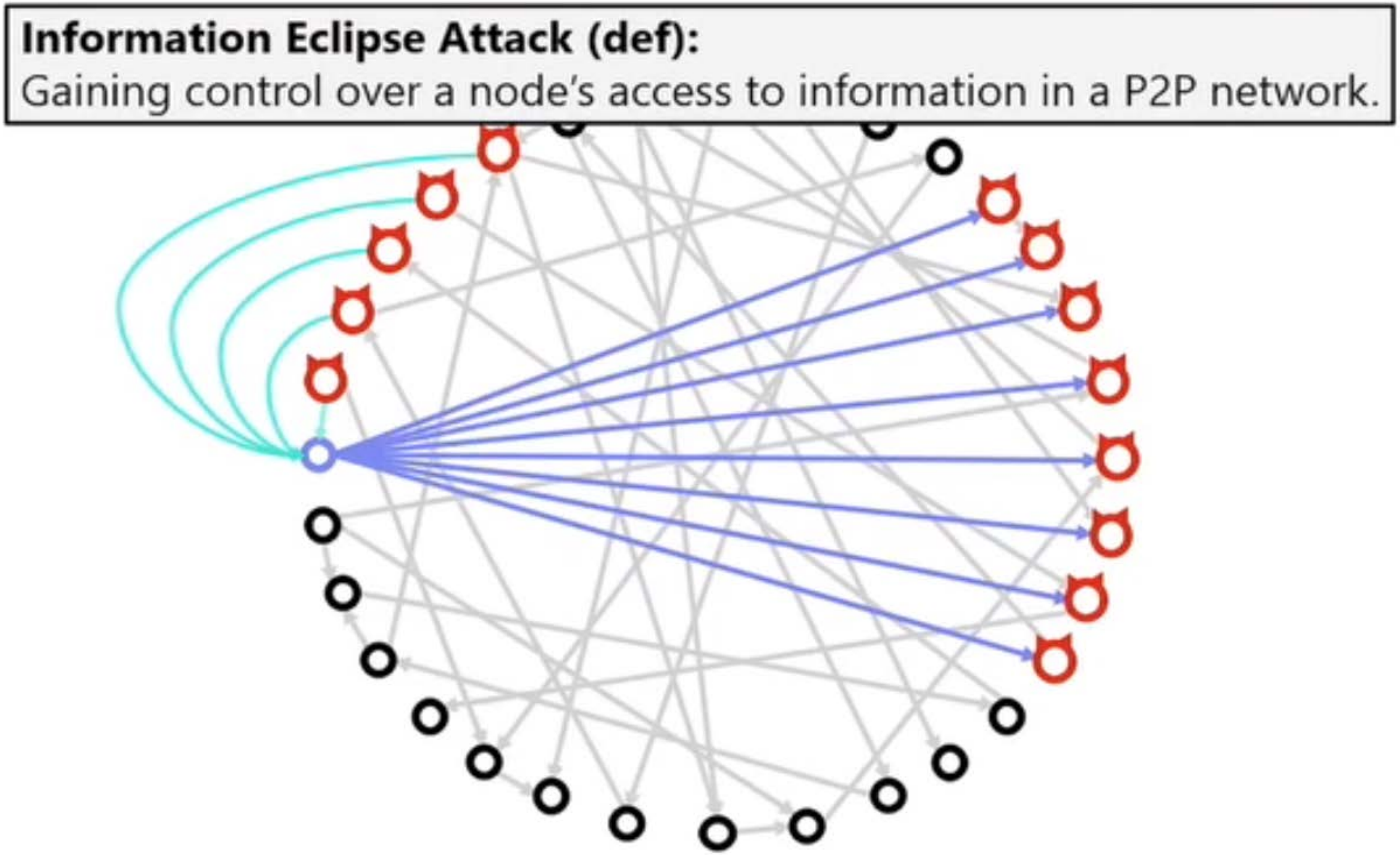
2. Eclipse Attacks & Implications – Bitcoin networking

Information Eclipse Attack (def):
Gaining control over a node's access to information in a P2P network.



2. Eclipse Attacks & Implications – Eclipse Attack On Bitcoin



By manipulation the P2P net, the attacker eclipses the node

2. Eclipse Attacks & Implications – Eclipse Attack On Bitcoin

https://youtu.be/J-lF0zxGpu0?t=70

What are the problems?

2. Eclipse Attacks & Implications – Implications

1. Engineering block races
   - engineering & controlling blocks propagation

2. Splitting mining power
   - Making it eaiser to launch mining attacks

3. Selfish Mining
   - By eclipsing miners, the attacker increases gamma
   - Mining Pools -> their gateways to the public bitcoin network

4. 0-Confirmation double spending
   - eclipse the merchant's bitcoin node
   - Send the merchants a tx T, but send T' to the rest of the network.

5. N-Confirmation double spending

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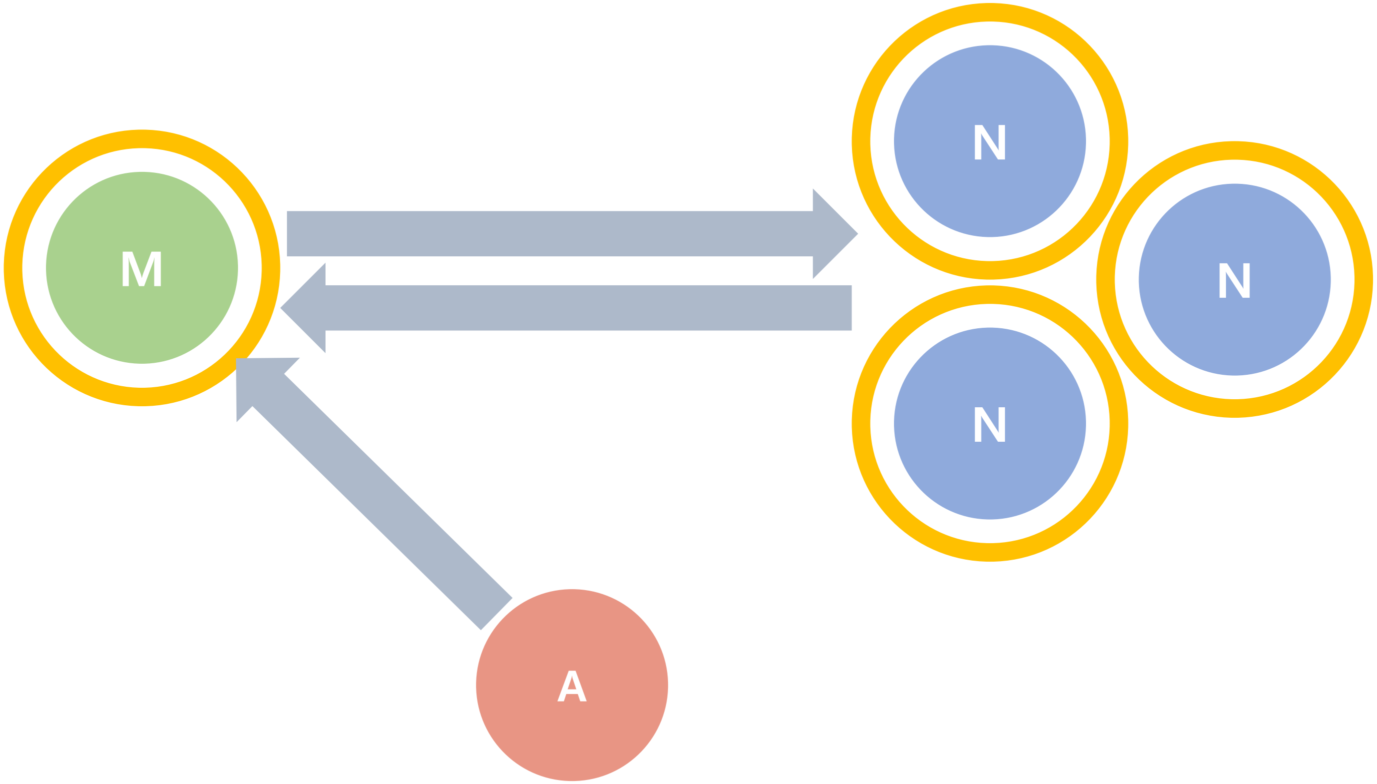
2. Eclipse Attacks & Implications

- N-Confirmation double spending



Chapter 3

: How to eclipse a Bitcoin node

Outline

- Eclipse Attacks & Implications
  - Explanation about eclipse attack
  - 51% attack, Selfish Mining
  - N-confirmation double spending
- **How to eclipse a Bitcoin node**
  - P2P network of Bitcoin
  - How to exploit Bitcoin's P2P networking
- How many IPs does the attacker need?
- Countermeasures
- Eclipse Attack on Ethereum

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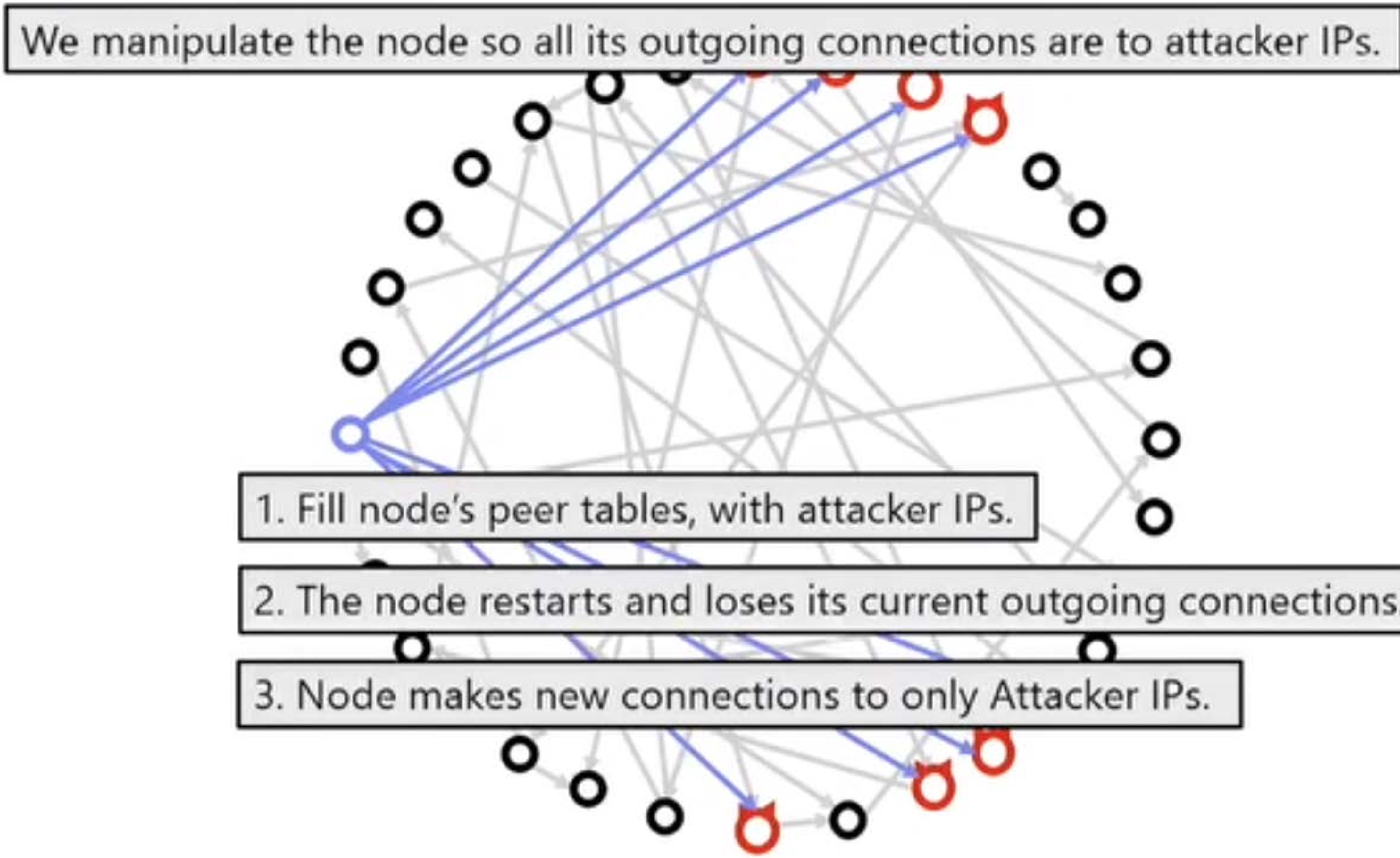
3. Eclipse Attack on Bitcoin – Simlpe Overview



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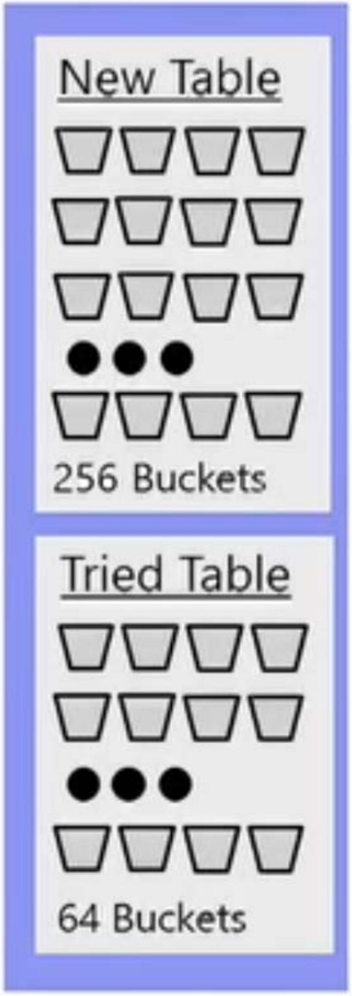
3. Eclipse Attack on Bitcoin – 2 Tables



- Each node selects its peers from IP addresses stored in two tables.
  - New table : IPs the node has heard about.
  - Tried table: IPs the node peered with at some point
- Each bucket has 64 unique IP addresses.
- The tables also store a timestamp for each IP
- To find an IP to make an outgoing connection to:
  1. Choose new or tried tables to select from
  2. Select an IP biased toward **"fresher"** timestamps
  3. Attempt an outgoing connection to that IP

Attacker ensures that its IPs are fresher.
They are more likely to be selected as outgoing connection

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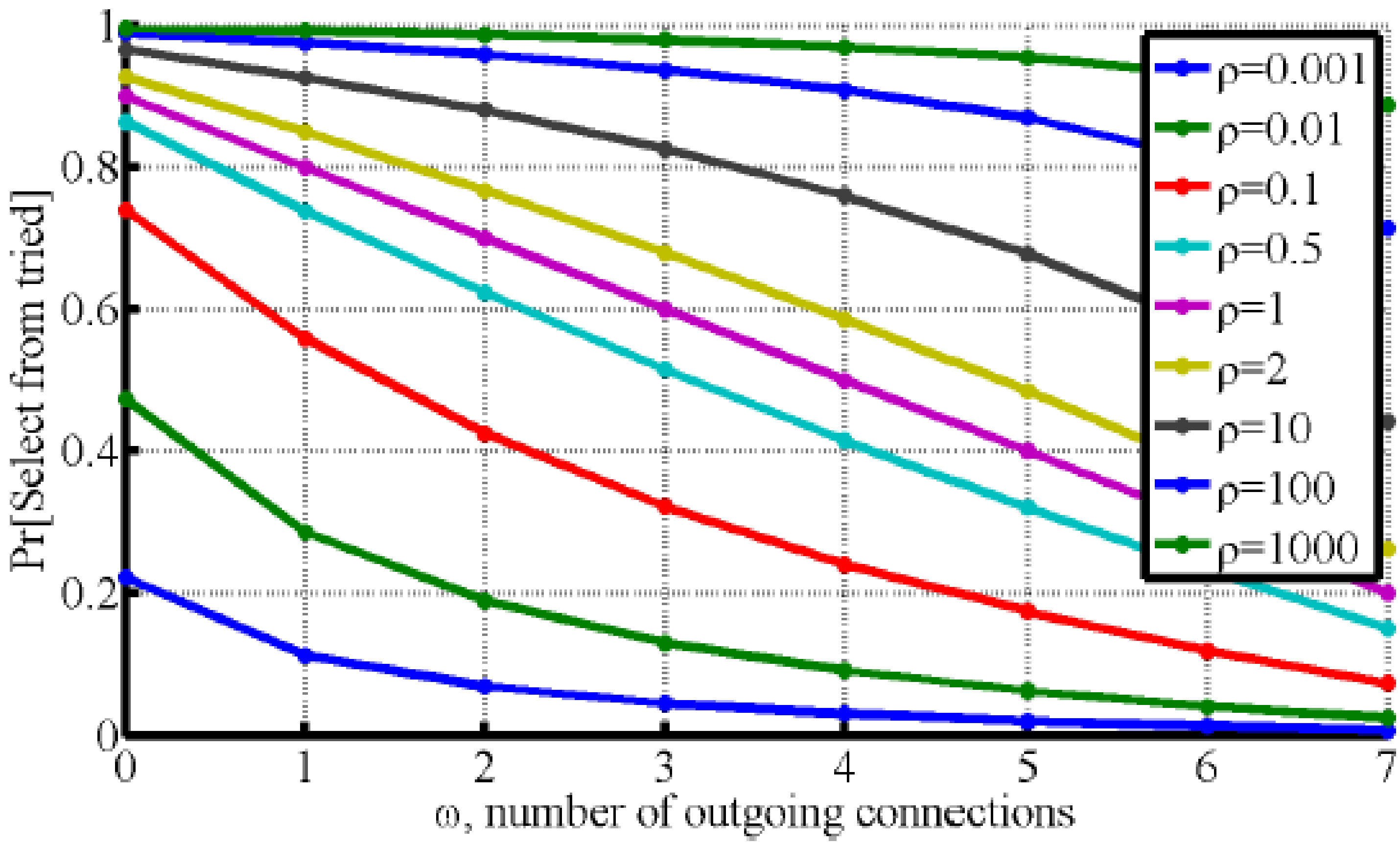
3. Eclipse Attack on Bitcoin – Peer Selection



$$\Pr[\text{Select from } \texttt{tried}] = \frac{\sqrt{\rho}(9-\omega)}{(\omega+1)+\sqrt{\rho}(9-\omega)}$$

$$p(r,\tau) = \min(1, \tfrac{1.2^r}{1+\tau})$$

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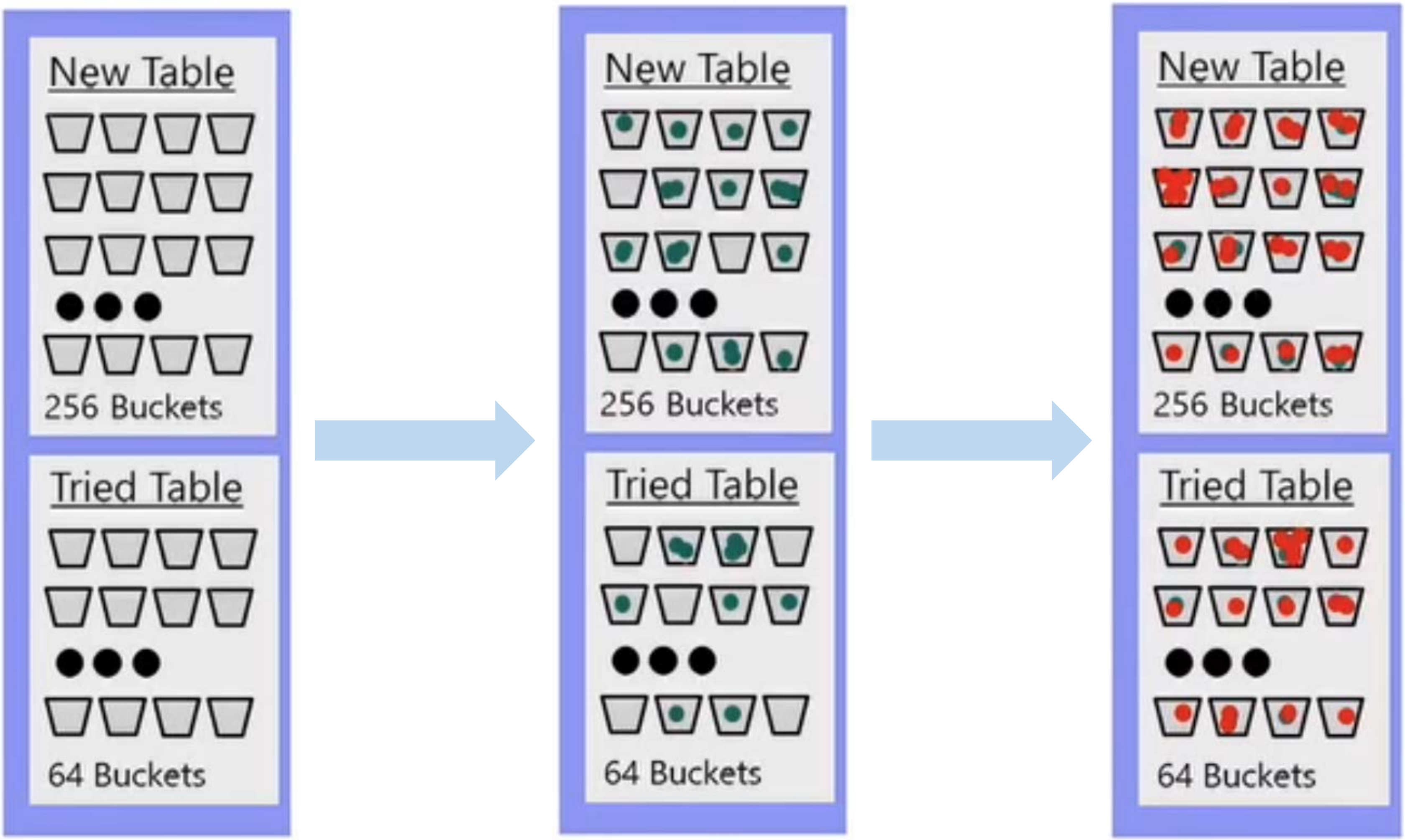
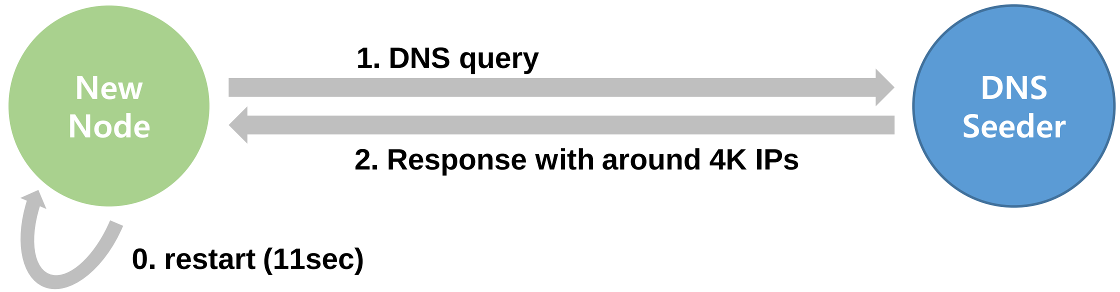
3. Eclipse Attack on Bitcoin – Polluting 2 Tables

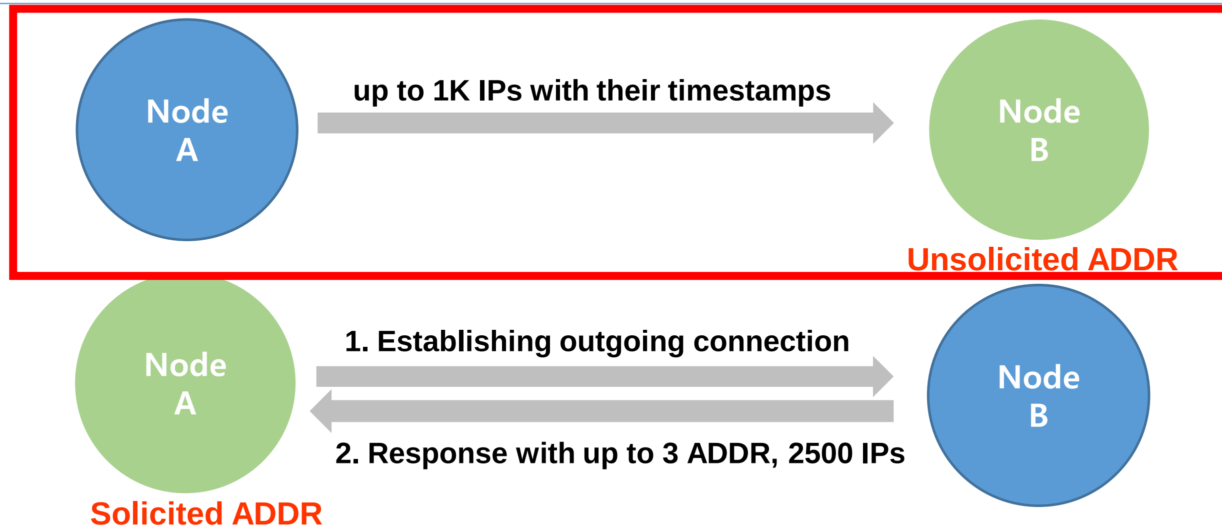


3. Eclipse Attack on Bitcoin – Propagating network information

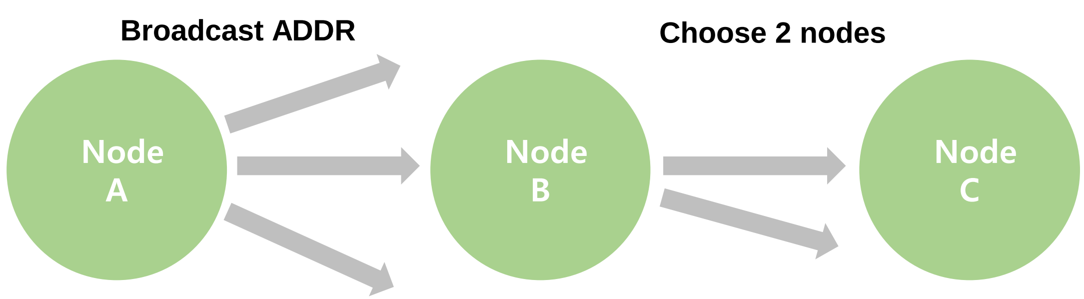
- Join/Re-join Case



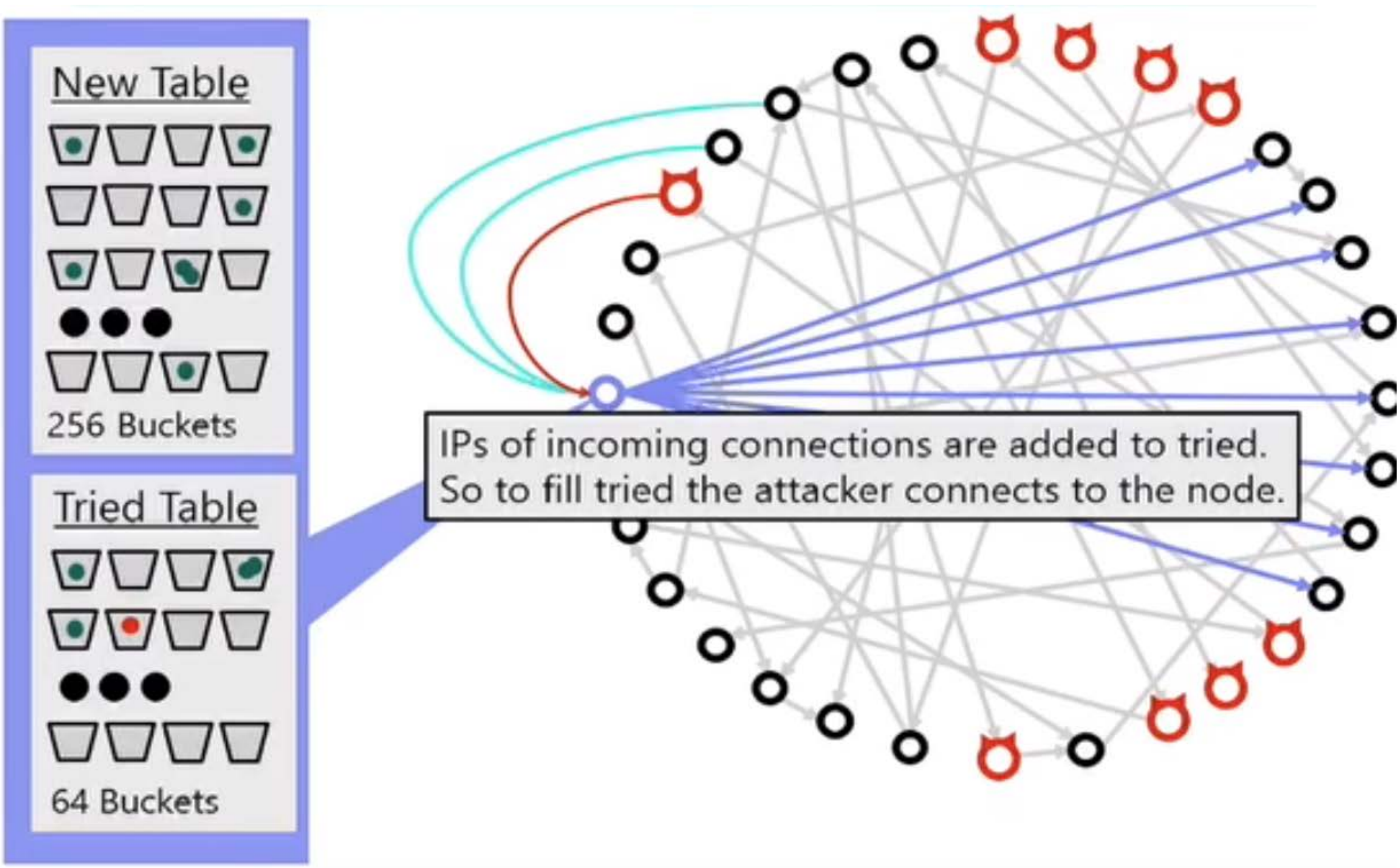
- ADDR msg



- Periodical Hello msg



3. Eclipse Attack on Bitcoin – Tried Table polluting



1 slot per 1 incoming connection

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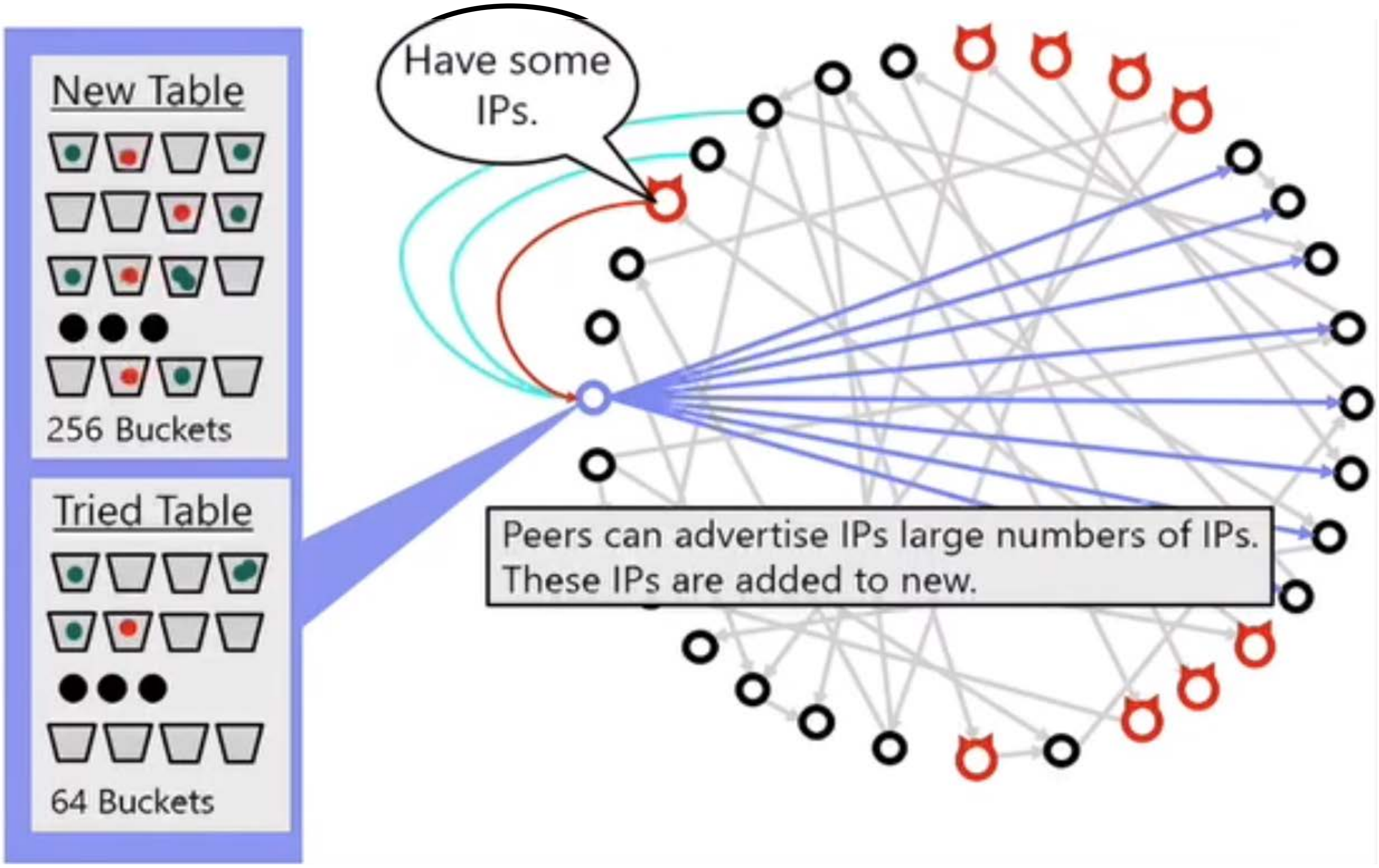
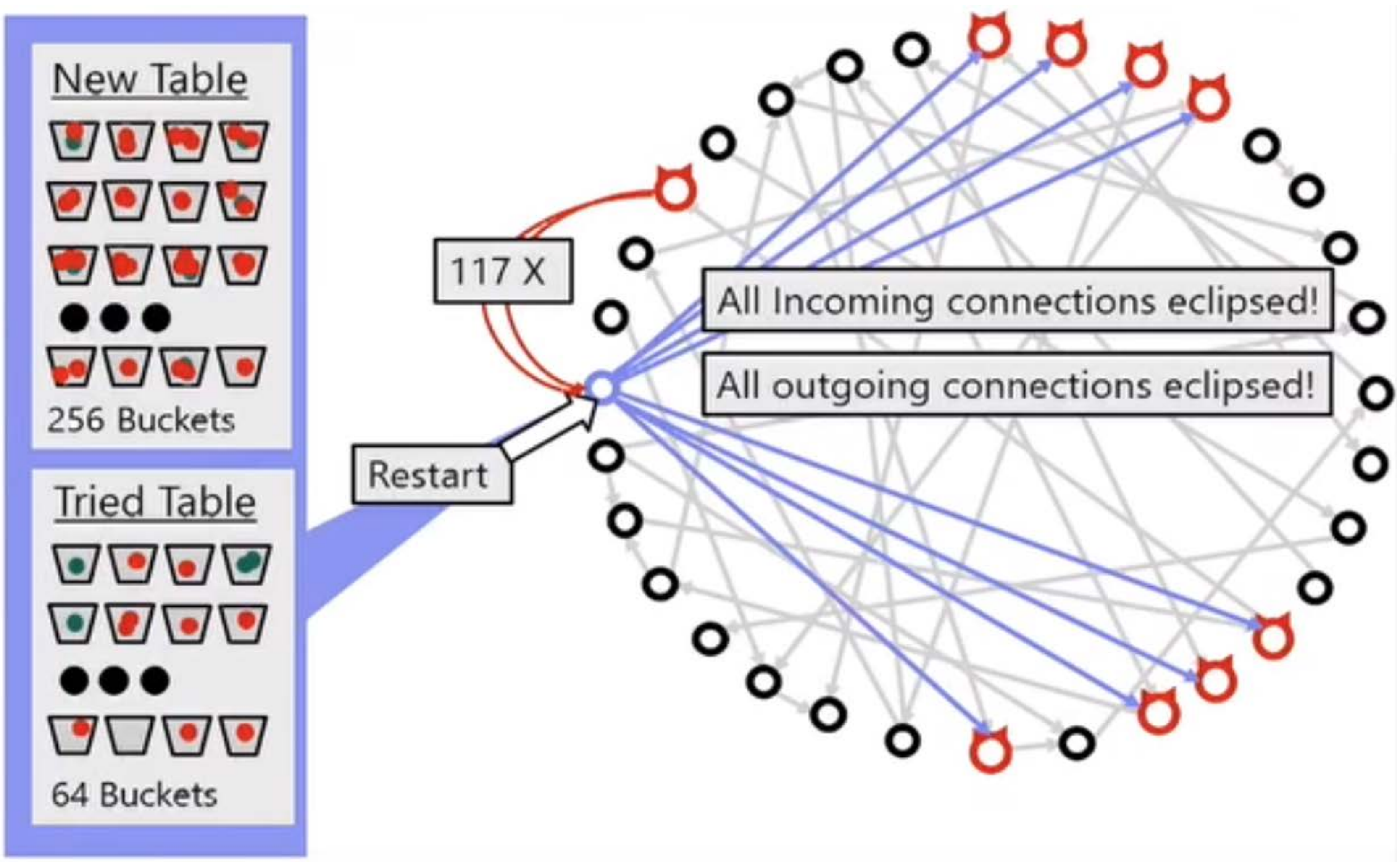
3. Eclipse Attack on Bitcoin – New table polluting



1000 slots of New table per 1 ADDR message
-> Use trash IPs for New table pollution

3. Eclipse Attack on Bitcoin – Eclipsing target node



Polluting entire New table & almost Tried Table
Not finished!

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3. Eclipse Attack on Bitcoin – Eclipsing target node

https://youtu.be/J-lF0zxGpu0?t=425

3. Eclipse Attack on Bitcoin – Restart Target Node

- Eclipse Attack requires the target/victim node restart.

- Software/Security Updates
  - Predictable for the attacker, users are notified of upcoming updates
  - lose for the victim, restart or remain vulnerable

- Packets of Death/Dos Attacks
  - Ten Dos CVEs in Bitcoin[1], many more on underlying OSes.

- Power/Network Failures
  - Bitcoin nodes have 25% chance of going offline within 10 hours[2]

After restart, victim node select new outgoing connections from the tables!

[1]: https://en.bitcoin.it/wiki/Common_Vulnerabilities_and_Exposures
[2]: Biryukov, A. et al., Deanonymisation of clients in Bitcoin P2P network

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Chapter 4

: How many IPs does the attacker need?

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- **Eclipse Attacks & Implications**
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  - P2P network of Bitcoin
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- **How many IPs does the attacker need?**
  - Models & Experimental Results
  - Botnets, Infrastructure attack
- **Countermeasures**
- **Eclipse Attack on Ethereum**

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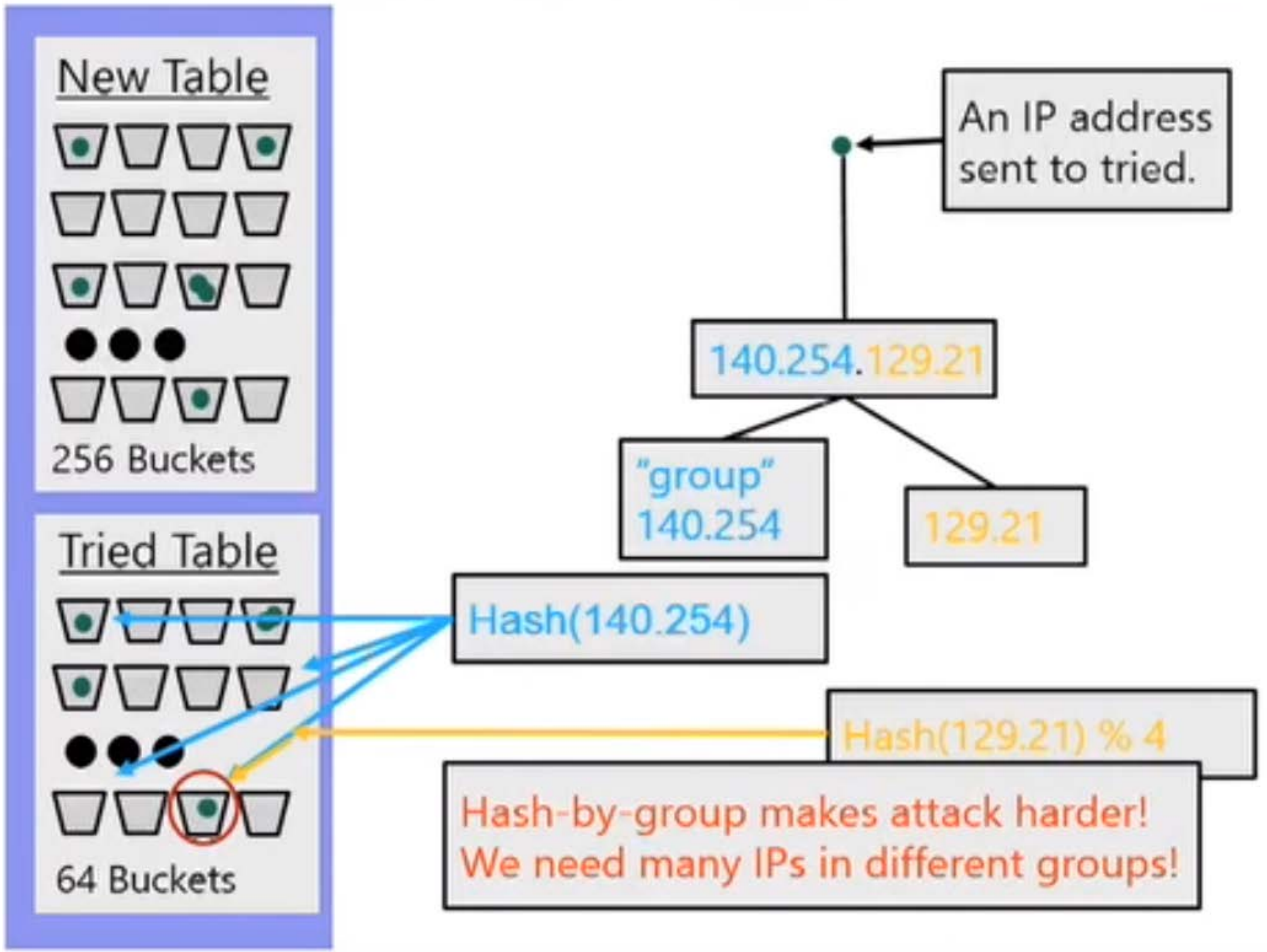
4. Eclipse Attack on Bitcoin – IP Insertion



Filling New table is easy to do, even though it also does Hash-by-group

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4. Eclipse Attack on Bitcoin – Use limited # of IPs

- The attack gets eaiser IF

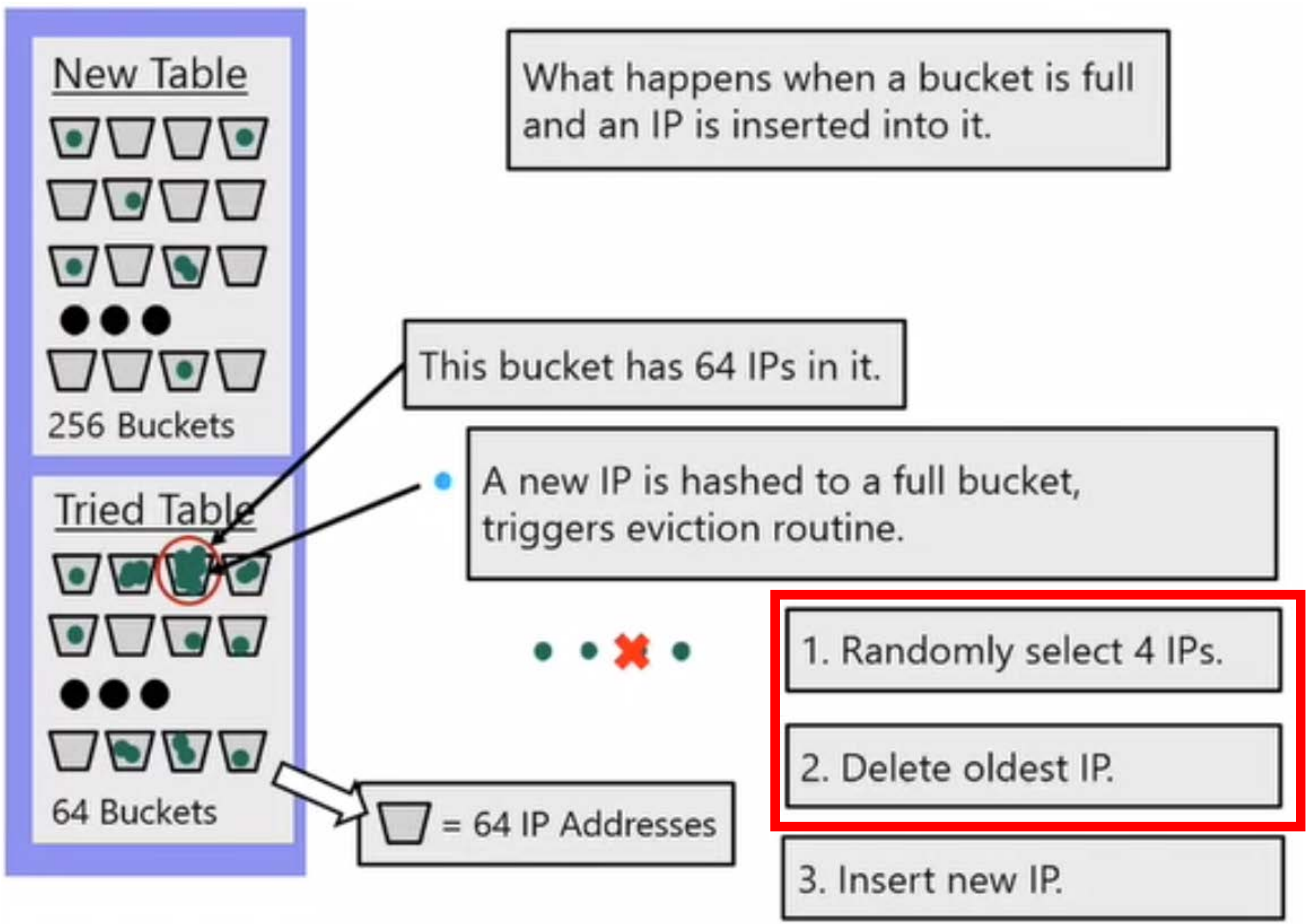
1. More attacker IPs in distinct groups
2. Few honest IPs in the tried table

- **Due to Hash-by-Group. Need many IPs in different group**

3. Stale honest IPs in the tried table
4. Fresh attacker IPs in the tried table

- **can age honest IPs by investing more time**
- **can ensure fresh IPs by continually filling the new table**

4. Eclipse Attack on Bitcoin – Bucket Eviction by Investing Time



Actually, move to New and deleted

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4. Eclipse Attack on Bitcoin – Modeling and Simulating

- Approach

1. Model Bitcoin with probability analysis & Monte-Carlo simulations
2. Use these models to determine effective attack parameters.
3. Experimentally verify these parameters against Bitcoin nodes

- Botnet vs Infrastructure

1. Botnet attacker holds several IPs, each in a distinct group
2. Infrastructure attacker holds several IPs blocks (same group)

4. Eclipse Attack on Bitcoin – Botnet Attack

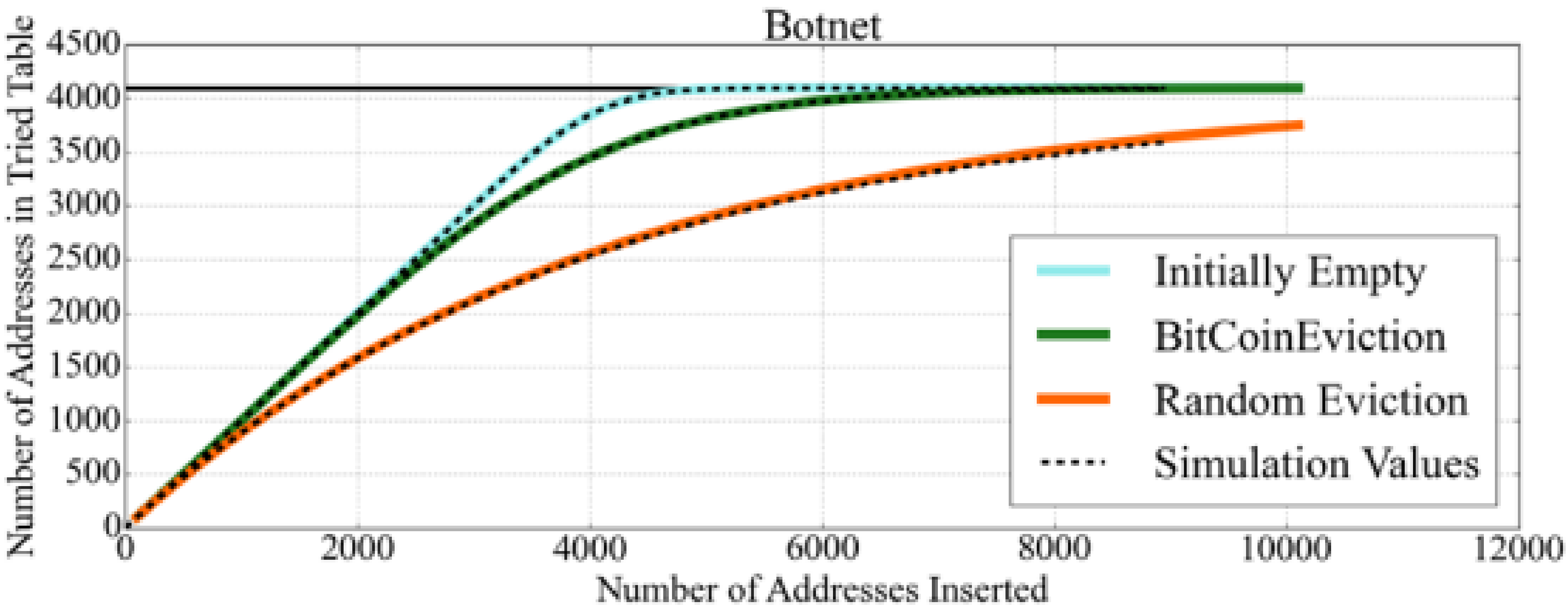

Figure. Botnet Attack simulation results

4. Eclipse Attack on Bitcoin – Infrastructure Attack

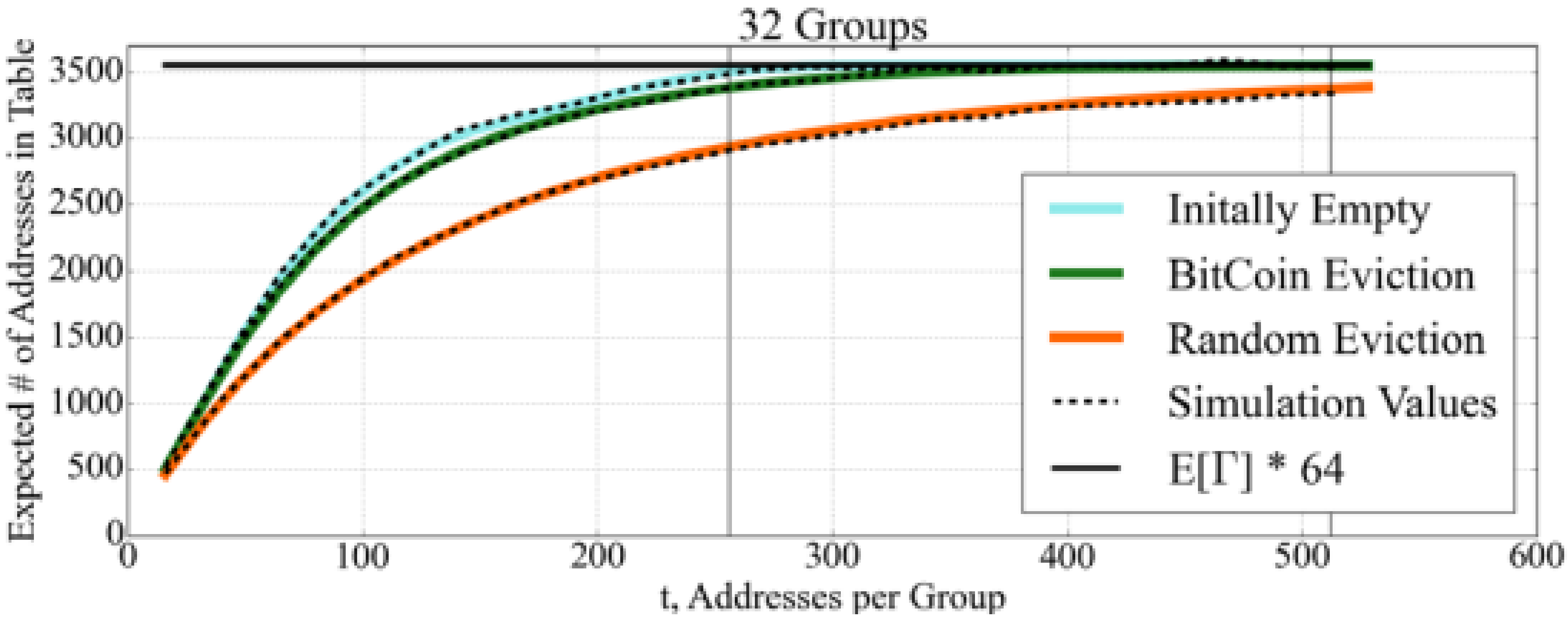

Figure. Infrastructure Attack simulation results

4. Eclipse Attack on Bitcoin – Botnet Results (Worst case)

Before Attack

- Artificially fill a node's tried table
- Tried table is 99.9% full of honest IPs (4093 IPs)

- Botnet of 4600 IPs, 2 IPs per group
- 5 hours invested, 26 min interval

After Attack

- Node's tried table is now 98.8% attacker IPs

- 100% attacker success rate, all 8 outgoing connections eclipsed

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4. Eclipse Attack on Bitcoin – Infrastructure Results (Worst case)

Before Attack

- Artificially fill a node's tried table
- Tried table is 99.8% full of honest IPs (4090 IPs)

- 32 groups of size /24(256 addresses), total 8192 IPs
- 10 hours invested, 43 min interval

After Attack

- Node's tried table is now 83.1% attacker IPs

- 98% attacker success rate, all 8 outgoing connections eclipsed

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4. Eclipse Attack on Bitcoin – Live Experiment

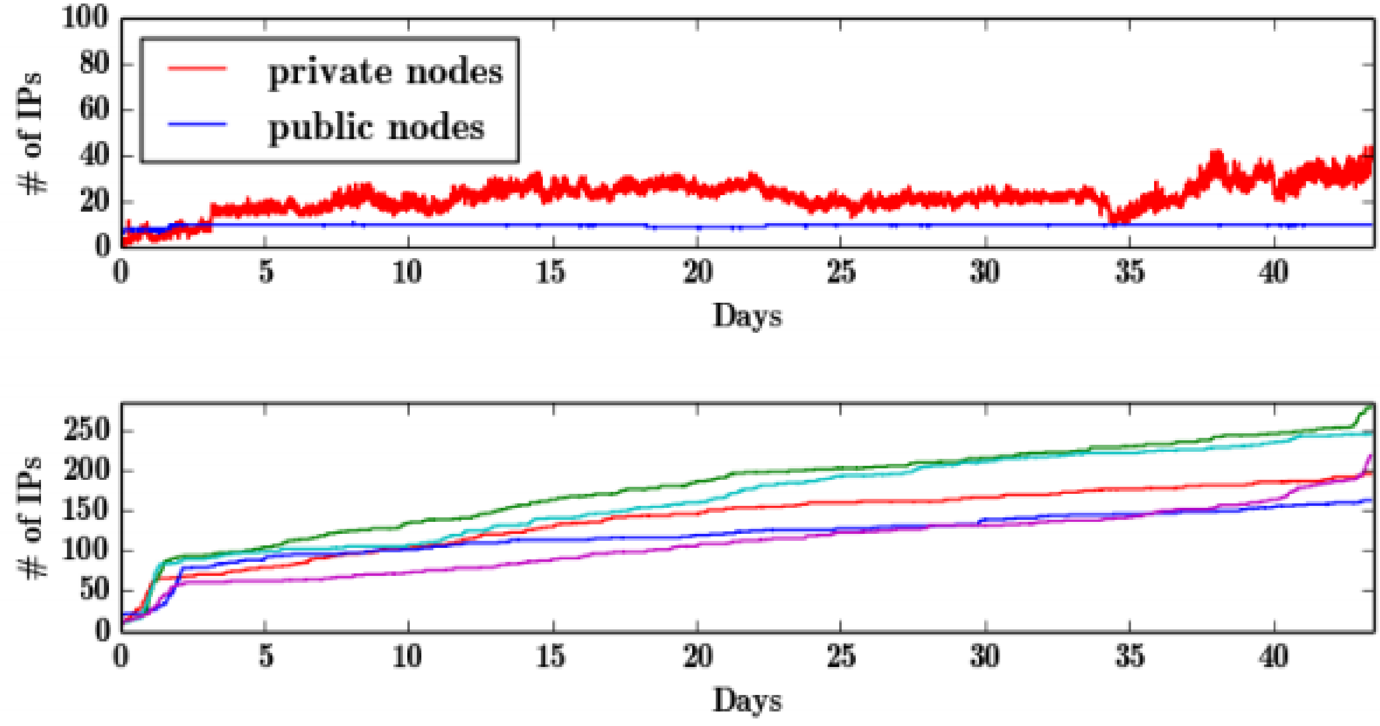

Figure. # of Connections, Tried entries

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4. Eclipse Attack on Bitcoin – Botnet Results (Live)

Before Attack

- Connected a node to the bitcoin network for +50 days
- Tried table has 298 honest IPs

- Botnet of 400 IPs, 1 IPs per group
- 1 hours invested, 90 sec interval

After Attack

- Node’s tried table is still mostly empty, but 57% are attacker IPs

- 84% attacker success rate, all 8 outgoing connections eclipsed

4. Eclipse Attack on Bitcoin – Infrastructure Results (Live)

Before Attack

- Connected a node to the bitcoin network for +50 days
- Tried table has 346 honest IPs

- 20 groups of size /24(256 addresses), total 5120 IPs
- 1 hours invested, 27 min interval

After Attack

- 94% are attacker IPs (Tried Table)

- 84% attacker success rate, all 8 outgoing connections eclipsed

4. Eclipse Attack on Bitcoin

Attack Type	Attacker resources					Experiment							Predicted		
	grps s	addrs/ grp t	total addrs	τ_ℓ, time invest	τ_a, round	Total pre-attack new	Total pre-attack tried	Total post-attack new	Total post-attack tried	Attack addrs new	Attack addrs tried	Wins	Attack addrs new	Attack addrs tried	Wins
Infra (Worstcase)	32	256	8192	10 h	43 m	16384	4090	16384	4096	15871	3404	**98%**	16064	3501	**87%**
Infra (Transplant)	20	256	5120	1 hr	27 m	16380	278	16383	3087	14974	2947	**82%**	15040	2868	**77%**
Infra (Transplant)	20	256	5120	2 hr	27 m	16380	278	16383	3088	14920	2966	**78%**	15040	2868	**87%**
Infra (Transplant)	20	256	5120	4 hr	27 m	16380	278	16384	3088	14819	2972	**86%**	15040	2868	**91%**
Infra (Live)	20	256	5120	1 hr	27 m	16381	346	16384	3116	14341	2942	**84%**	15040	2868	**75%**
Bots (Worstcase)	2300	2	4600	5 h	26 m	16080	4093	16384	4096	16383	4015	**100%**	16384	4048	**96%**
Bots (Transplant)	200	1	200	1 hr	74 s	16380	278	16384	448	16375	200	**60%**	16384	200	**11%**
Bots (Transplant)	400	1	400	1 hr	90 s	16380	278	16384	648	16384	400	**88%**	16384	400	**34%**
Bots (Transplant)	400	1	400	4 hr	90 s	16380	278	16384	650	16383	400	**84%**	16384	400	**61%**
Bots (Transplant)	600	1	600	1 hr	209 s	16380	278	16384	848	16384	600	**96%**	16384	600	**47%**
Bots (Live)	400	1	400	1 hr	90 s	16380	298	16384	698	16384	400	**84%**	16384	400	**28%**

Table 2: Summary of our experiments.

Which one is better?

Is Bitcoin safe?

Chapter 5

: Countermeasures

Outline

- **Eclipse Attacks & Implications** — chapter 2
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- **How to eclipse a Bitcoin node** — chapter 3
  - P2P network of Bitcoin
  - How to exploit Bitcoin's P2P networking
- **How many IPs does the attacker need?** — chapter 4
  - Models & Experimental Results
  - Botnets, Infrastructure attack
- **Countermeasures** — chapter 5
  - Effectiveness of countermeasures
  - Current deployment
- **Eclipse Attack on Ethereum** — chapter 6

5. Countermeasures : Random Selection

- Vunlerability 1 – Selection Bias

Attacker ensures its IPs are fresher so they are more likely to be selected

- Countermeasure : Random Selection

Randomly select IPs with no bias toward fresher timestamps

$$p(r, \tau) = \min(1, \frac{1.2^r}{1+\tau})$$

5. Countermeasures : Deterministic Random Eviction

- Vunlerability 2 – Eviction Bias

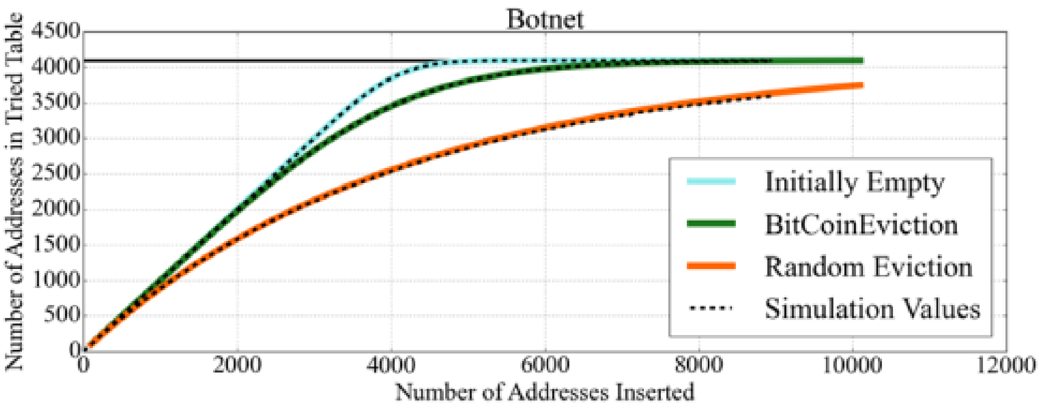
Attacker exploited Eviction bias toward older IPs

- Vunlerability 3 – Try Again

Attacker exploited randomness in eviction process to improve odds of stuffing tried table by running the attack multiple times

- Countermeasure : Deterministic Random Eviction

Deterministically map IPs to buckets and positions in buckets, evicting whatever happens to be in that position



5. Countermeasures : Feelers & Test-Before-Evict

- Problem:

Tried table fills up very slowly and contain mostly dead IPs.
The fewer honest IPs in tried

- Countermeasure : Feeler Connection

Make test connections to IPs in new to fill tried table faster

- Problem:

Good IP addresses from tried get evicted

- Countermeasure : Test Before Evict

Test IPs in tried before evicting them, if online do not evict

5. Countermeasures : Deployment

- Countermeasurement

1. Deterministic Random Eviction
2. Random Selection
6. More Buckets

→ **Bitcoind 10.1 version**

3. Test-Before-Evict
4. Feeler Connections

→ **In a Patch, awaiting review**

5. Anchor Connections

And More!

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5. Countermeasures : How Effective?

	No countermeasures	1,2,6 countermeasures Bitcoin 0.10.1	1,2,3,4,6 countermeasures Bitcoin 0.10.1 + patch
Full tried table (worst case)	**4600** IPs **100%** attacker success	**41,000** IPs (model) **~50%** attacker success	test-before-evict keeps attacker IPs out. **0%** attacker success
Live node (298 IPs)	**400** IPs **84%** attacker success	**3,700** IPs (model) **~50%** attacker success	

Better Security →

5. Summary

- Eclipse Attacks violate Bitcoin's core security gurantees
  - N-Confirmation double spending
  - 51% attack, Selfish mining, and so on

- The paper develop practical attacks
  - A botnet of 400 IPs is sufficient
  - In an attackers worst case >> a botnet of 4600 IPs

- The paper have effective countermeasures to resist these attacks
  - Some of the countermeasures have already been deployed
  - Others are awaiting review

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Chapter 6

: Eclipse Attack on Ethereum

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Outline

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- **How many IPs does the attacker need?**
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  - Botnets, Infrastructure attack
- **Countermeasures**
  - Effectiveness of countermeasures
  - Current deployment
- **Eclipse Attack on Ethereum**
  - simple case study of Ethereum Attack

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6. Eclipse Attack on Ethereum – Overview

1. Monopolizing Connection

2. Table Poisoning

6. Eclipse Attack on Ethereum – Overview about Data Structure

- Table
  1. empty when the client reboot
  2. 256 buckets, 16 entries
  3. store node information prior to db
- DB
  1. DB is stored on disk, persistant
  2. information about nodes the client has seen

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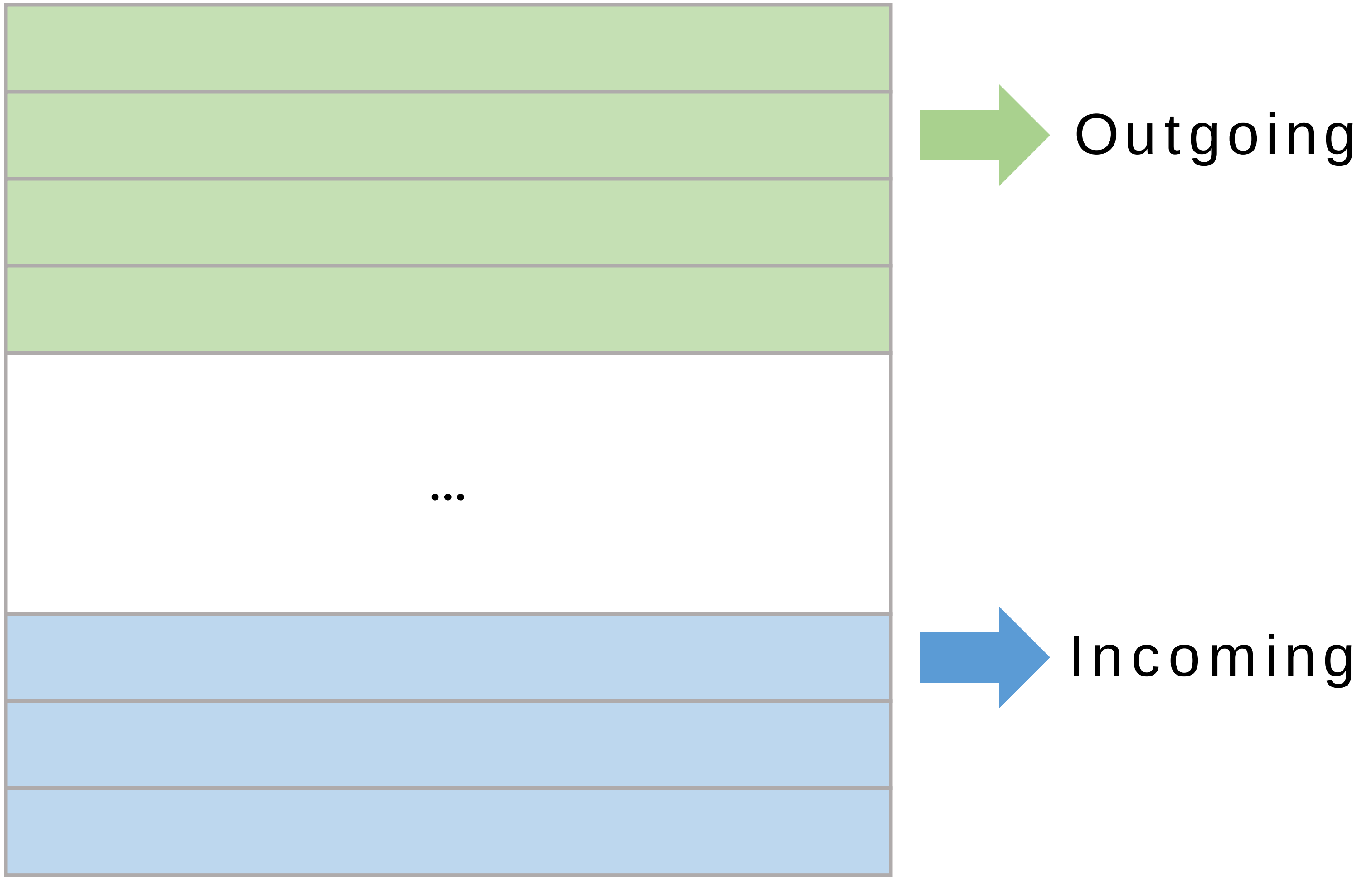
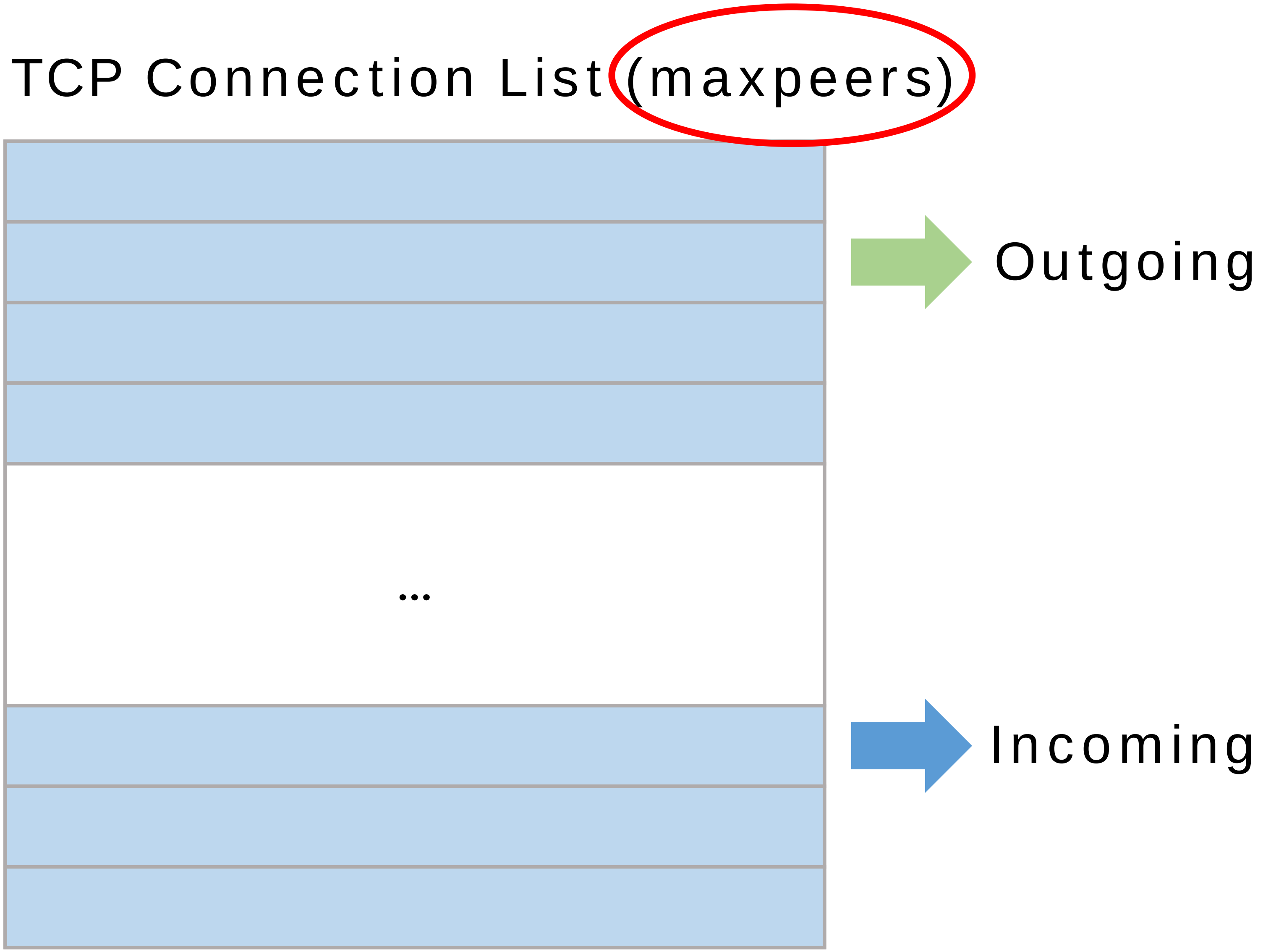
6. Eclipse Attack on Ethereum – Monopolizing Connections

TCP Connection List (maxpeers)



Using TCP to exchange blockchain information

6. Eclipse Attack on Ethereum – Monopolizing Connections



When a client **reboot**, no incoming/outgoing
Establishing incoming is faster than outgoing(db)

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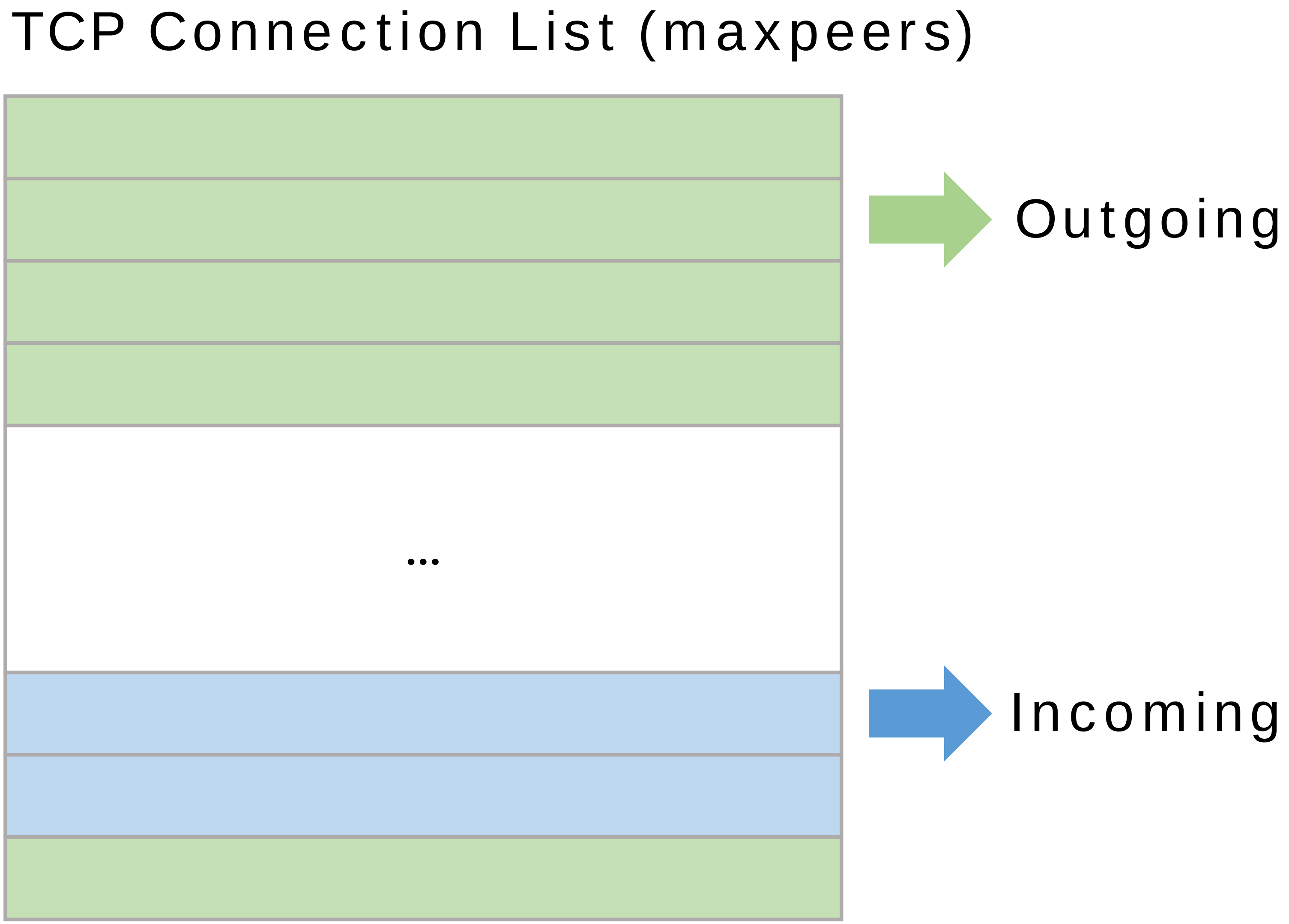
6. Eclipse Attack on Ethereum – Monopolizing Connections



Set "Upper limit" on number of incoming TCPs
(geth v1.8.0, limit = 8)

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6. Eclipse Attack on Ethereum – Overview

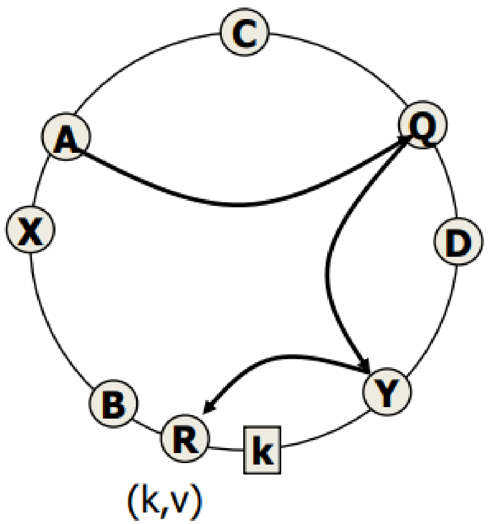
1. Monopolizing Connection

2. Table Poisoning

6. Eclipse Attack on Ethereum – Brief Review

DHT: Terminologies

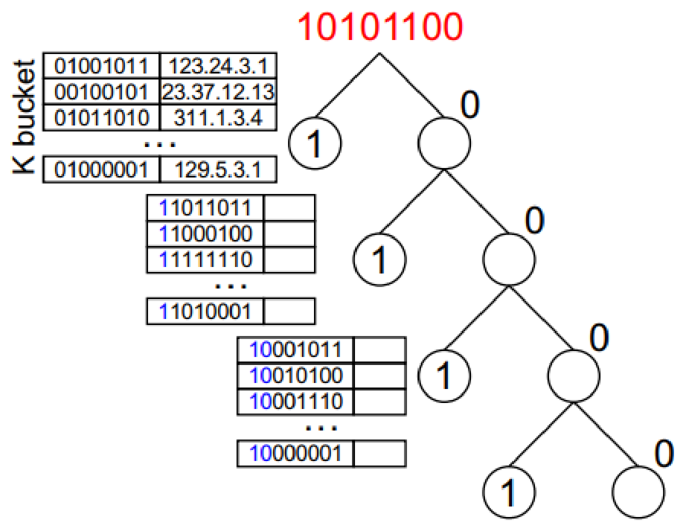
- Every node has a unique ID: *nodeID*
- Every object has a unique ID: *key*
- Keys and nodeIDs are logically arranged on a *ring* (*ID space*)
- A data object is stored at its *root(key)* and several *replica roots*
  - Closest nodeID to the key (or successor of k)

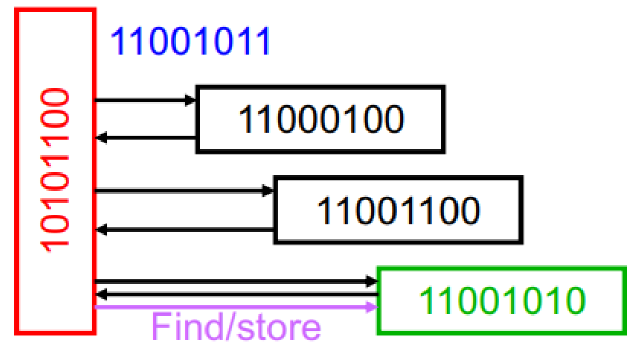


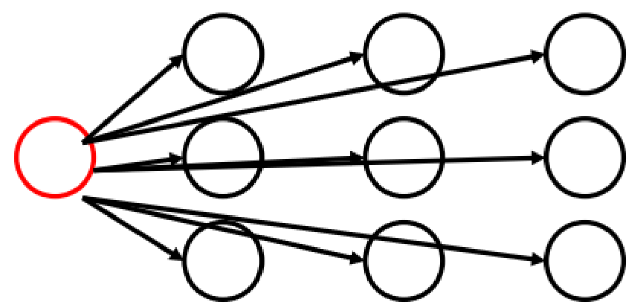
- *Range:* the set of keys that a node is responsible for
- Routing table size: O(log(N))
- Routing delay: O(log(N)) hops
- Content addressable!

6. Eclipse Attack on Ethereum – Brief Review

Kademlia Protocol







- d(X, Y) = X XOR Y
- An entry in k-bucket shares at least k-bit prefix with the nodeID
  - k=20 in overnet
- Add new contact if
  - k-bucket is not full

- Parallel, iterative, prefix-matching routing
- Replica roots: k closest nodes

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- **Ethereum is based on Kademlia,**

The Purpose of Kademlia Algorithm?

- For Neighboring, not find/store contents

The Problem of Kademlia Algorithm?

- Using Node Id, not IP
- Using XOR distance

6. Eclipse Attack on Ethereum – problem of this approach(1)

Attack Type	Attacker resources					Experiment							Predicted		
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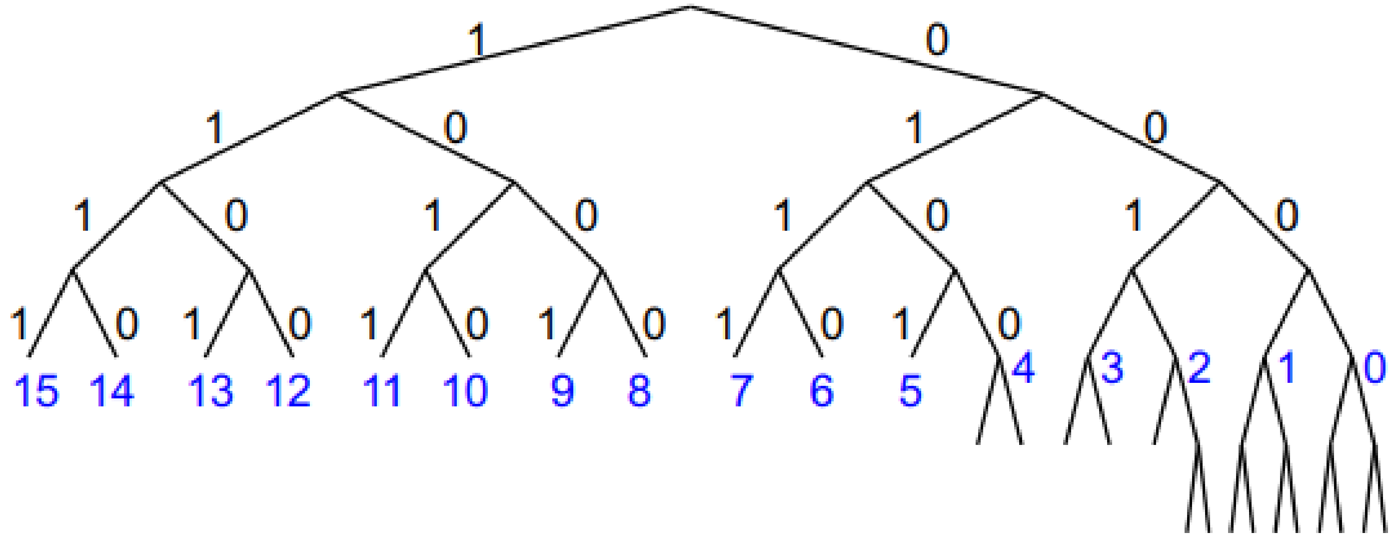
Infra (Transplant)	20	256	5120	2 hr	27 m	16380	278	16383	3088	14920	2966	**78%**	15040	2868	**87%**
Infra (Transplant)	20	256	5120	4 hr	27 m	16380	278	16384	3088	14819	2972	**86%**	15040	2868	**91%**
Infra (Live)	20	256	5120	1 hr	27 m	16381	346	16384	3116	14341	2942	**84%**	15040	2868	**75%**
Bots (Worstcase)	2300	2	4600	5 h	26 m	16080	4093	16384	4096	16383	4015	**100%**	16384	4048	**96%**
Bots (Transplant)	200	1	200	1 hr	74 s	16380	278	16384	448	16375	200	**60%**	16384	200	**11%**
Bots (Transplant)	400	1	400	1 hr	90 s	16380	278	16384	648	16384	400	**88%**	16384	400	**34%**
Bots (Transplant)	400	1	400	4 hr	90 s	16380	278	16384	650	16383	400	**84%**	16384	400	**61%**
Bots (Transplant)	600	1	600	1 hr	209 s	16380	278	16384	848	16384	600	**96%**	16384	600	**47%**
Bots (Live)	400	1	400	1 hr	90 s	16380	298	16384	698	16384	400	**84%**	16384	400	**28%**

Table 2: Summary of our experiments.

6. Eclipse Attack on Ethereum – problem of this approach(2)



- **Using SHA3 to make Node ID 256 bits.**
- **“Table” -> 256 buckets, 16 entries each**
- **Since Kademlia uses XOR distance, “Table” info is public**

6. Eclipse Attack on Ethereum – Table Poisoning

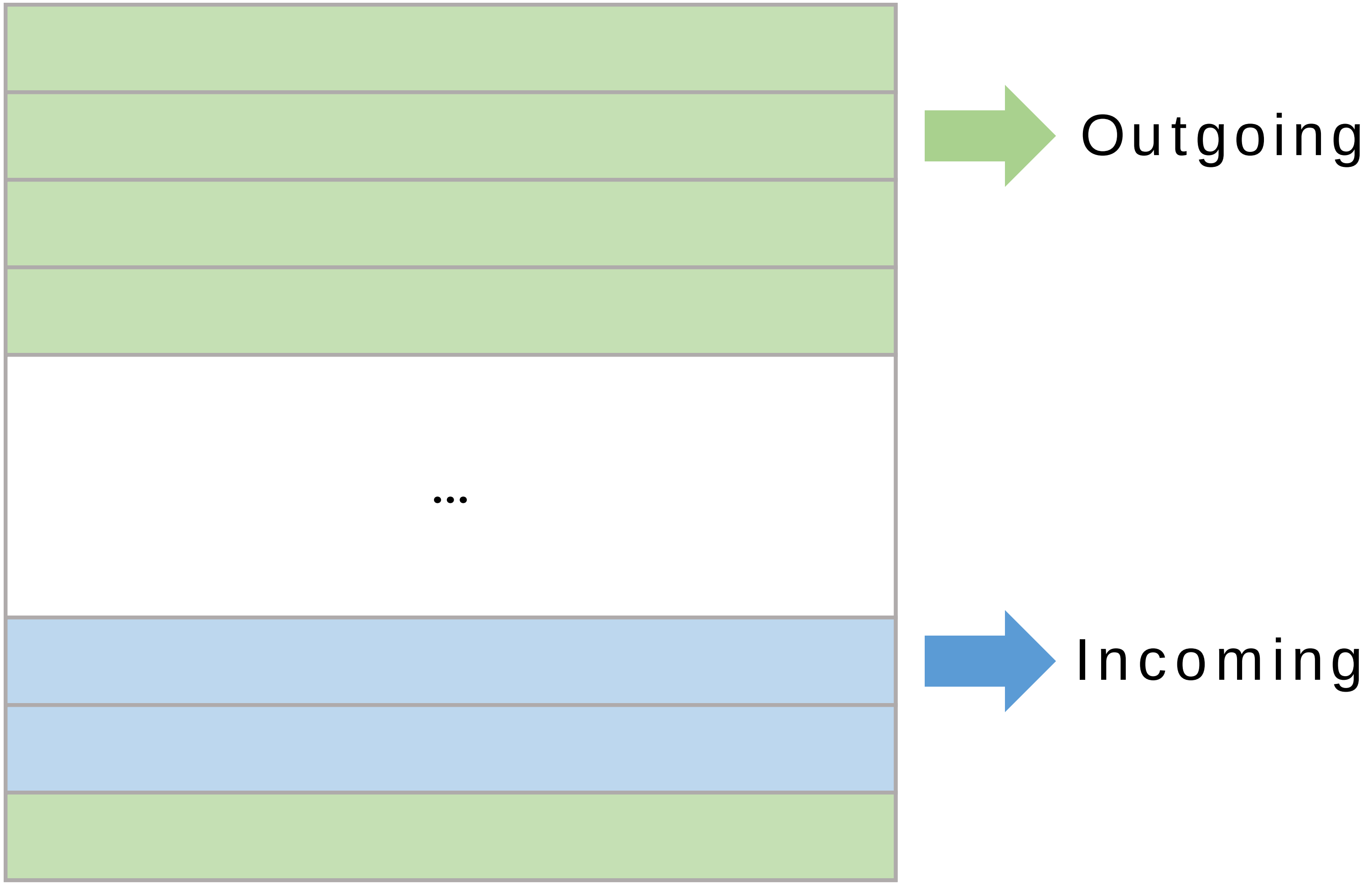
1. **Craft Attacker node IDs**
   - Make a lot of IDs using 1 or 2 IPs
   - Use rejection sampling

2. **Insert Attacker node IDs into db**
   - Send ping msg to the victim
   - Every 24 hours
   - Response to ping, findnode

3. **Reboot and eclipse the victim**
   - Do seeding to fill in Table
   - Seeding use info from db

Do Monopolizing agian

TCP Connection List (maxpeers)



THANK YOU