On the Robustness of Random Walk Algorithms for the Detection of Unstructured P2P Botnets

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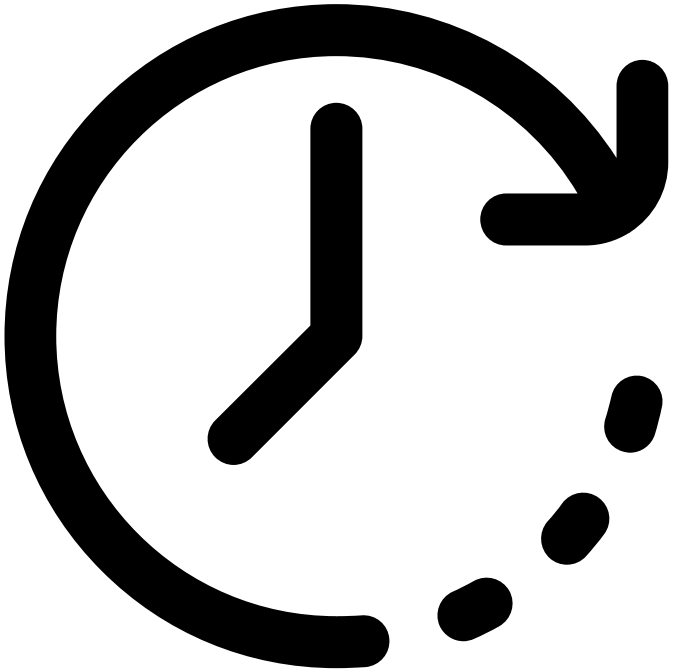
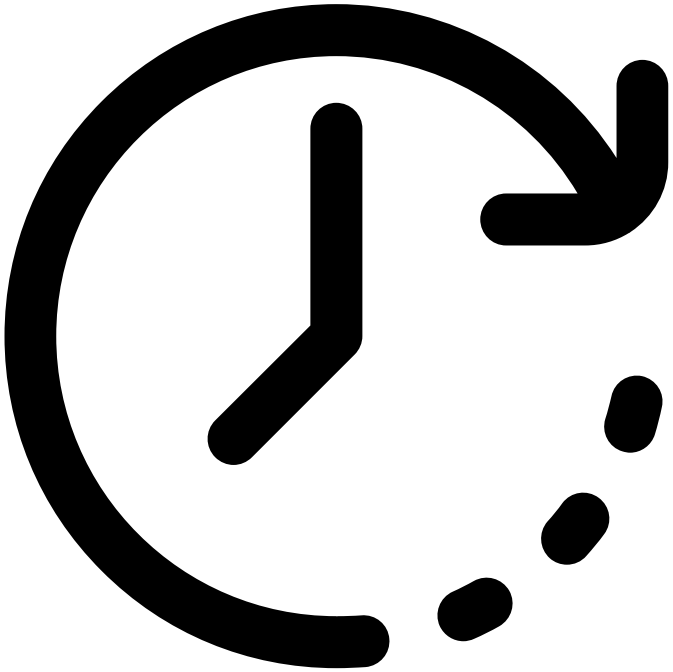
Outline



[7]

Outline

I. Motivation



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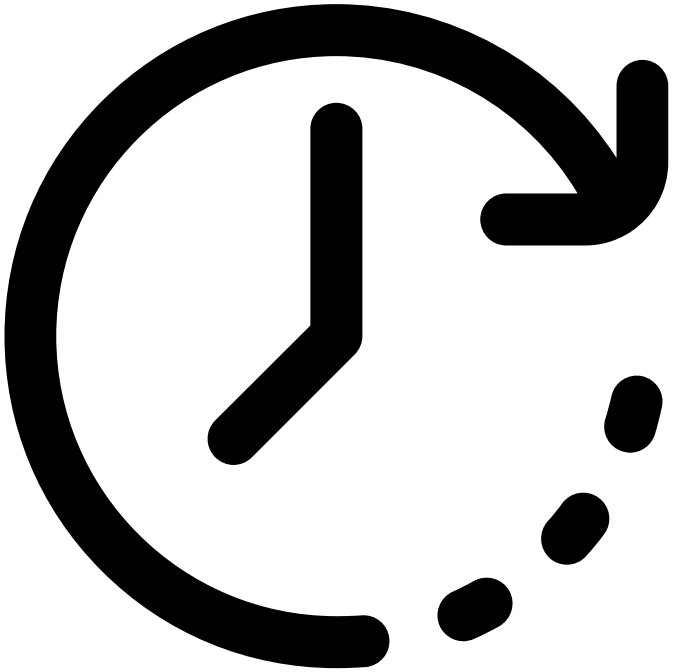
II. Botnets
    1. Definition
    2. Graph Model



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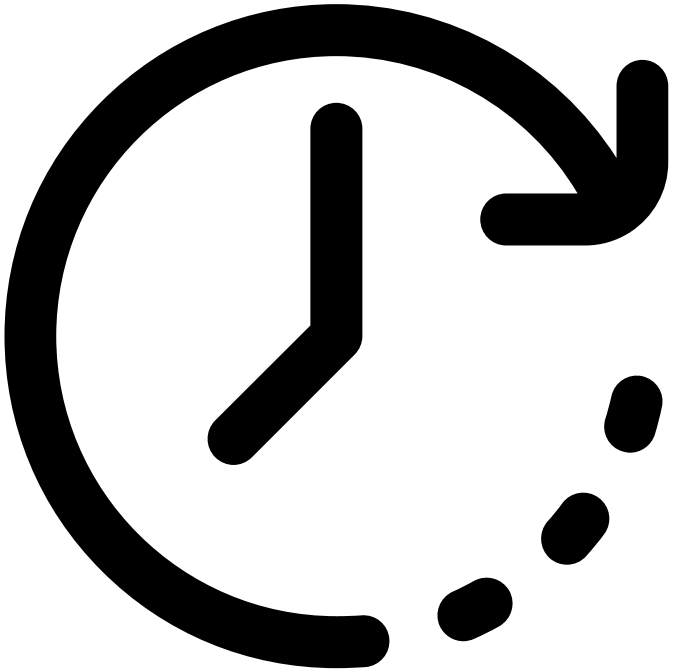

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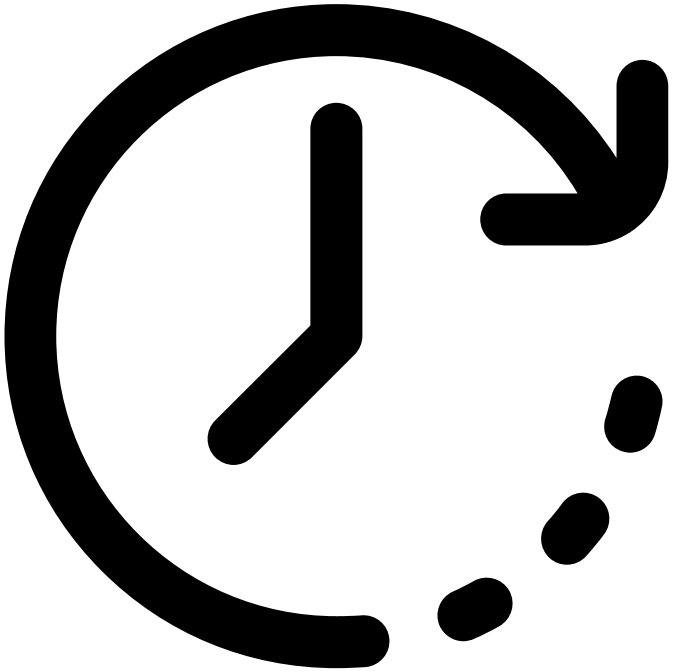

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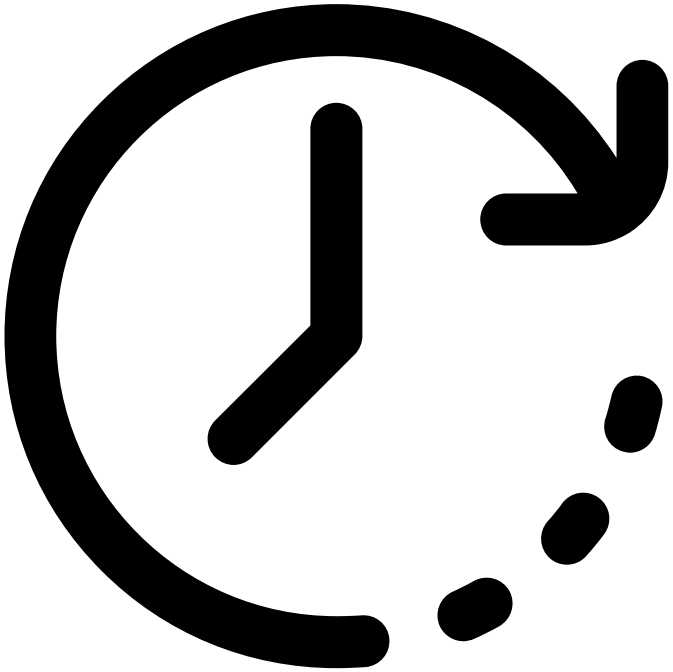

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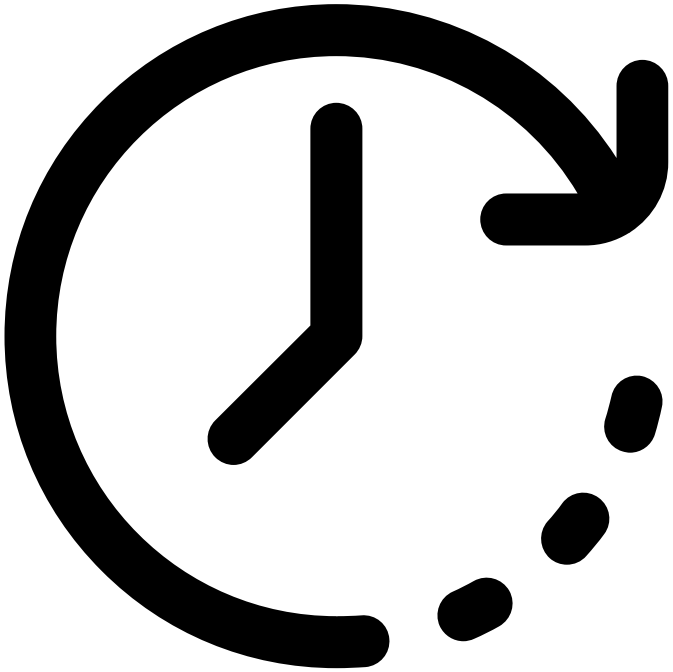
VI. Results



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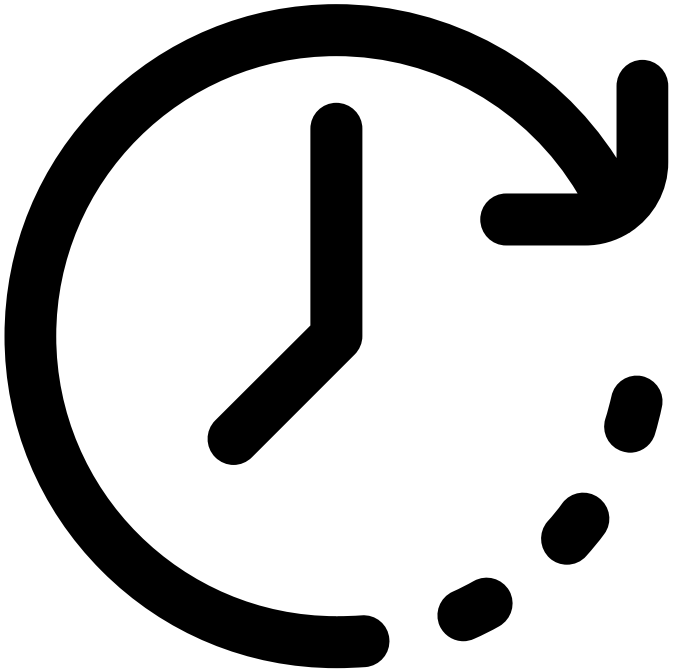

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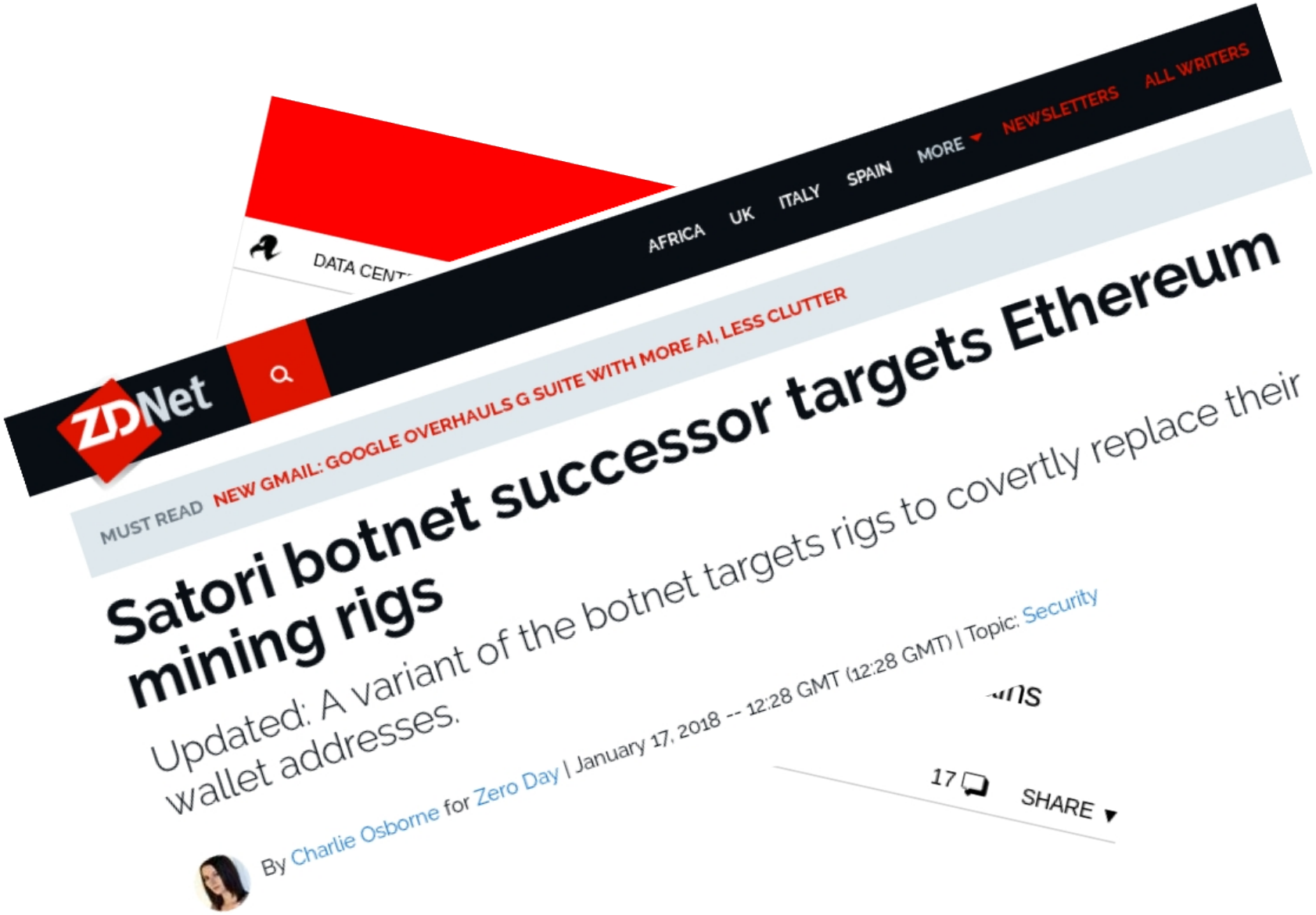
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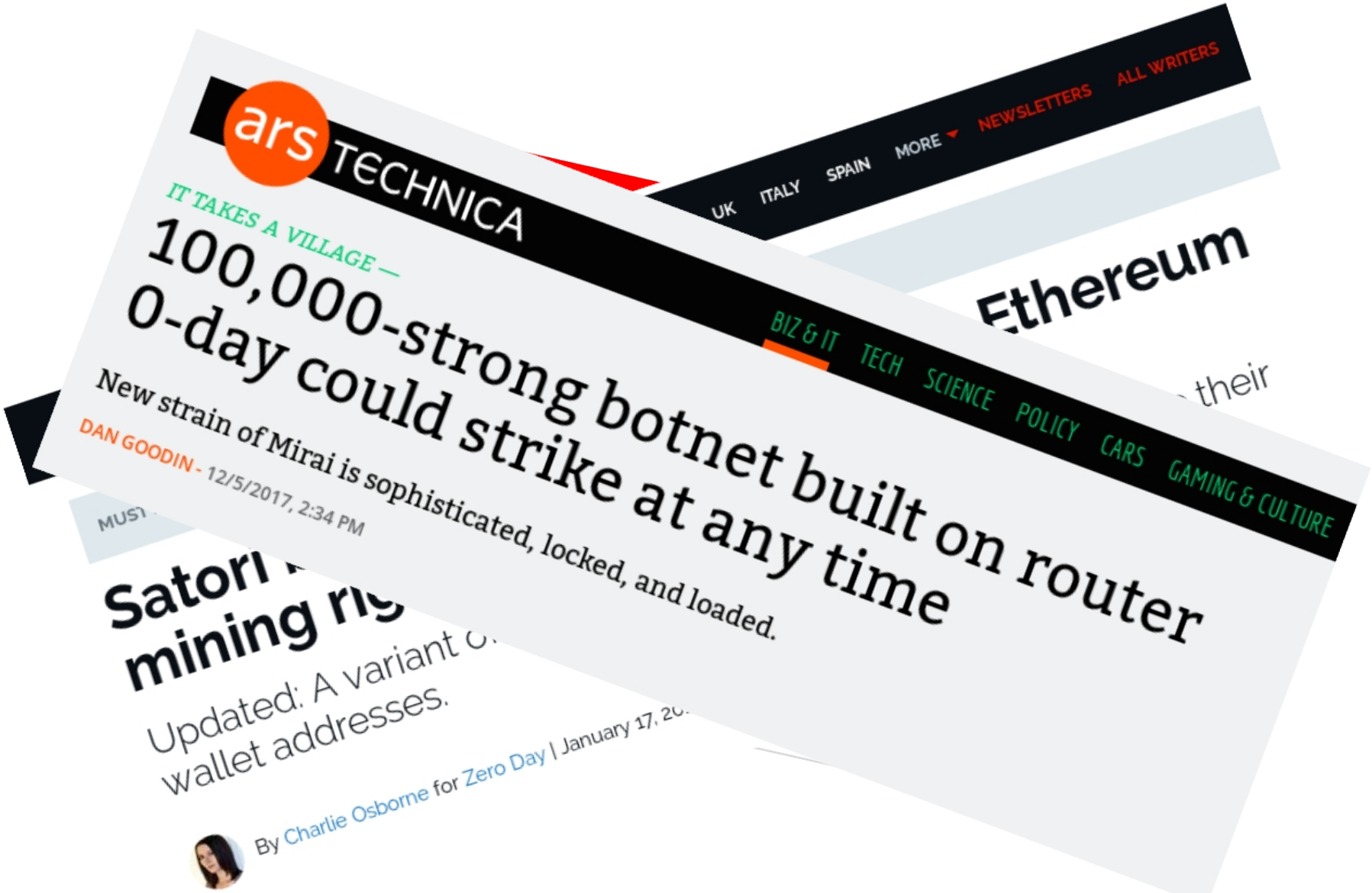
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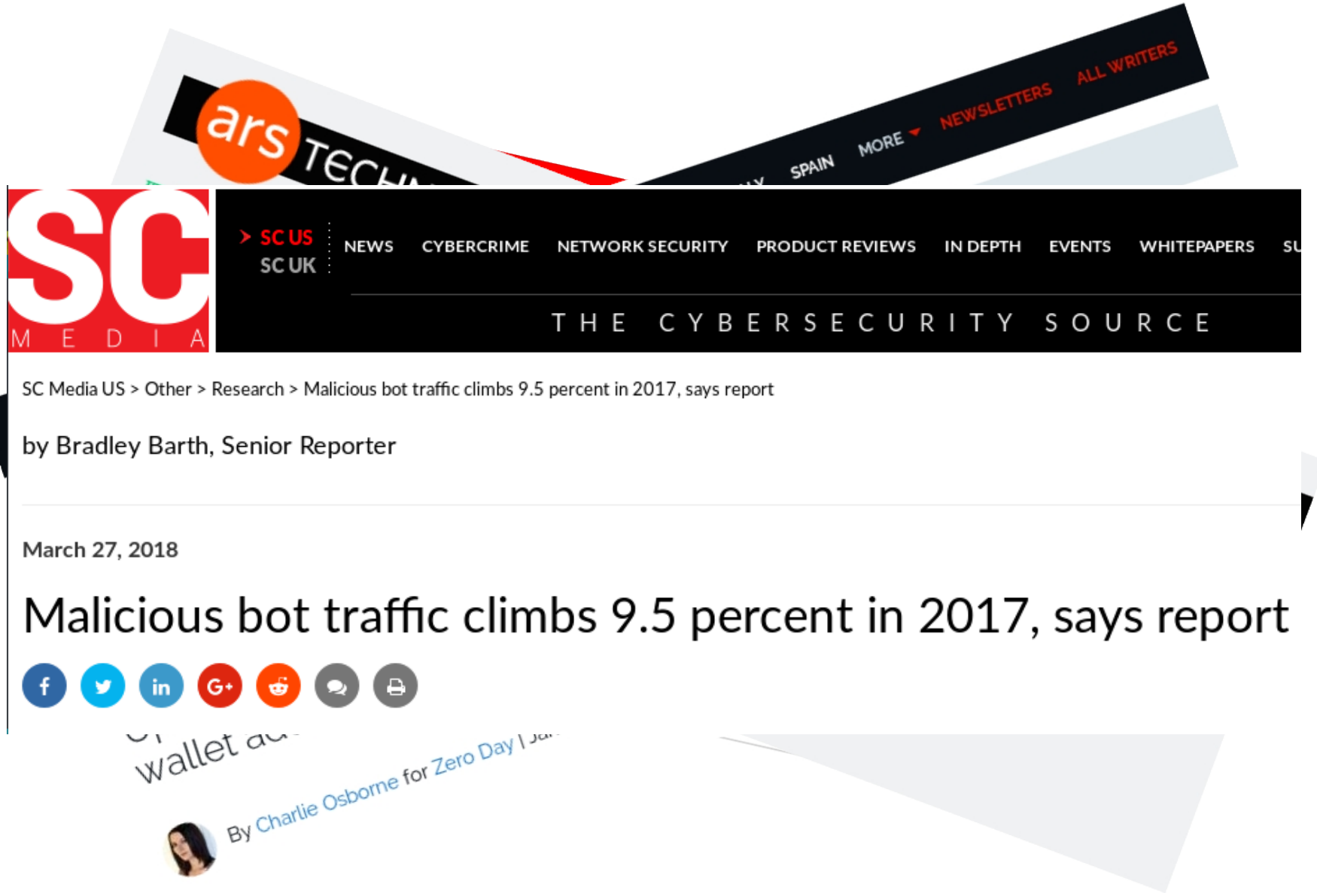
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by Bradley Barth, Senior Reporter
March 27, 2018
Malicious bot traffic climbs 9.5 percent in 2017, says report
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By Charlie Osborne for Zero Day

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A new Mirai-style botnet is targeting the financial sector
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By Zack Whittaker for Zero Day | April 5, 2018 -- 13:00 GMT (14:00 BST) | Topic: Security
percent in 2017, says report
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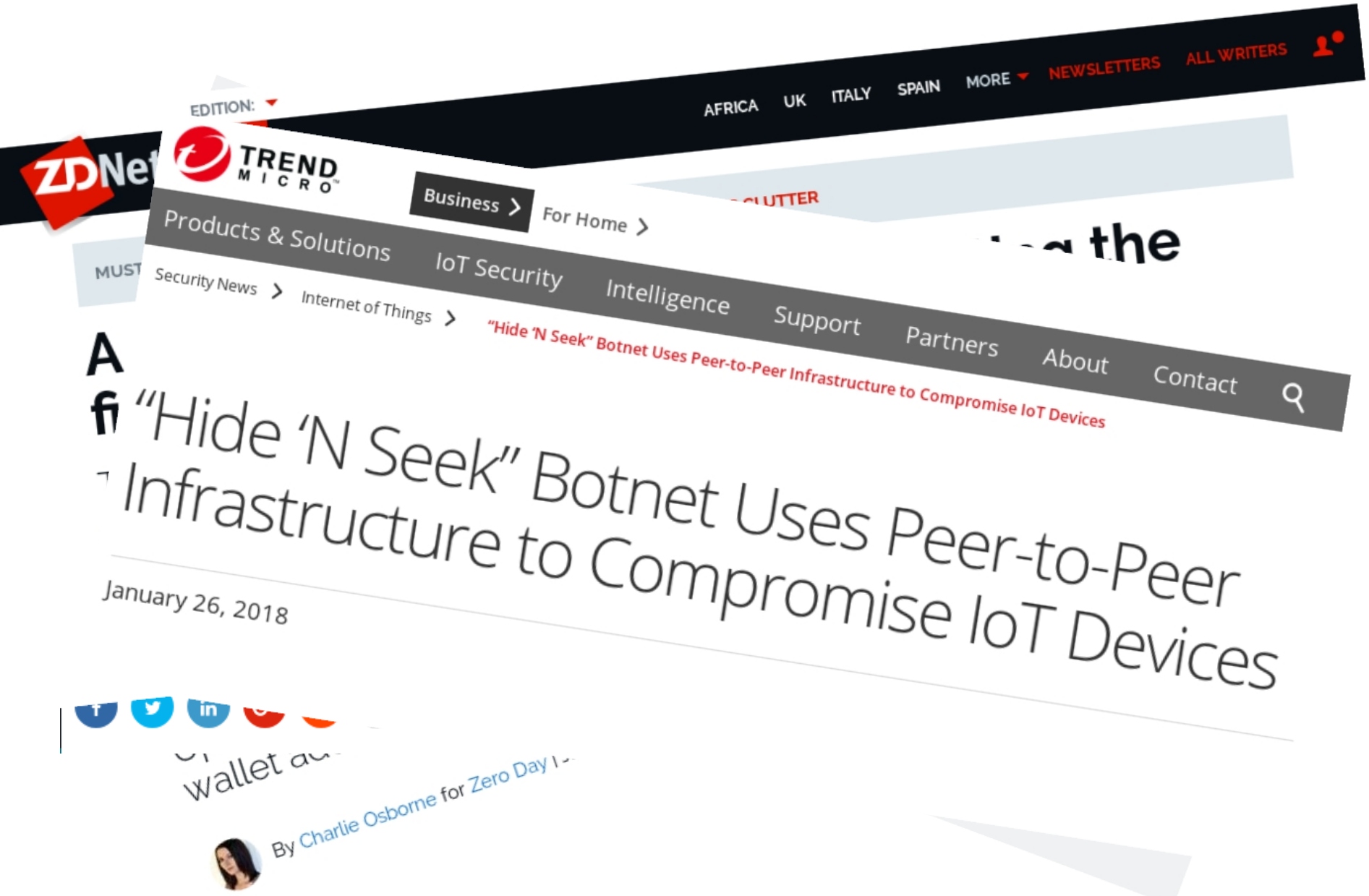
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"Hide 'N Seek" Botnet Uses Peer-to-Peer Infrastructure to Compromise IoT Devices
"Hide 'N Seek" Botnet Uses Peer-to-Peer Infrastructure to Compromise IoT Devices
January 26, 2018
By Charlie Osborne for Zero Day

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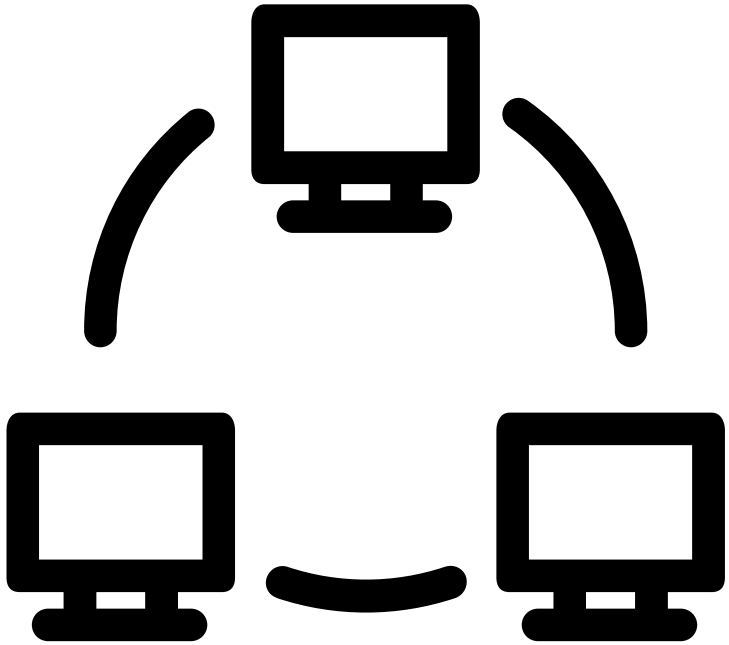
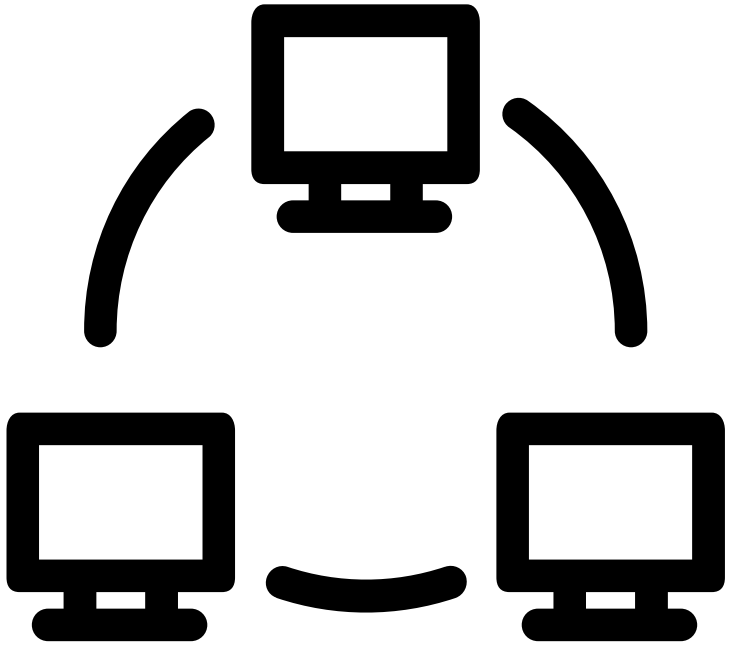
What are Botnets?



[9]

What are Botnets?

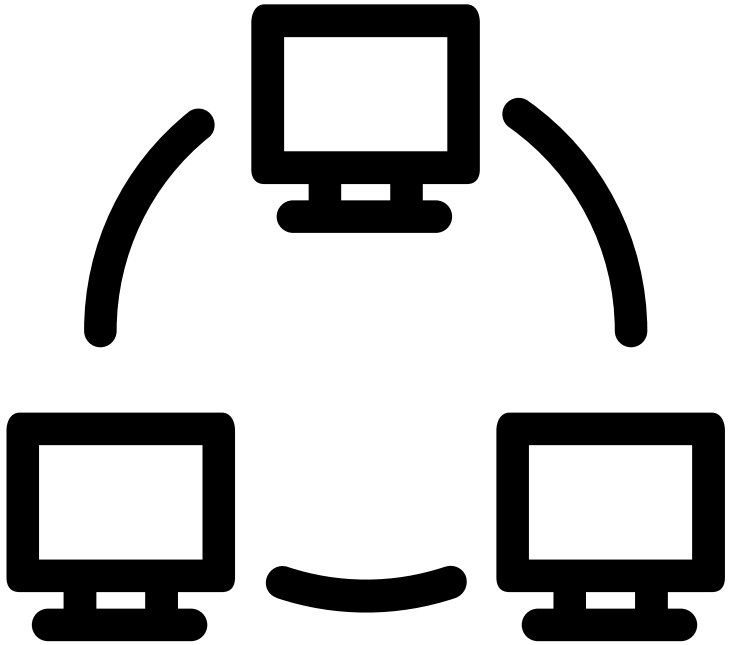
- Device collection



[9]

What are Botnets?

- Device collection
- Internet-connected



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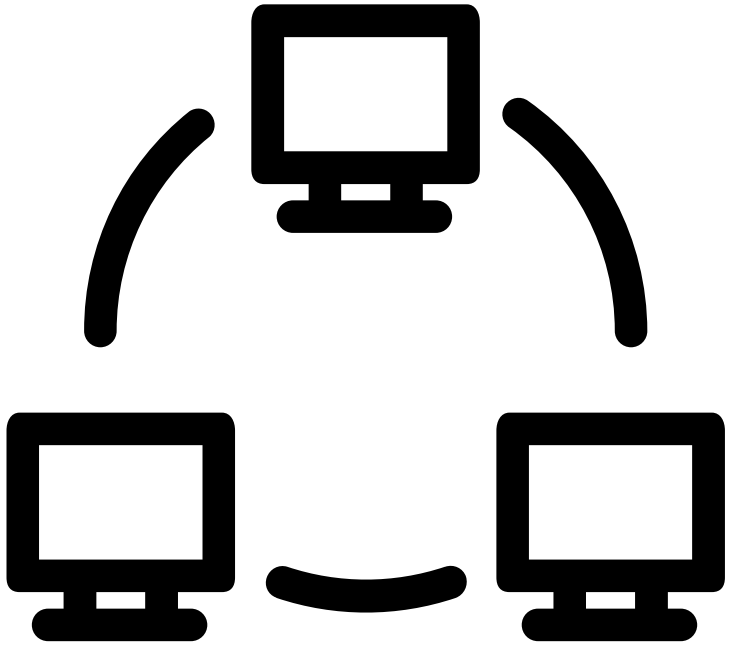
What are Botnets?

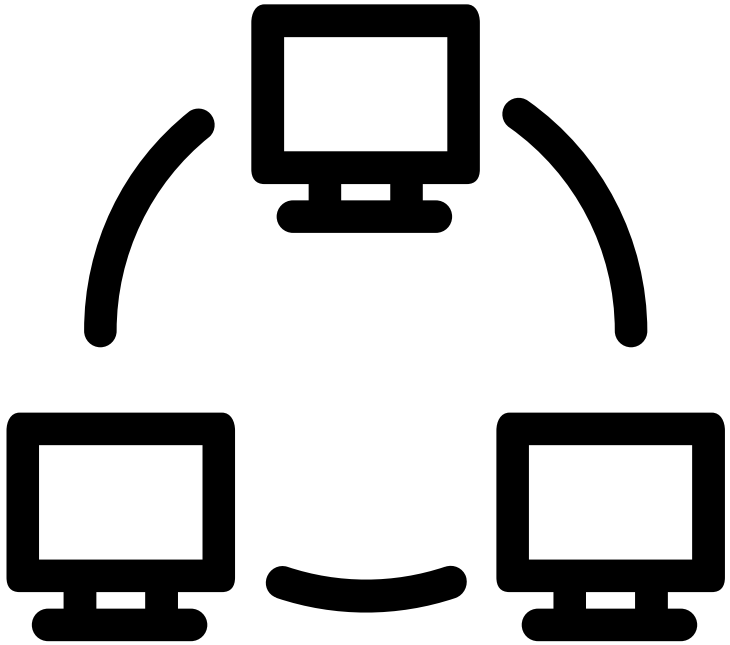
- Device collection
- Internet-connected
- Malware-infected



[9]

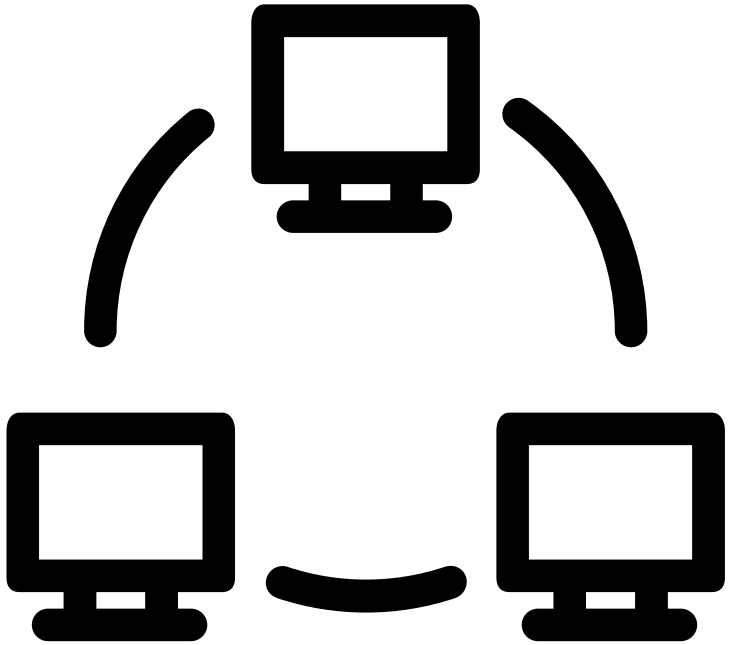
What are Botnets?

- Device collection
- Internet-connected
- Malware-infected
- Remotely controlled (usually centralized)



[9]

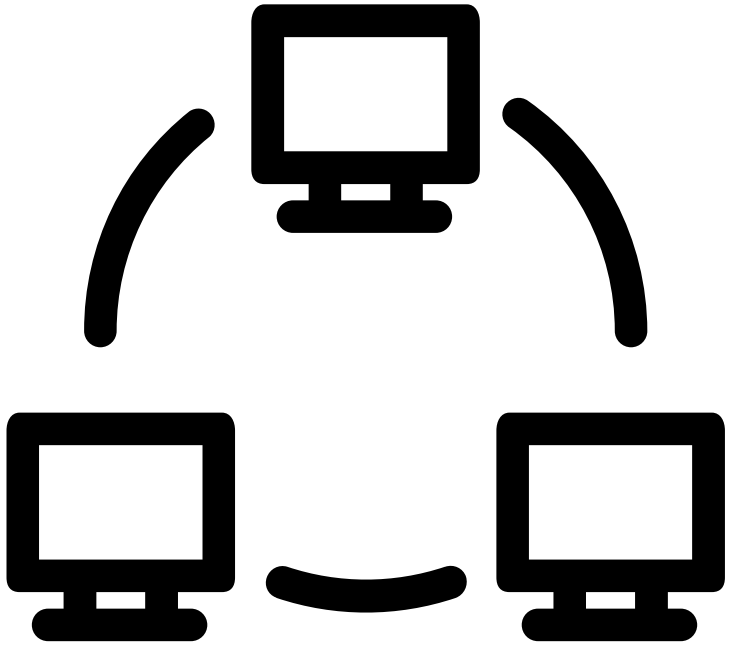
Why are Botnets bad?



[9]

Why are Botnets bad?

- Clickfraud



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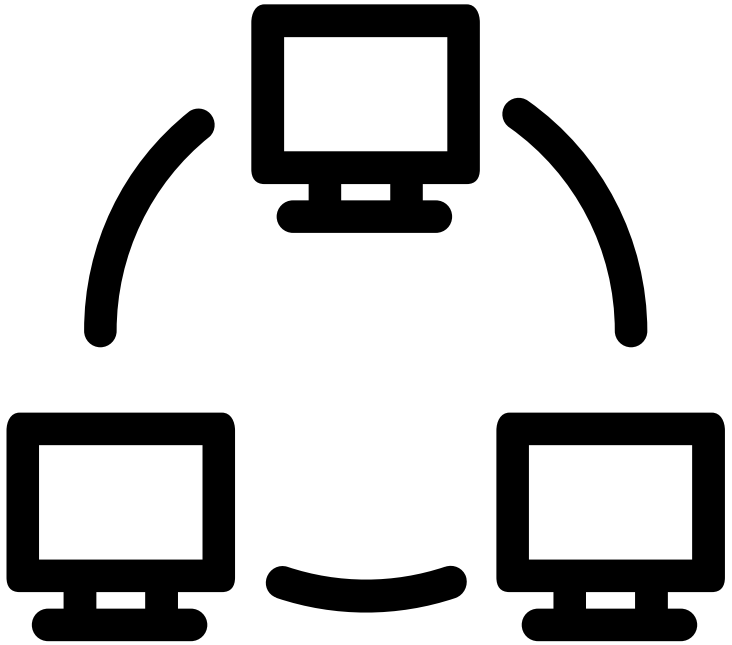
Why are Botnets bad?

- Clickfraud
- Spam



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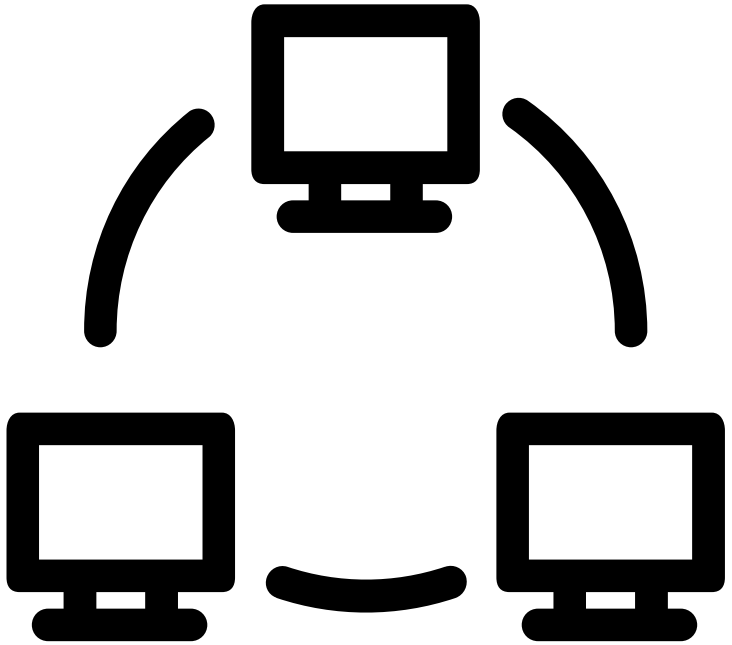
Why are Botnets bad?

- Clickfraud
- Spam
- DDoS attacks



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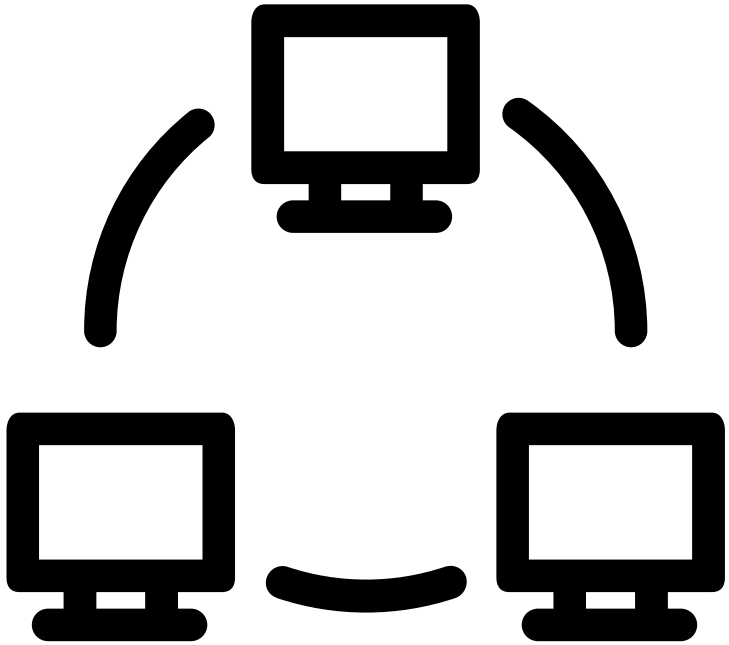
Why are Botnets bad?

- Clickfraud
- Spam
- DDoS attacks
- Cryptocurrency mining



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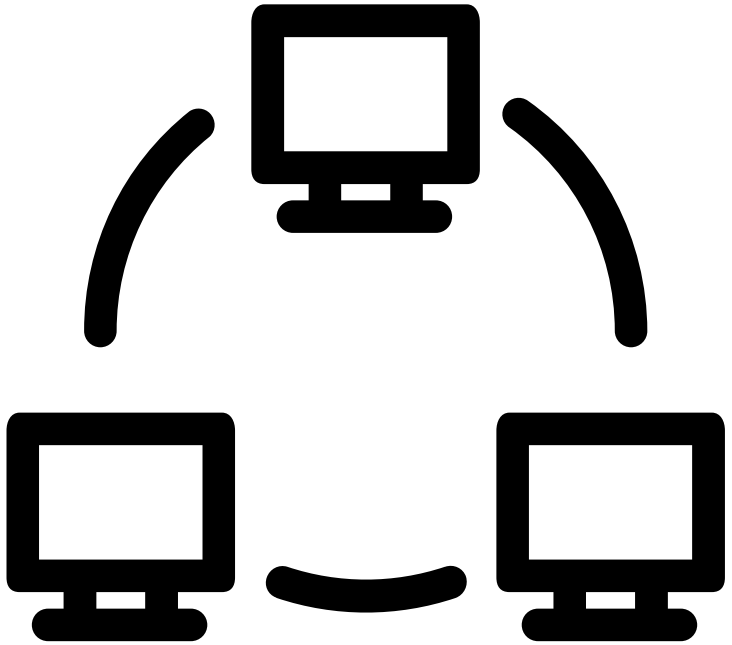
Why are Botnets bad?

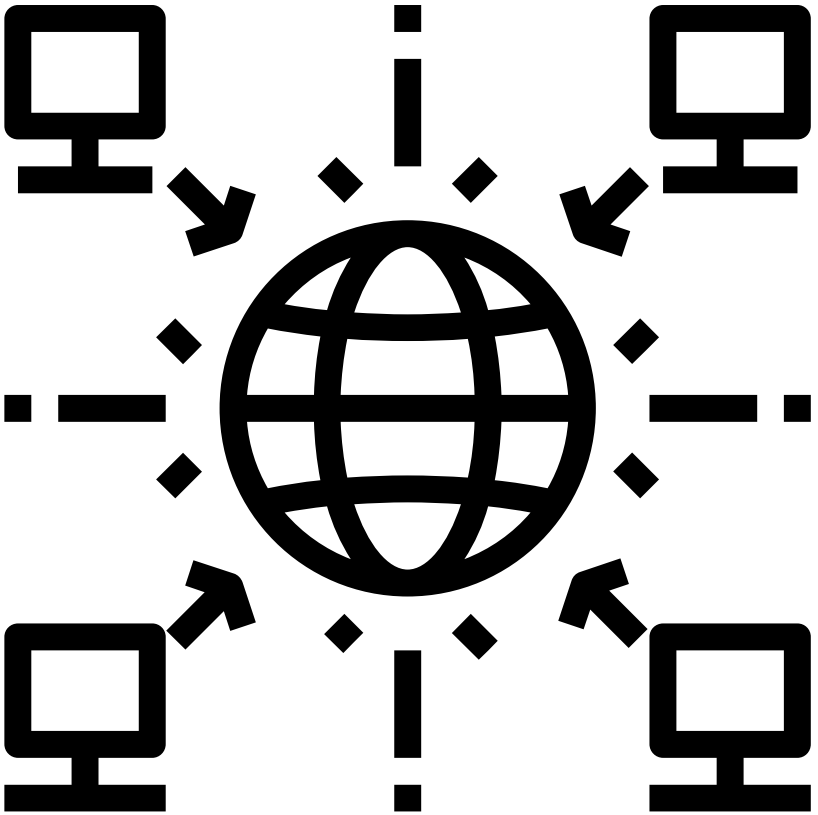
- Clickfraud
- Spam
- DDoS attacks
- Cryptocurrency mining
- Intellectual property theft



[9]

Topological Categories

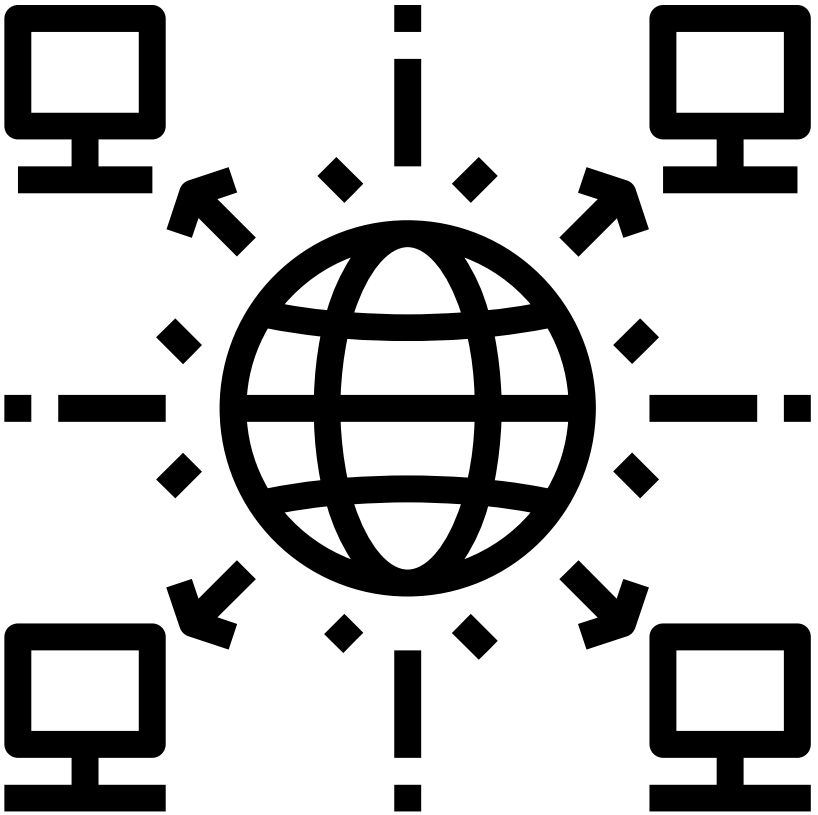
- Centralized



[8]

Topological Categories

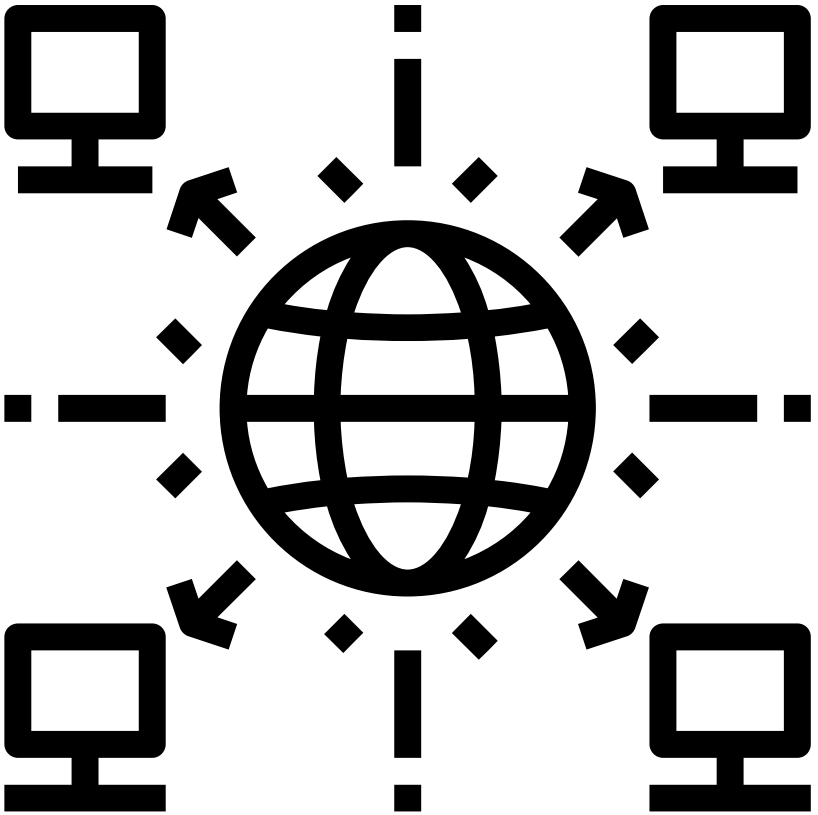
- Centralized
- Decentralized



[8]

Topological Categories

- Centralized
- Decentralized
  - Structured
  - Unstructured



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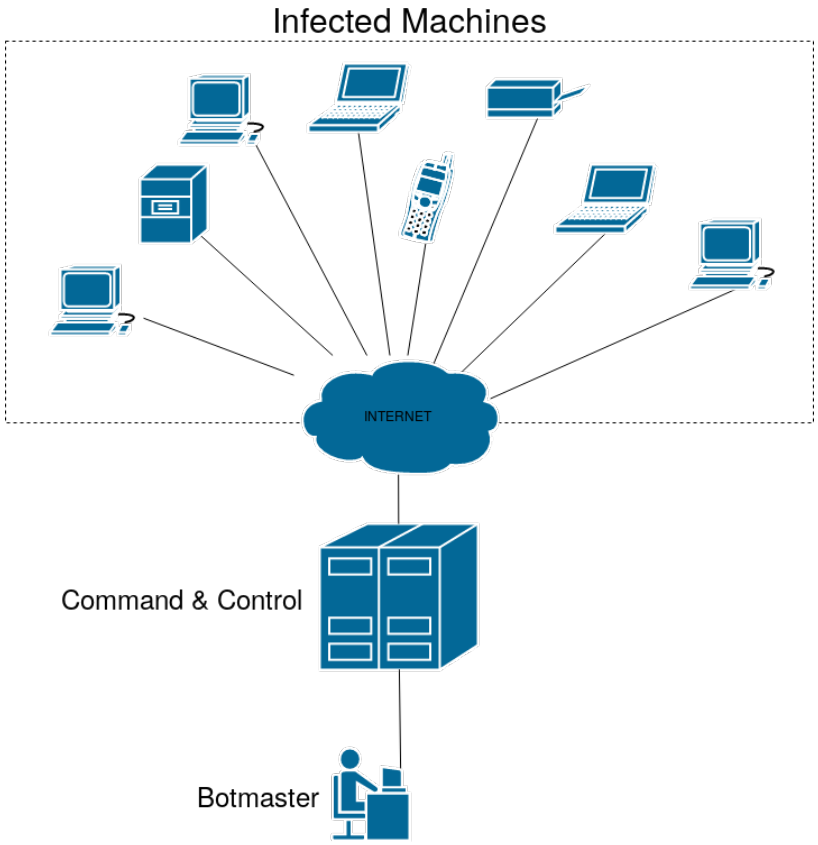
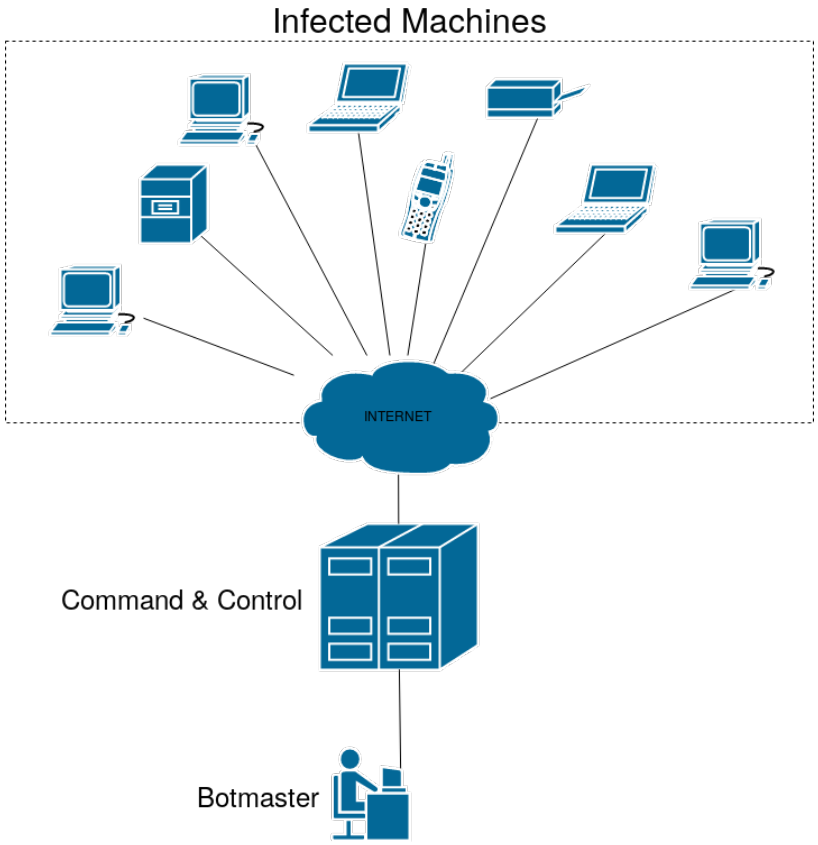
Centralized Botnets



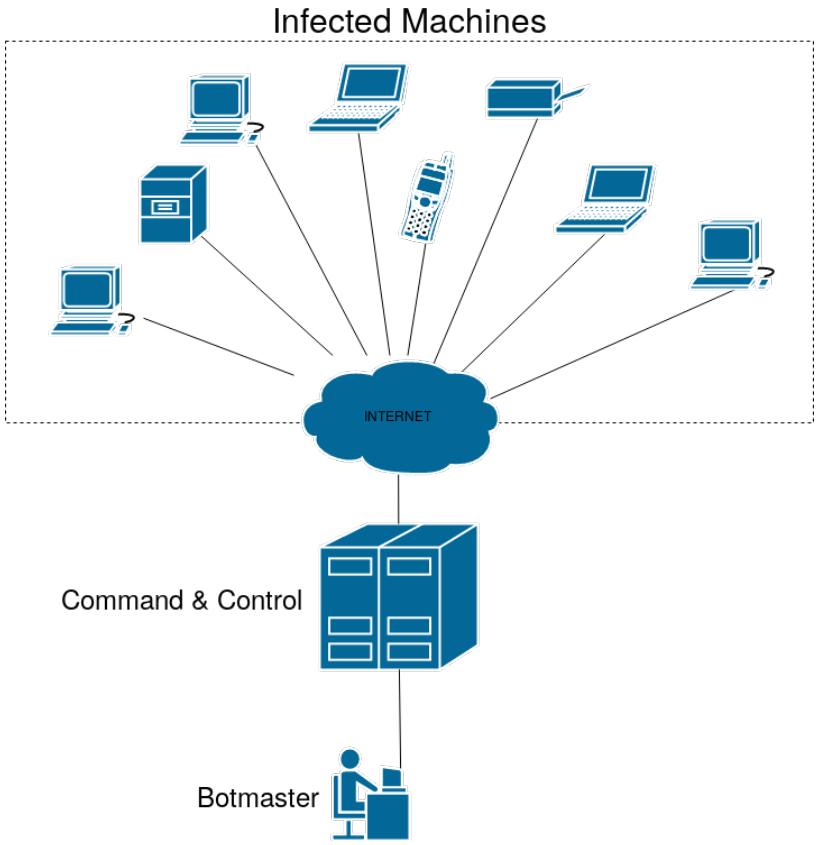
Centralized Botnets

- Central C2 server



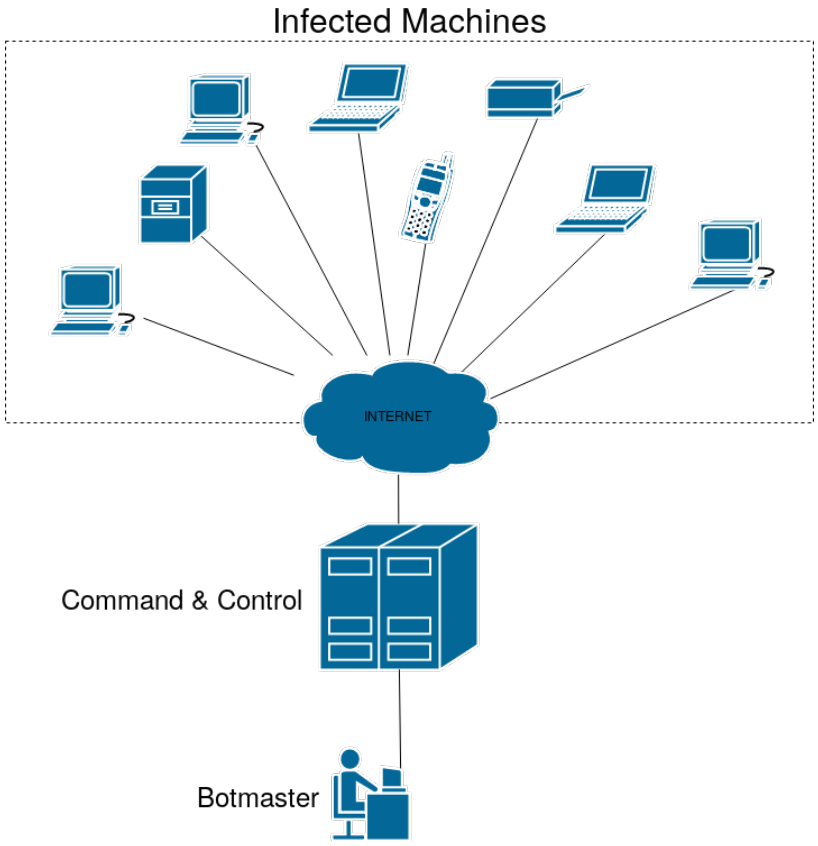
Centralized Botnets

- Central C2 server
- Star topology



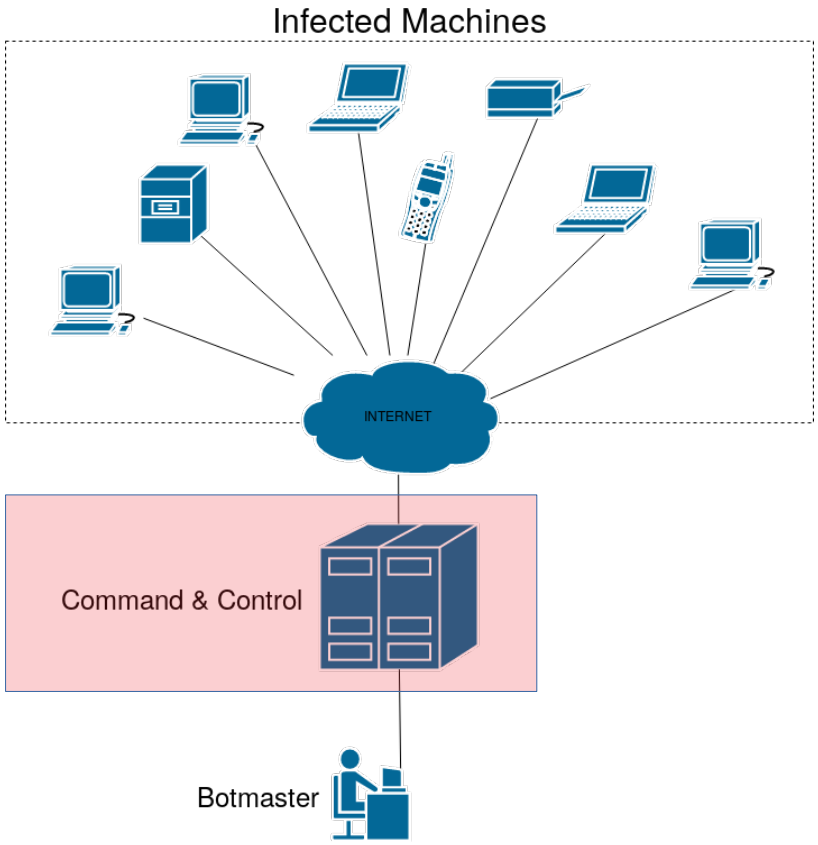
Centralized Botnets

- Central C2 server
- Star topology
- IRC/HTTP/…

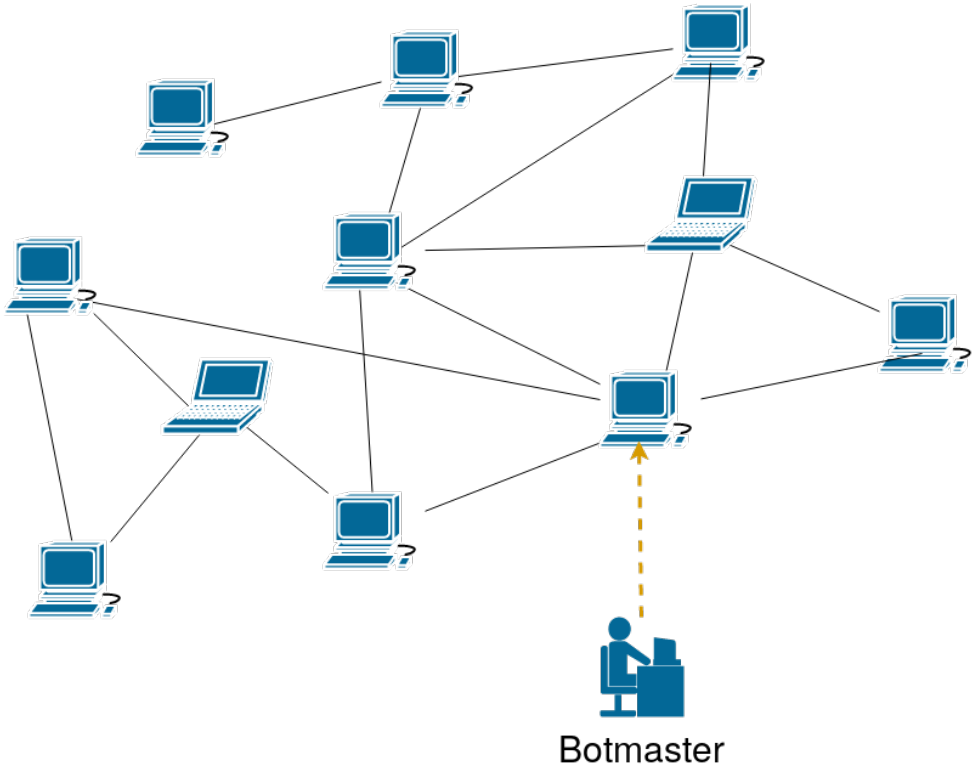


Centralized Botnets

- Central C2 server
- Star topology
- IRC/HTTP/…
- Single point of failure

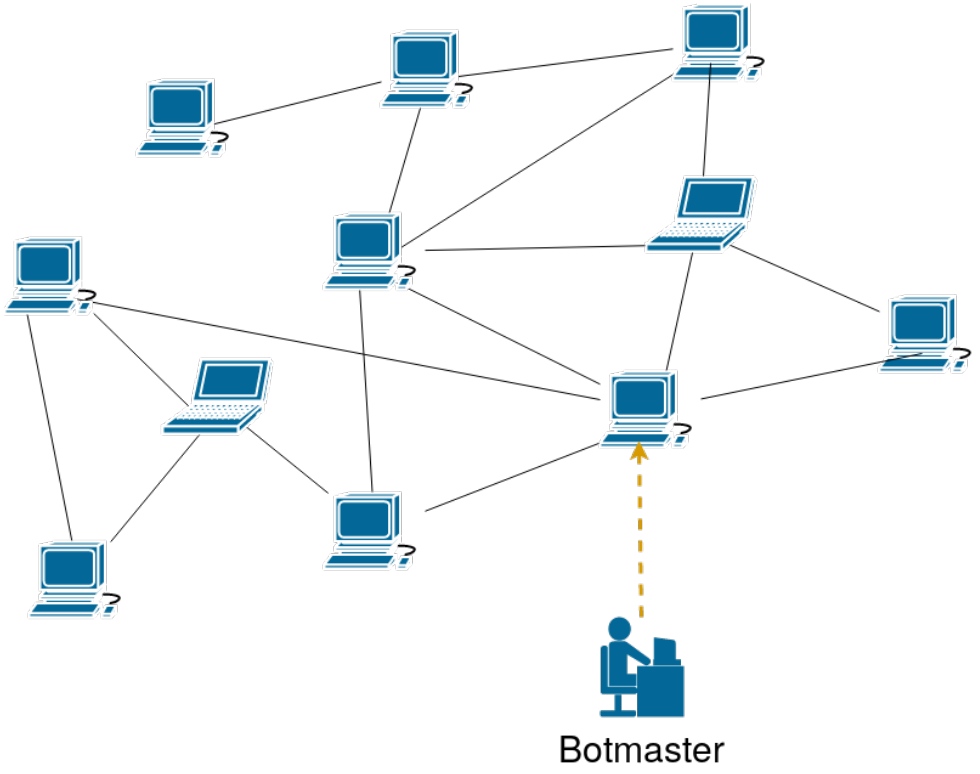


Structured P2P Botnets



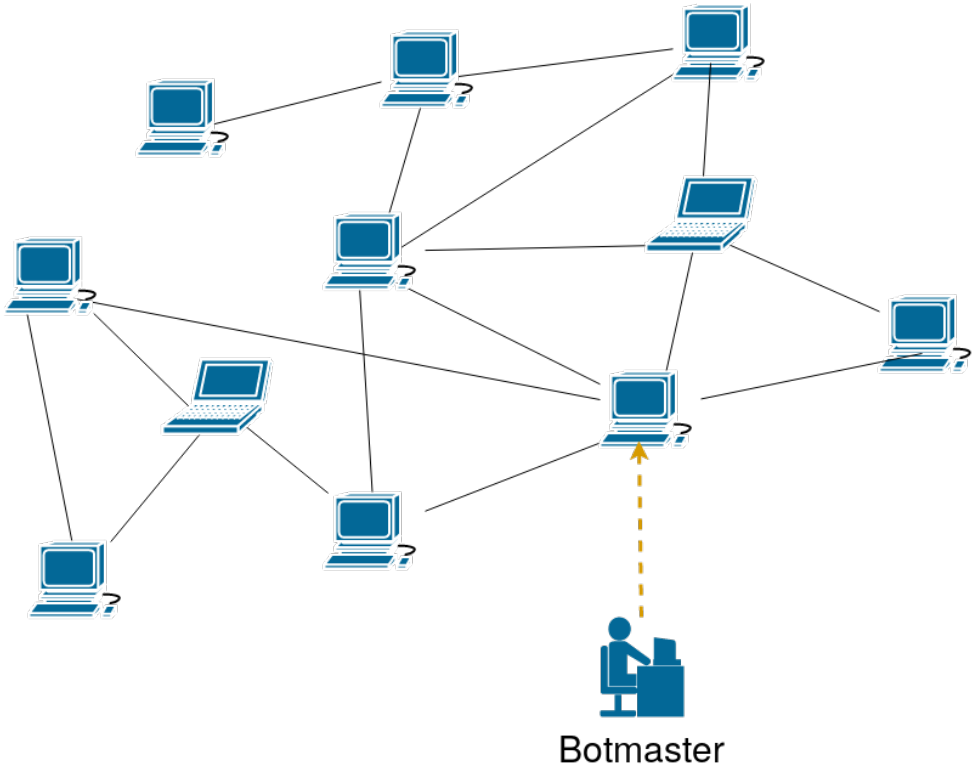
Structured P2P Botnets

- No C2 server



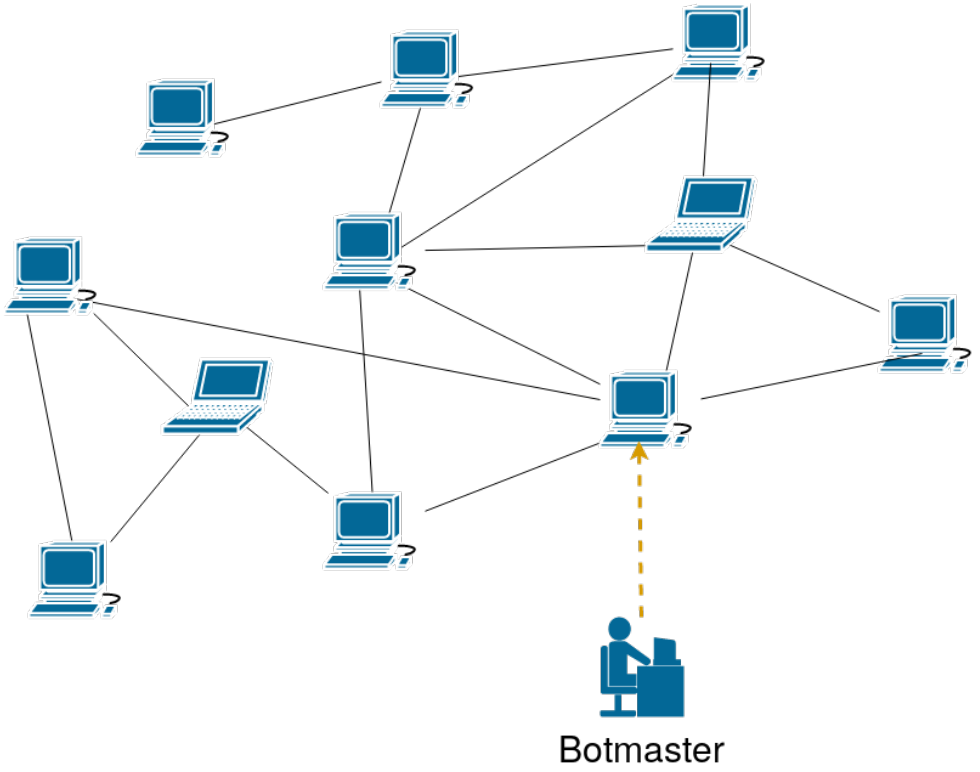
Structured P2P Botnets

- No C2 server
- Hard to take down



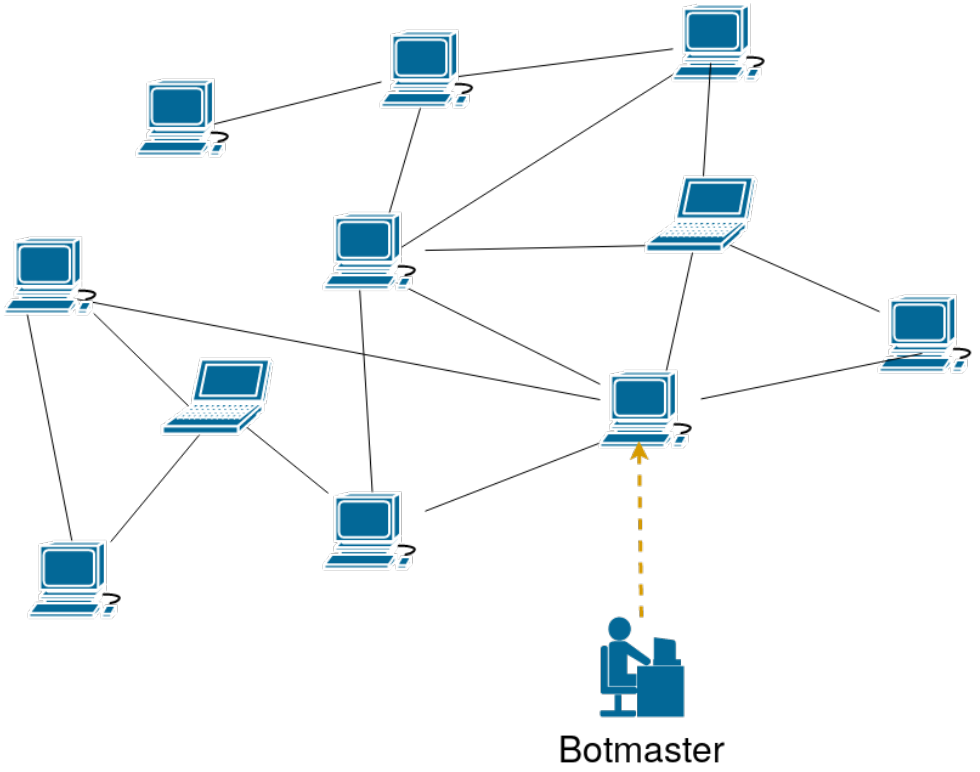
Structured P2P Botnets

- No C2 server
- Hard to take down
- Specific rule set

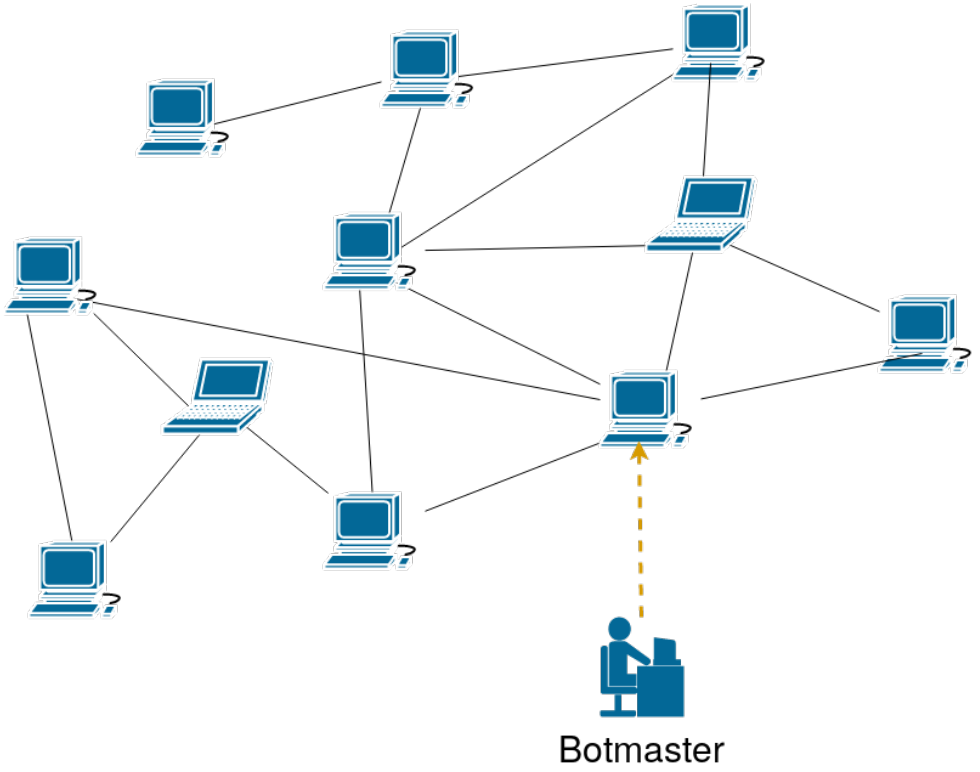


Structured P2P Botnets

- No C2 server
- Hard to take down
- Specific rule set
- Kademlia, Chord

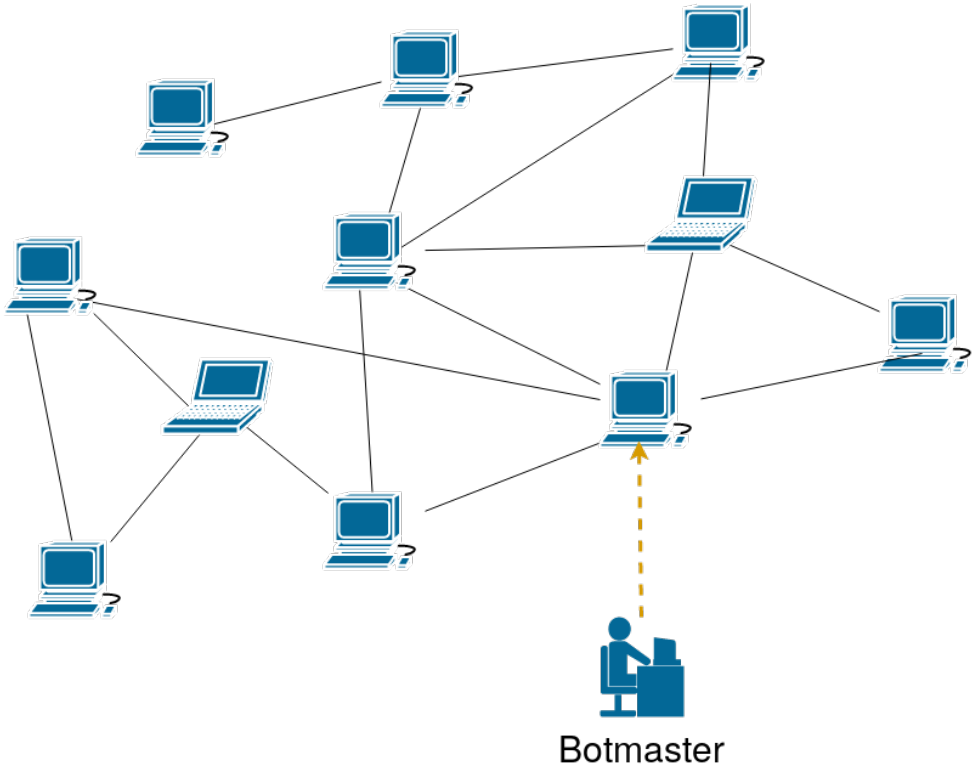


Unstructured P2P Botnets



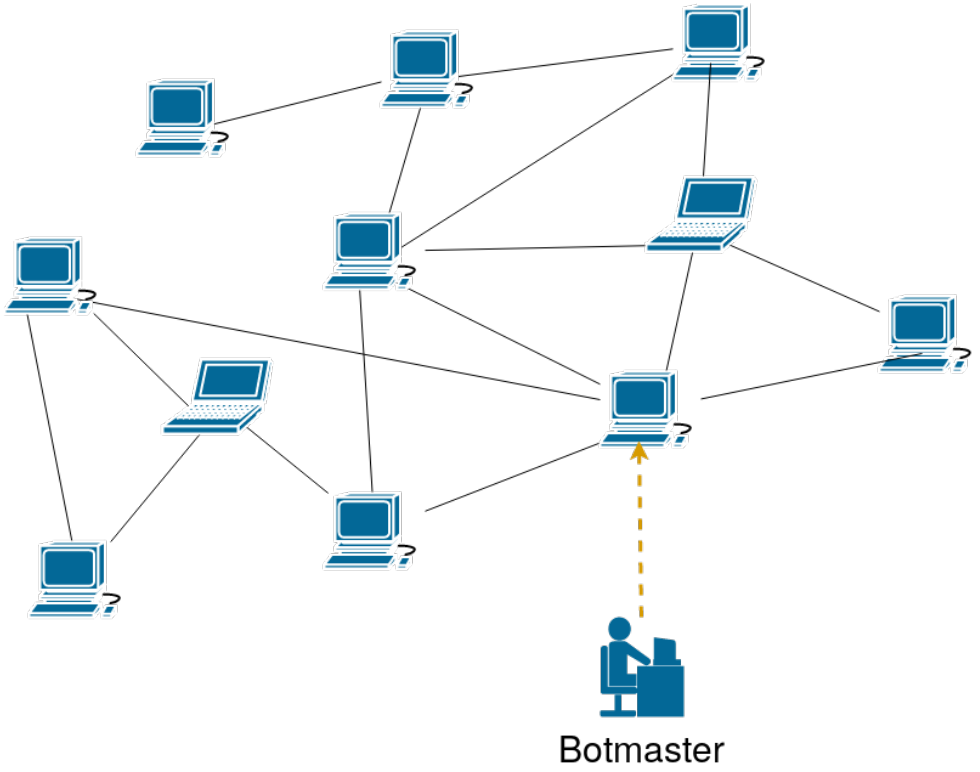
Unstructured P2P Botnets

- Randomized



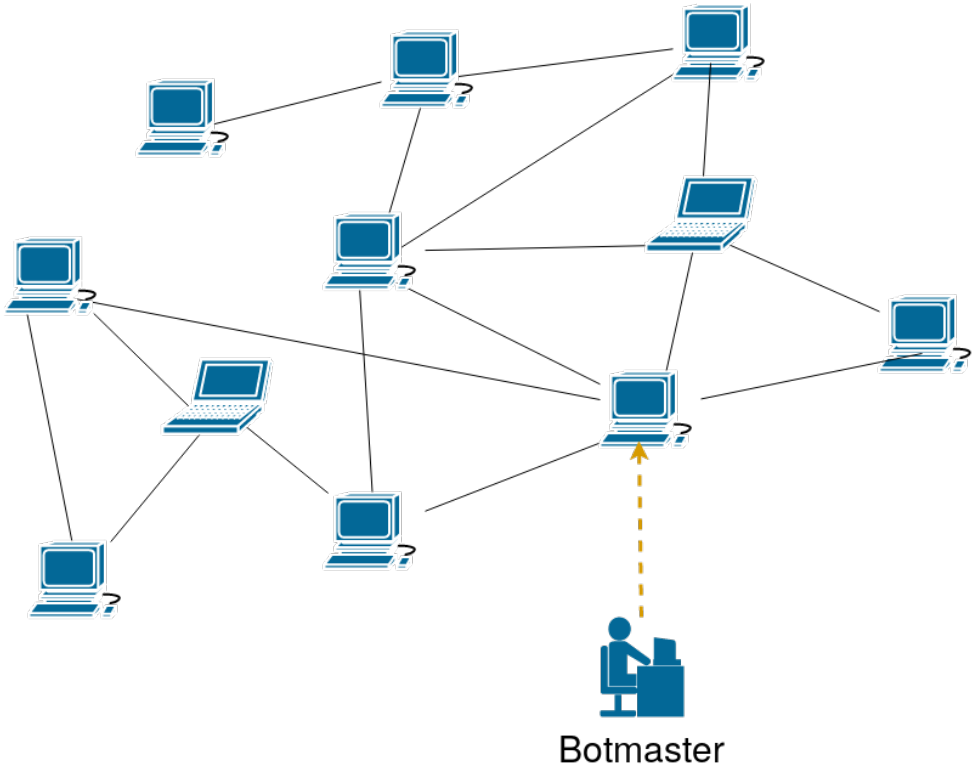
Unstructured P2P Botnets

- Randomized
- Evade topological matching

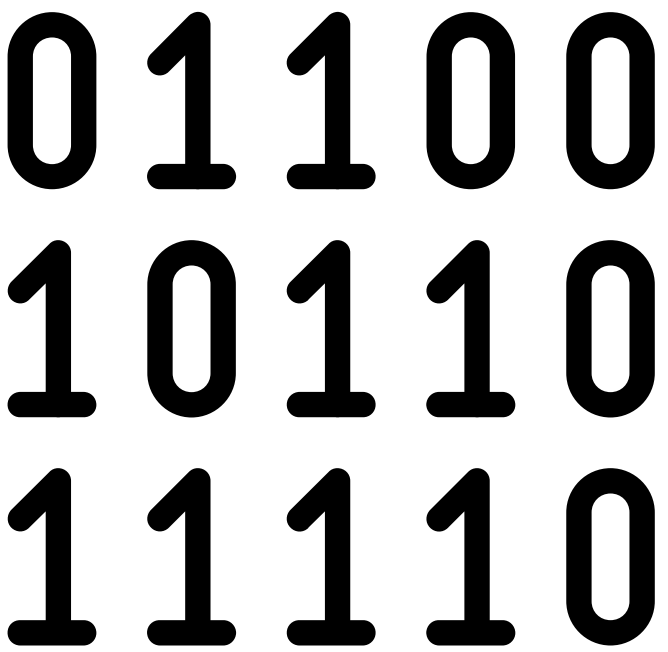


Unstructured P2P Botnets

- Randomized
- Evade topological matching
- Statistical methods necessary



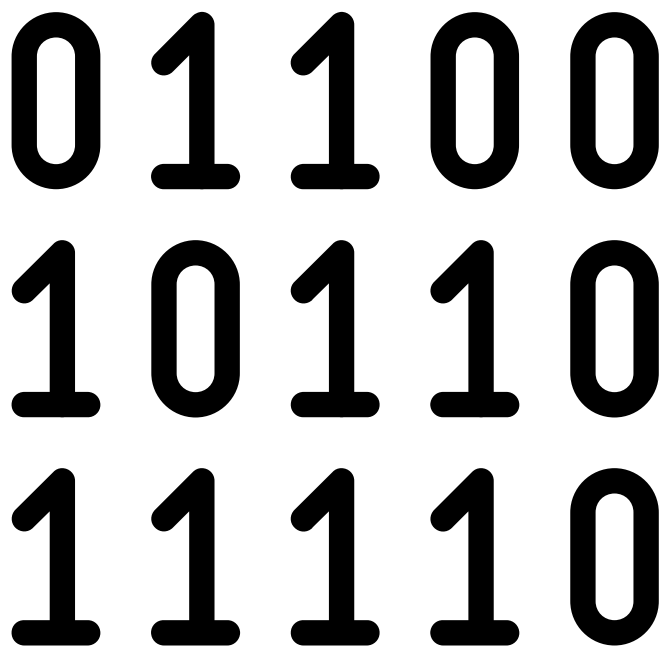
Existing Approaches



[7]

Existing Approaches

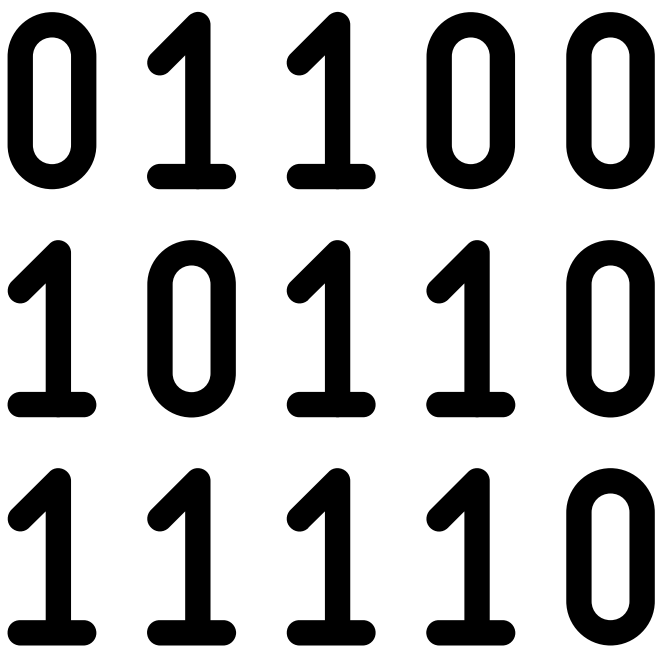
- Leverage graph models



[7]

Existing Approaches

- Leverage graph models
- … and random walks



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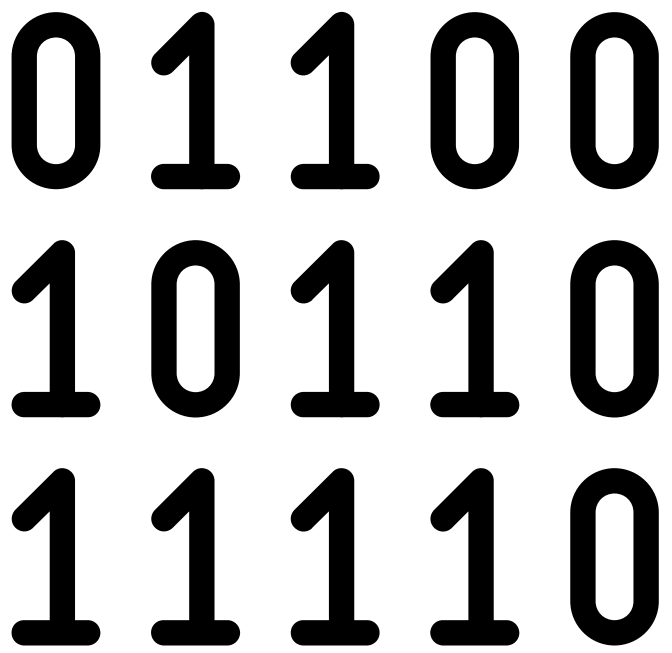
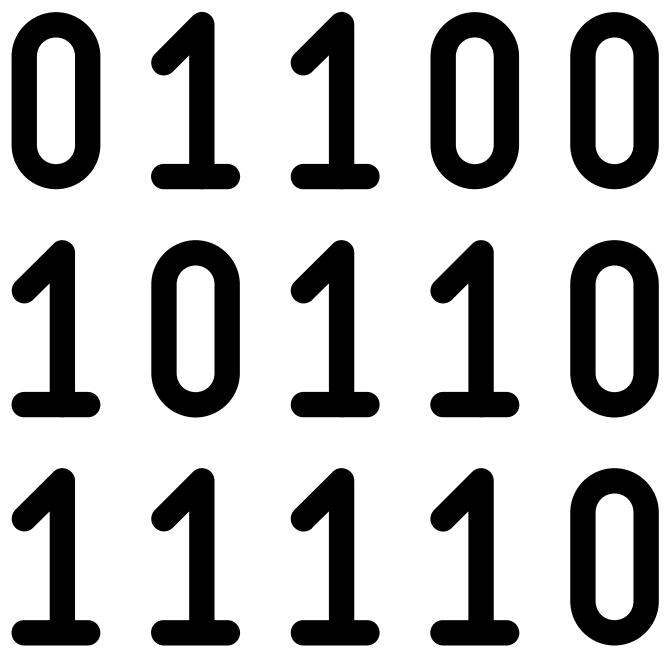


[7]

Existing Approaches

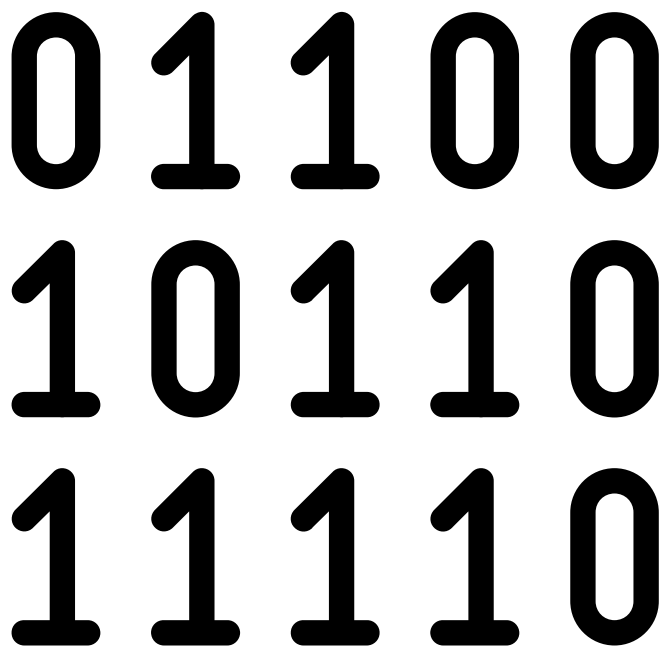
- Leverage graph models
- … and random walks
- Focus on structured botnets [10, 11, 12]



[7]

Existing Approaches

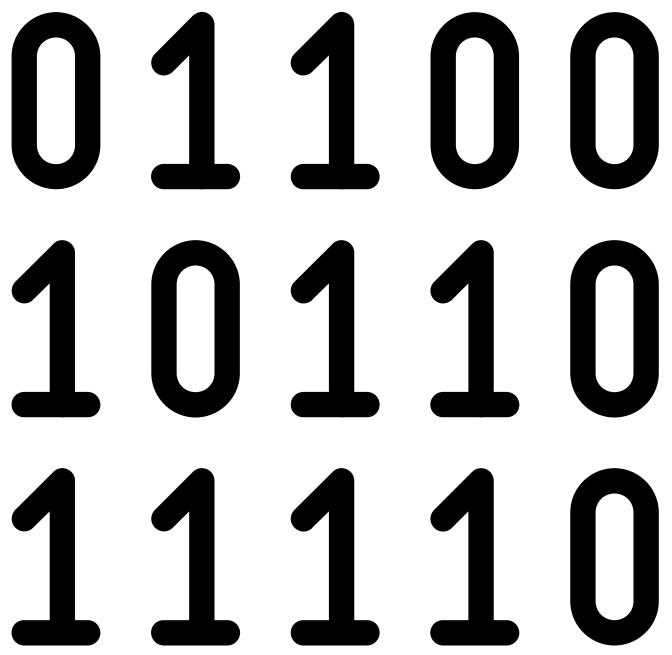
- Leverage graph models
- … and random walks
- Focus on structured botnets [10, 11, 12]
- Do not use open technologies



[7]

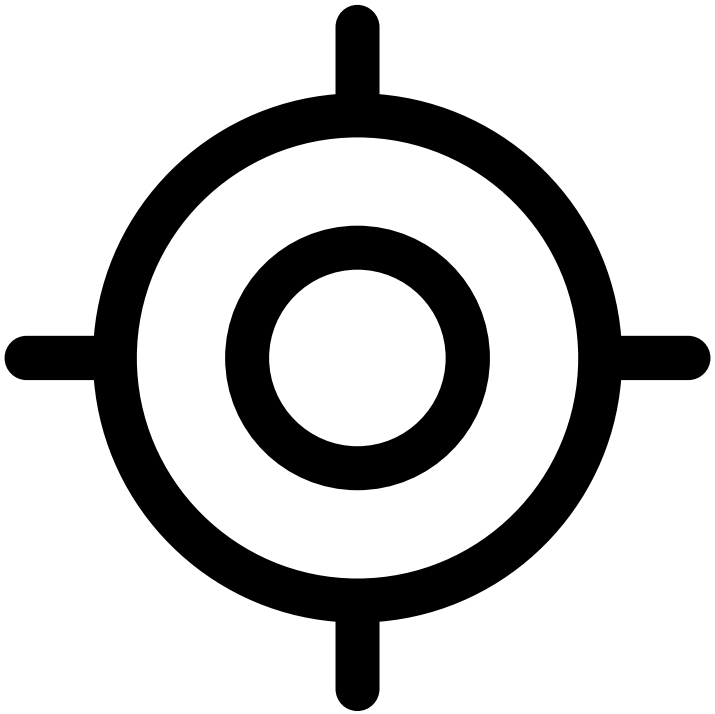
Existing Approaches

- Leverage graph models
- … and random walks
- Focus on structured botnets [10, 11, 12]
- Do not use open technologies
- Often assume complete knowledge on botnet communication



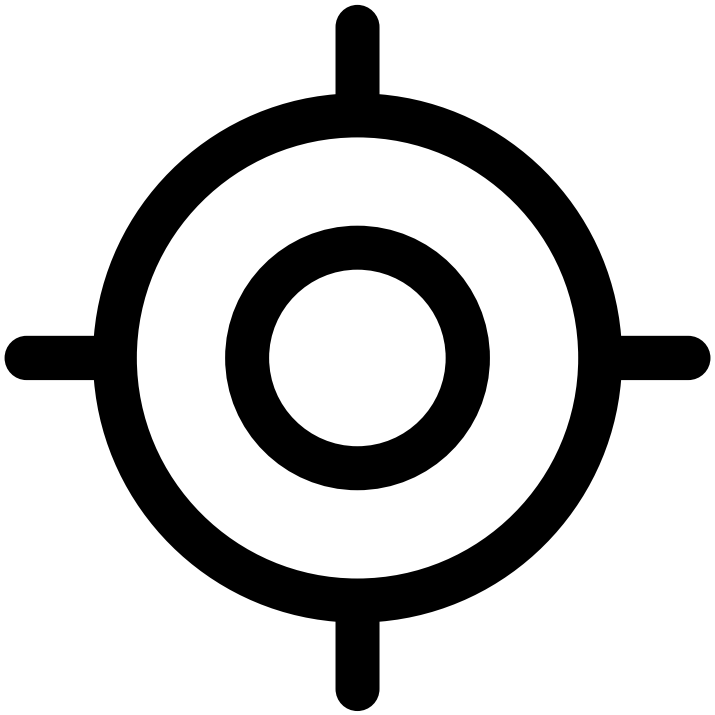
[7]

Our Approach



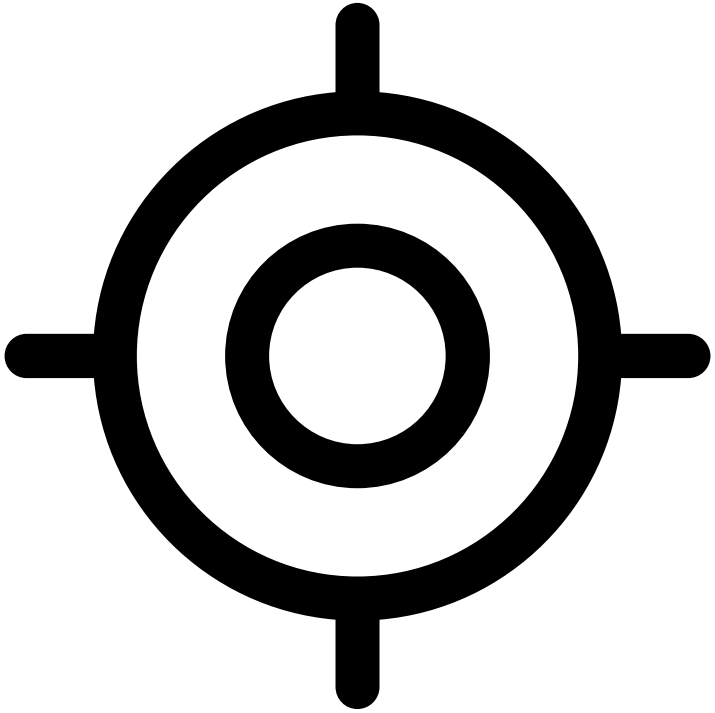
Our Approach

- Leverages random walks



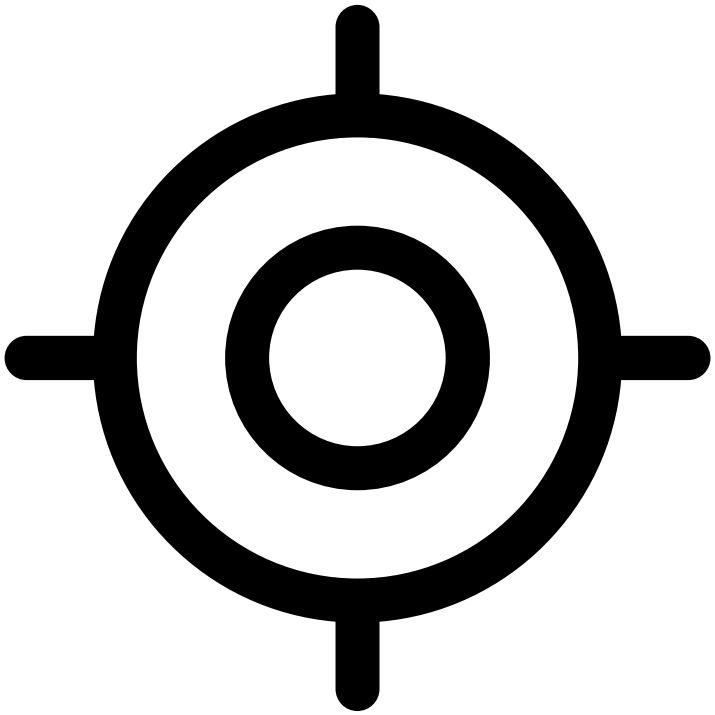
Our Approach

- Leverages random walks
- Uses open-source technologies



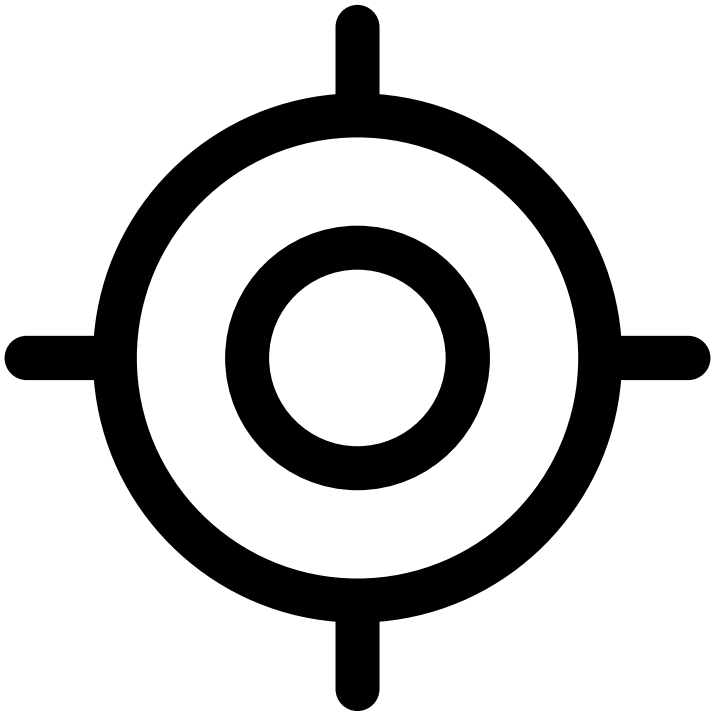
Our Approach

- Leverages random walks
- Uses open-source technologies
- Tested on unstructured botnets



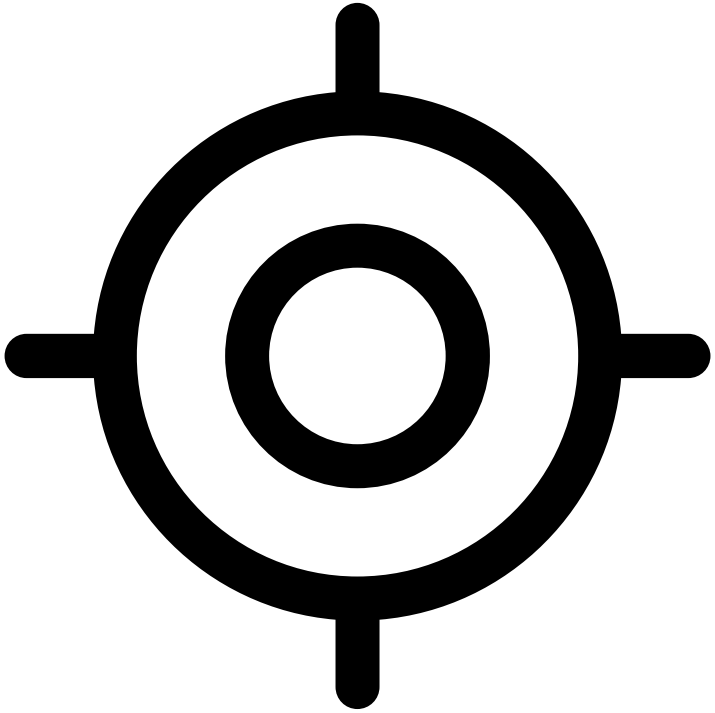
Our Approach

- Leverages random walks
- Uses open-source technologies
- Tested on unstructured botnets
- Precise when information is limited

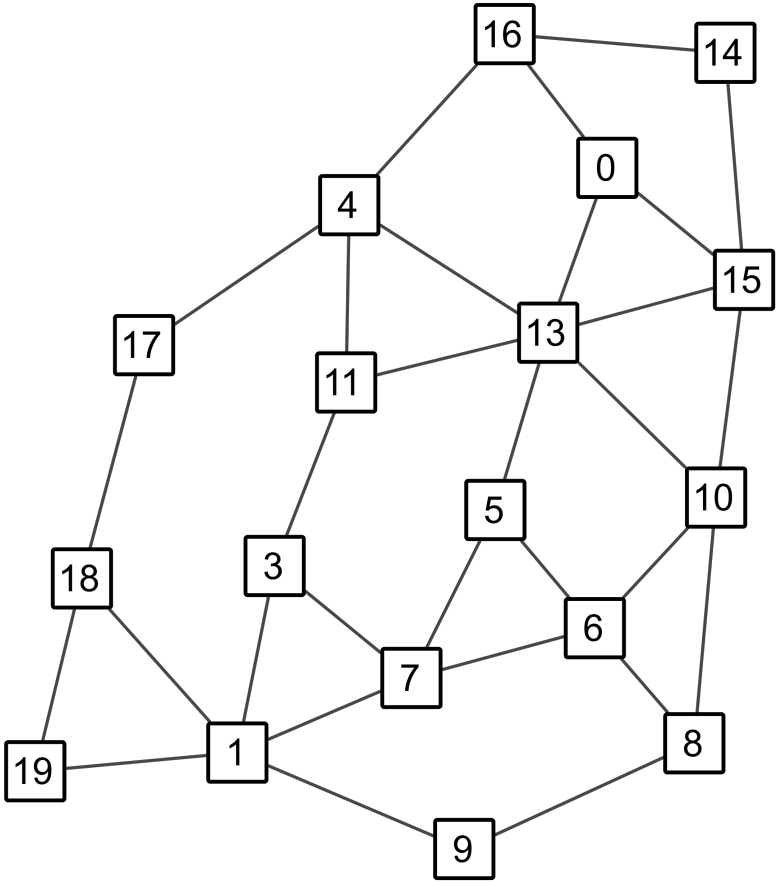


Our Approach

- Leverages random walks
- Uses open-source technologies
- Tested on unstructured botnets
- Precise when information is limited
- Can be combined with other approaches

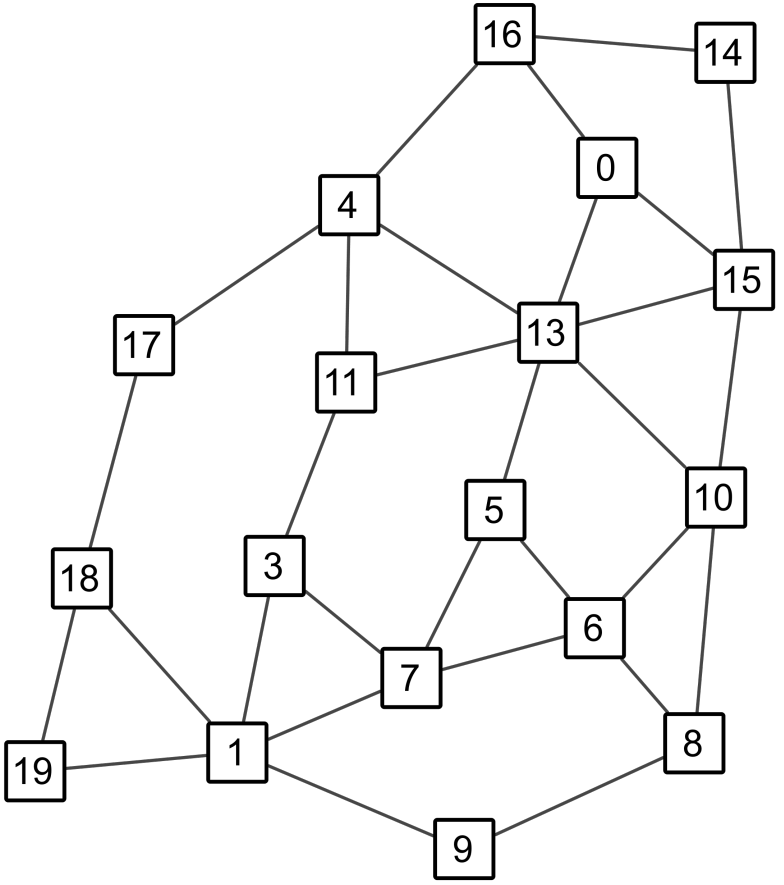


Communication Graph



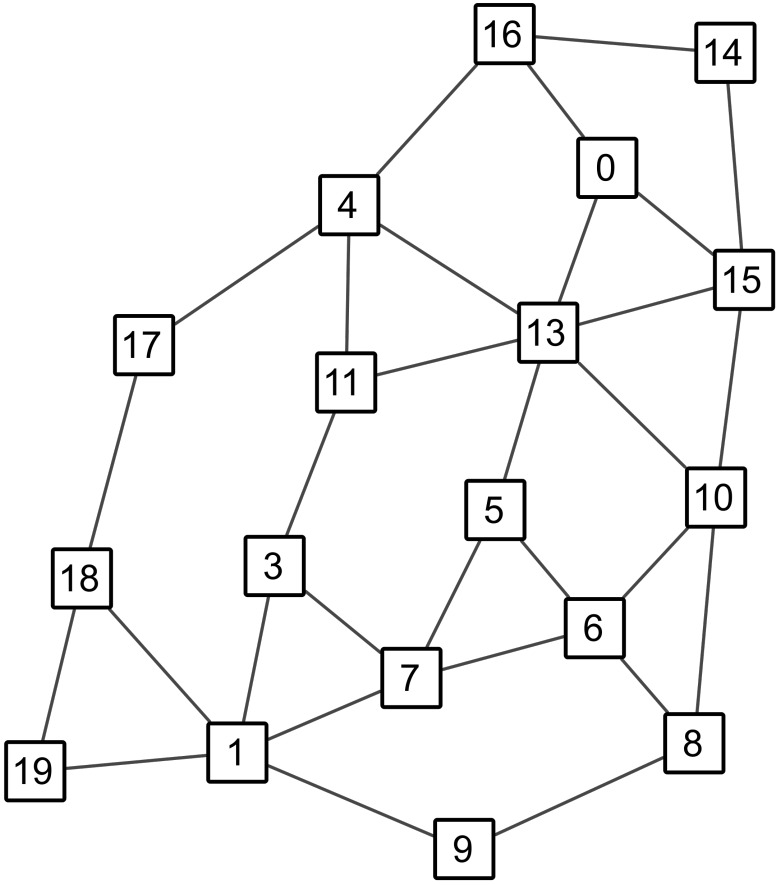
Communication Graph

- No payload data needed



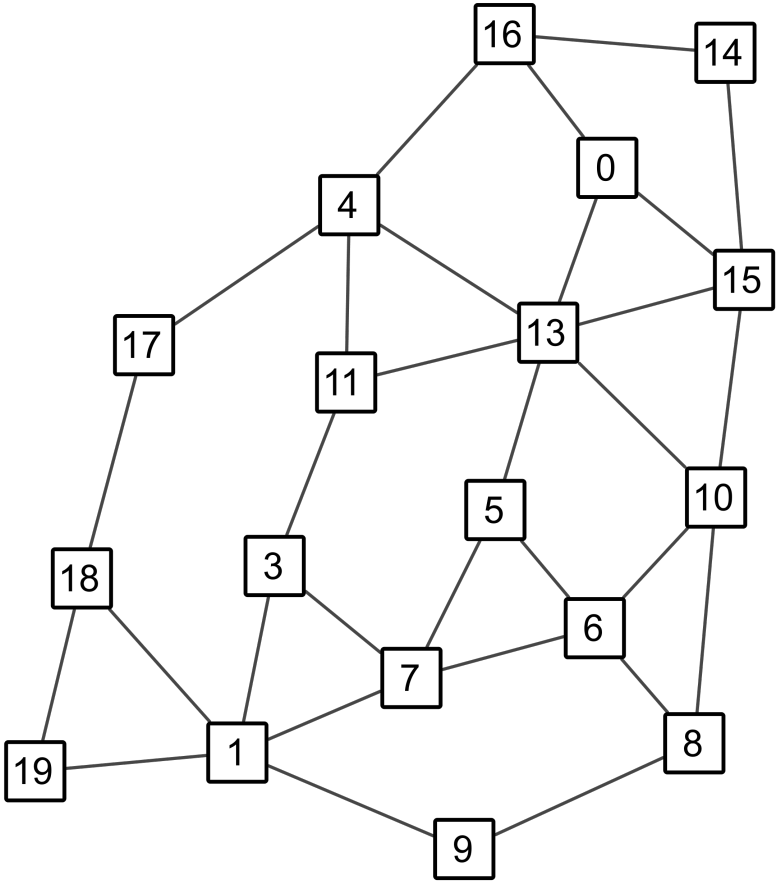
Communication Graph

- No payload data needed
- Network operator's view



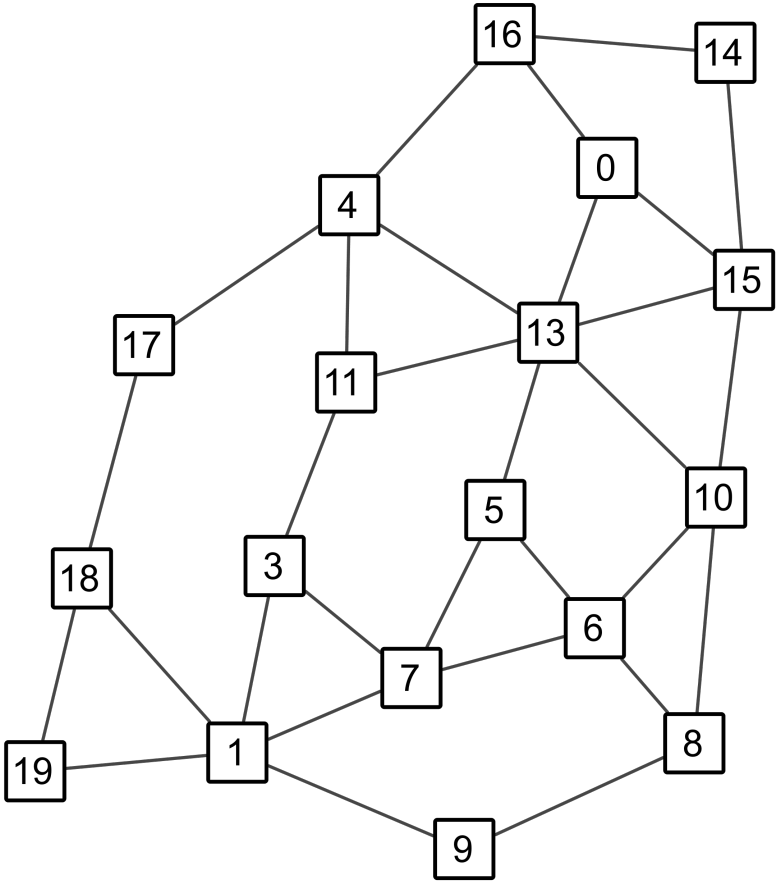
Communication Graph

- No payload data needed
- Network operator's view
- Aggregated NetFlow data



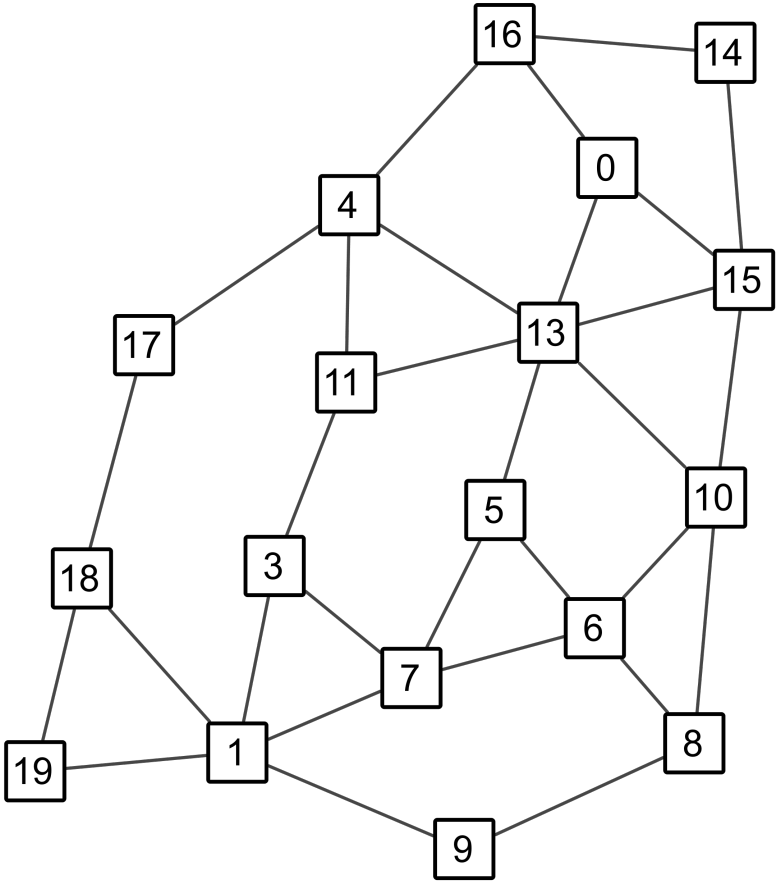
Communication Graph

- No payload data needed
- Network operator's view
- Aggregated NetFlow data
- Idea: extract well-connected subgraph

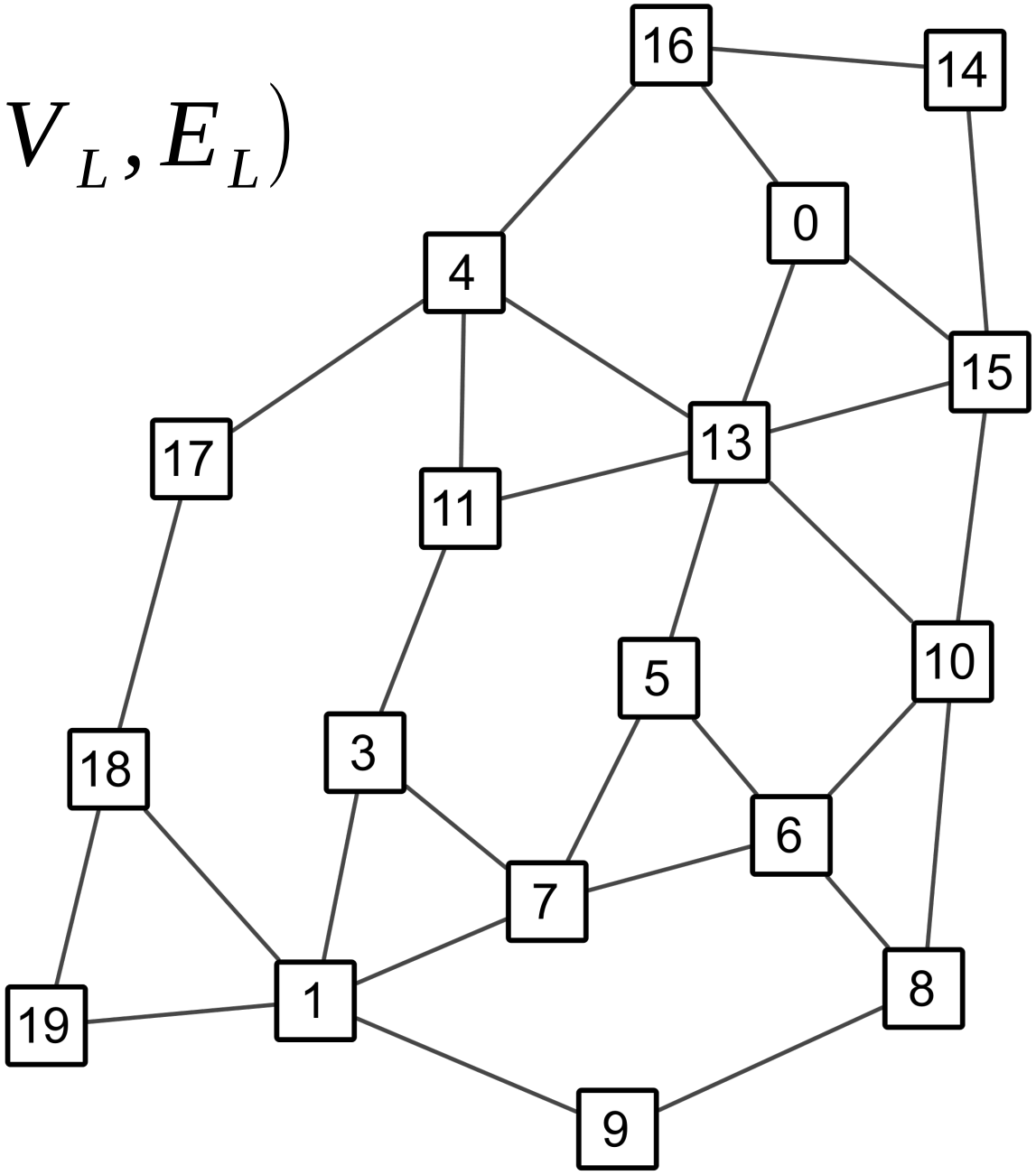


Communication Graph

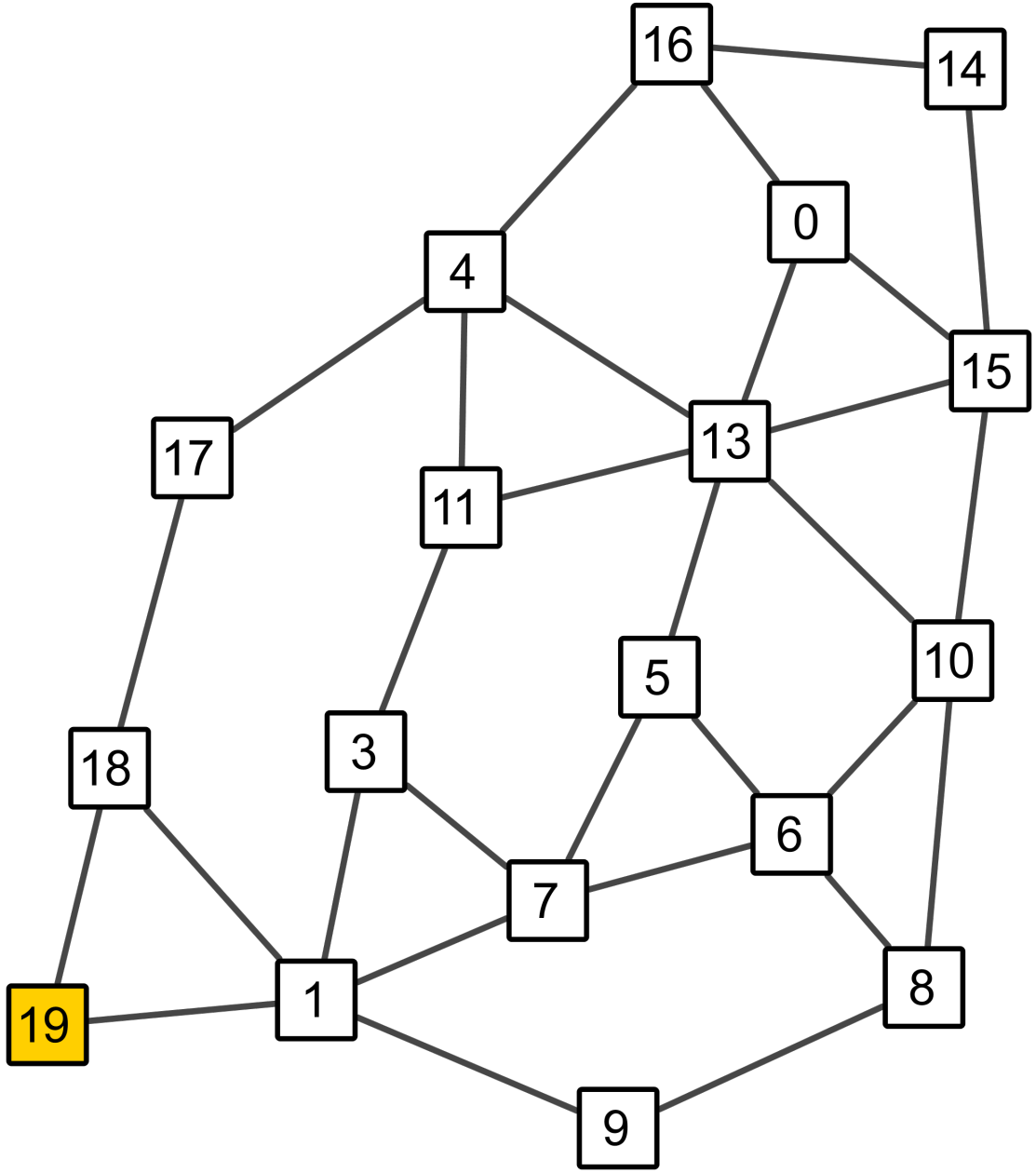
- No payload data needed
- Network operator's view
- Aggregated NetFlow data
- Idea: extract well-connected subgraph
- Approach: Random Walks



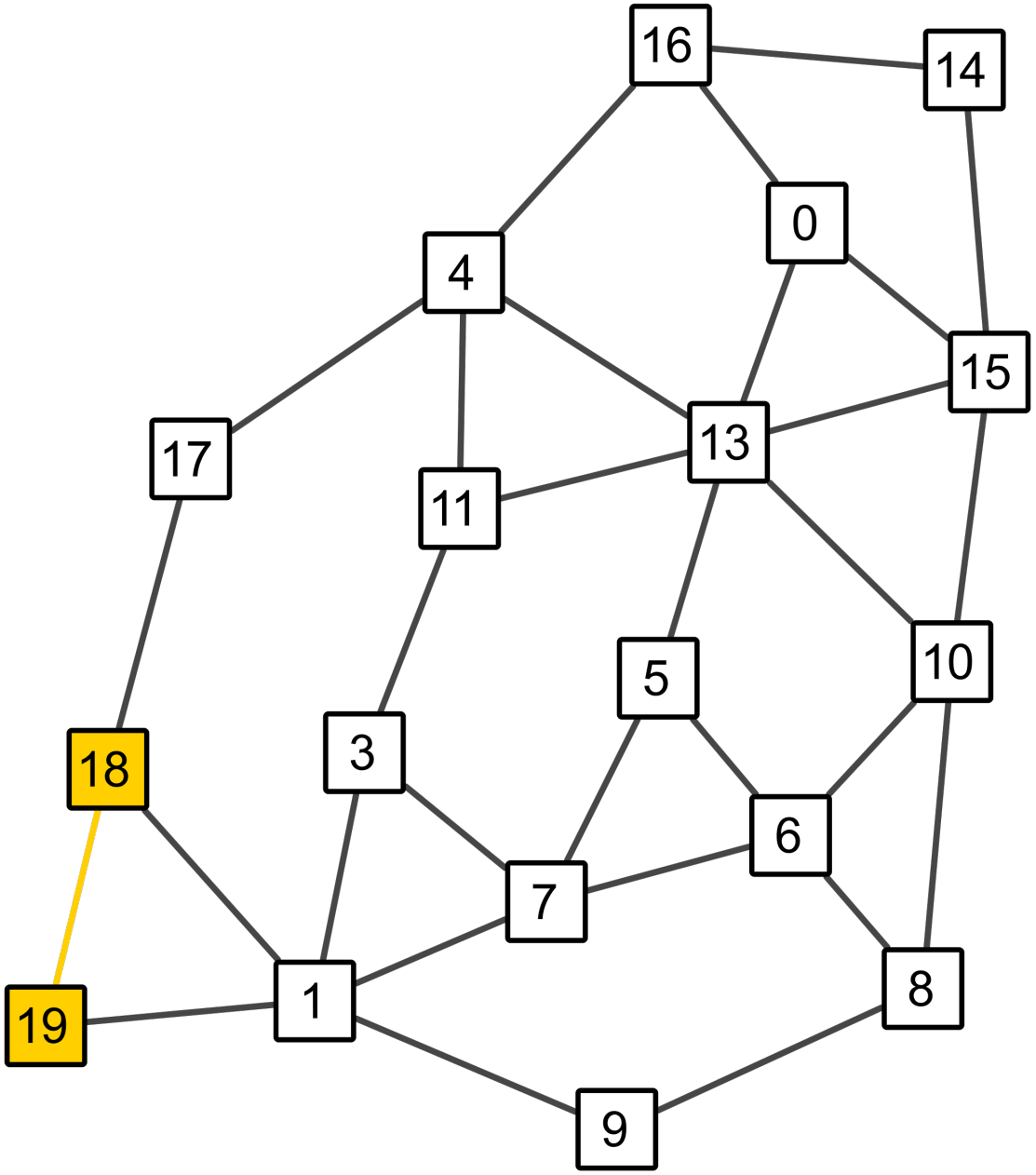
$$G_L = (V_L, E_L)$$



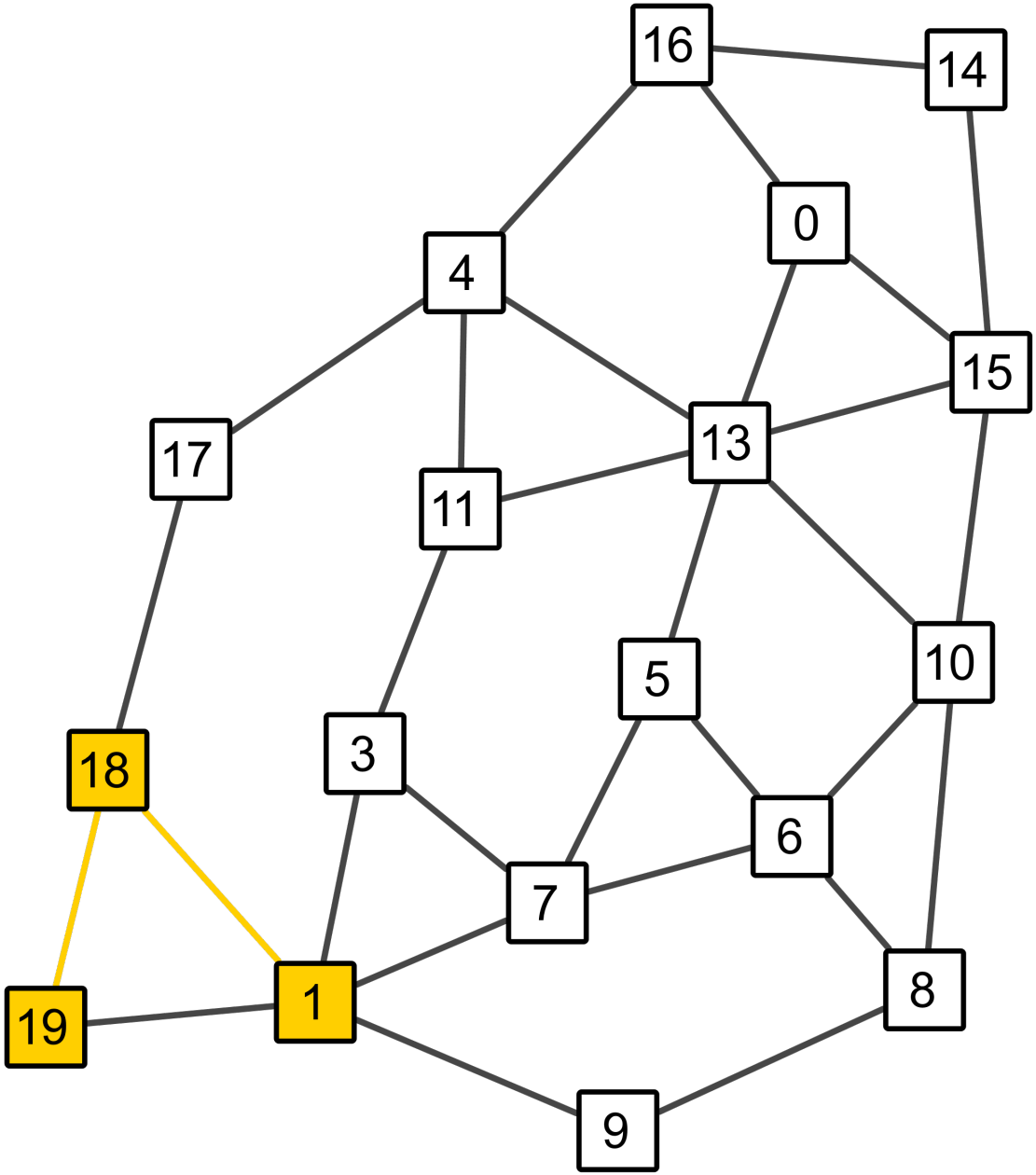
$k=0$



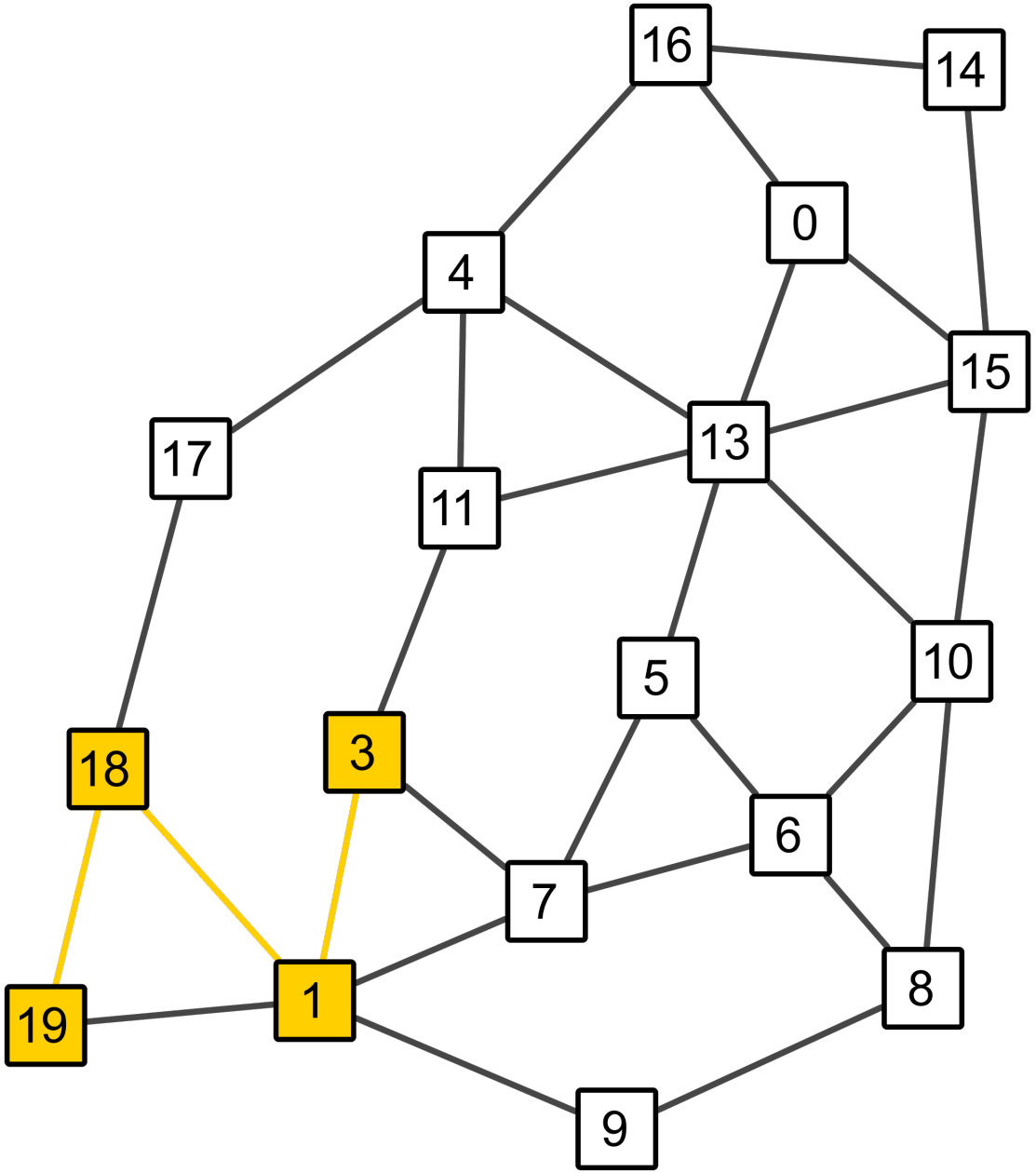
$k=1$



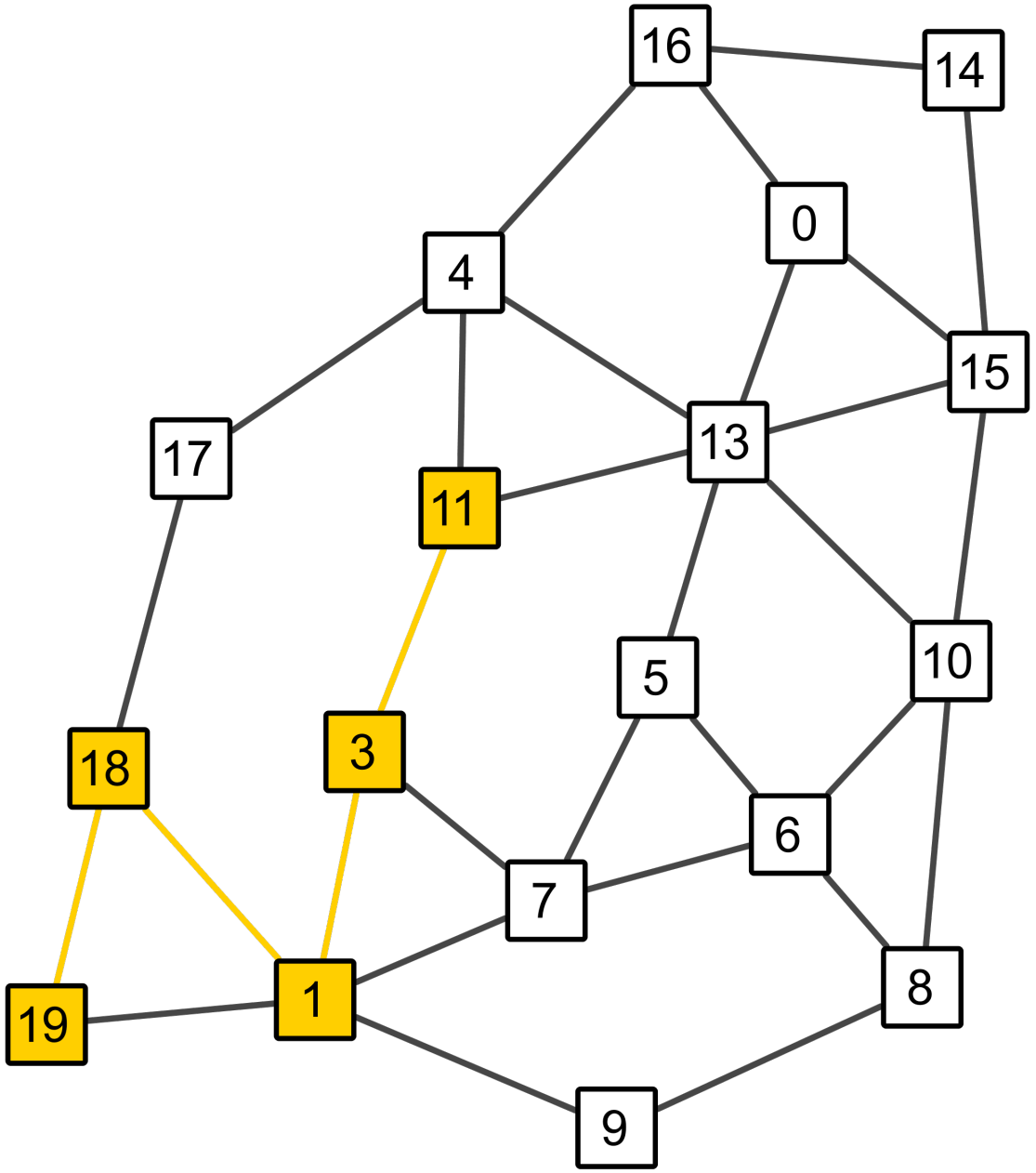
$k=2$



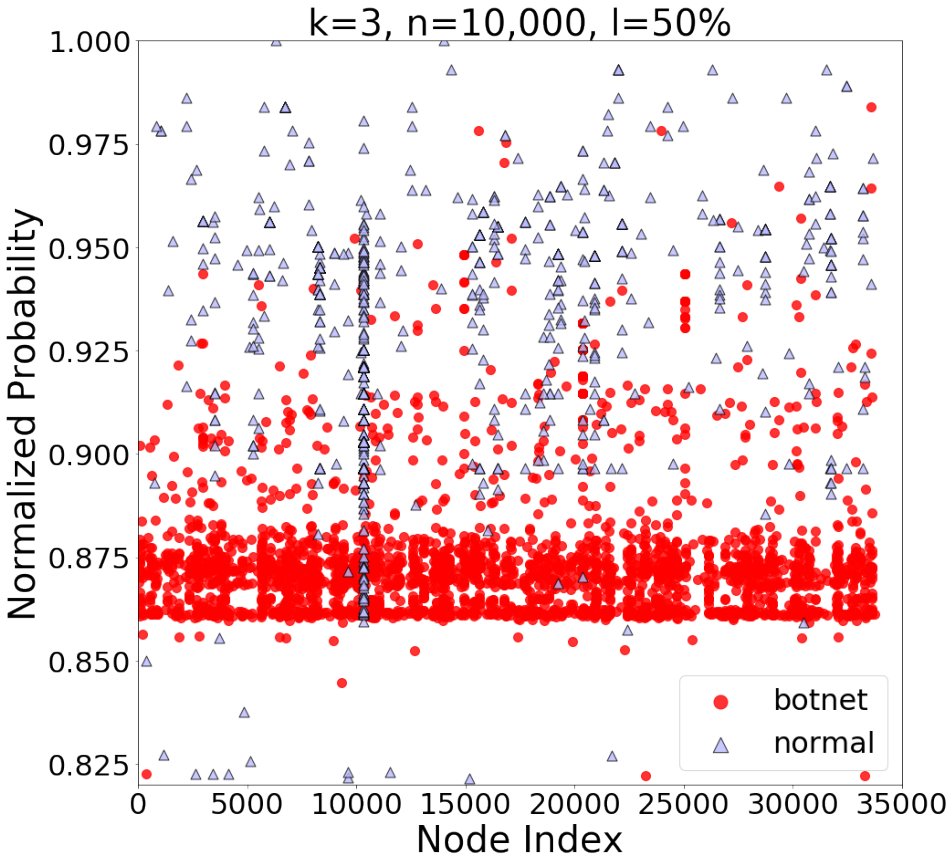
$k=3$



$k = 4$

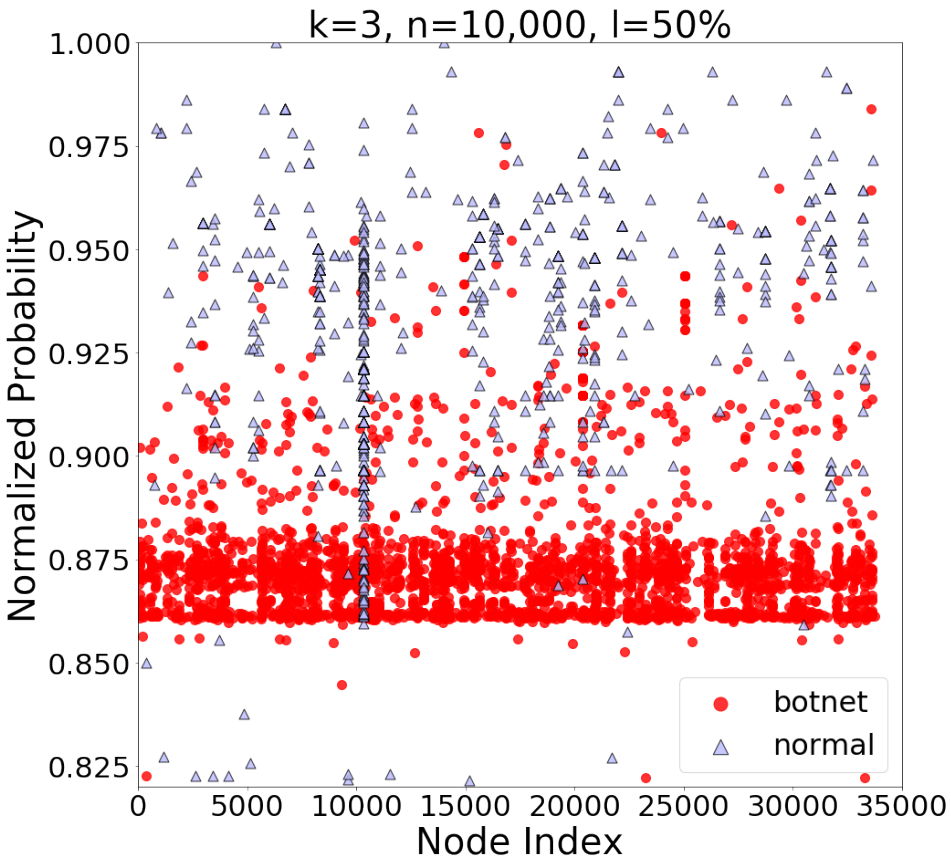


Probability Distribution



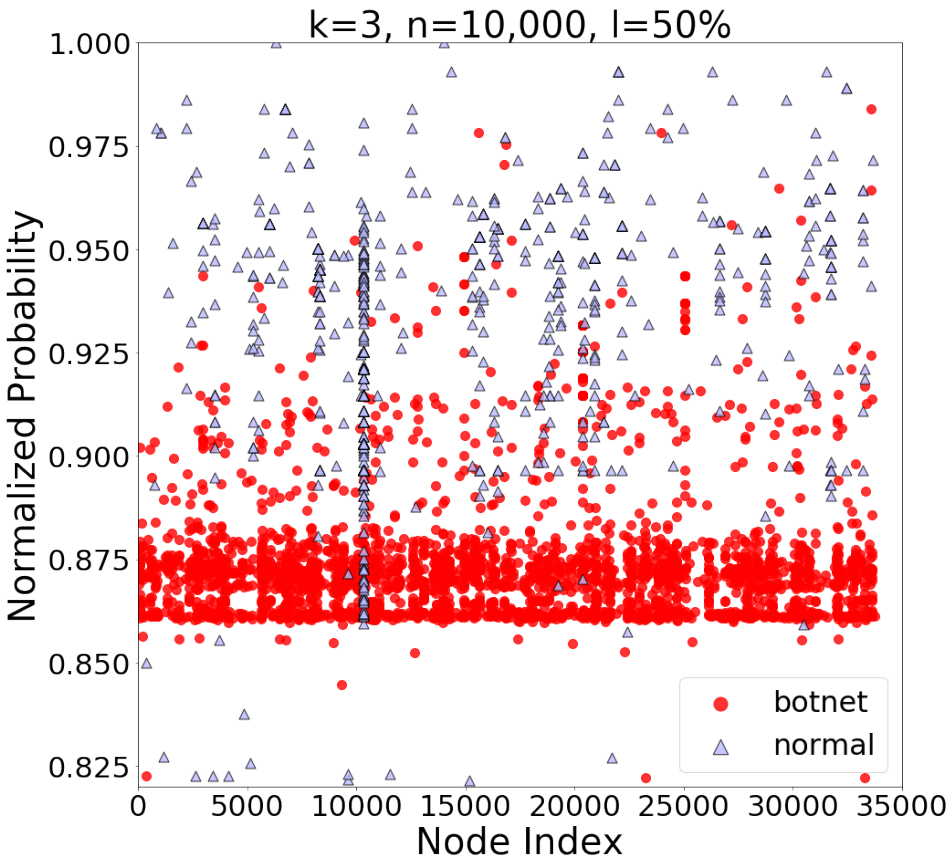
Probability Distribution

- n=10,000 walks



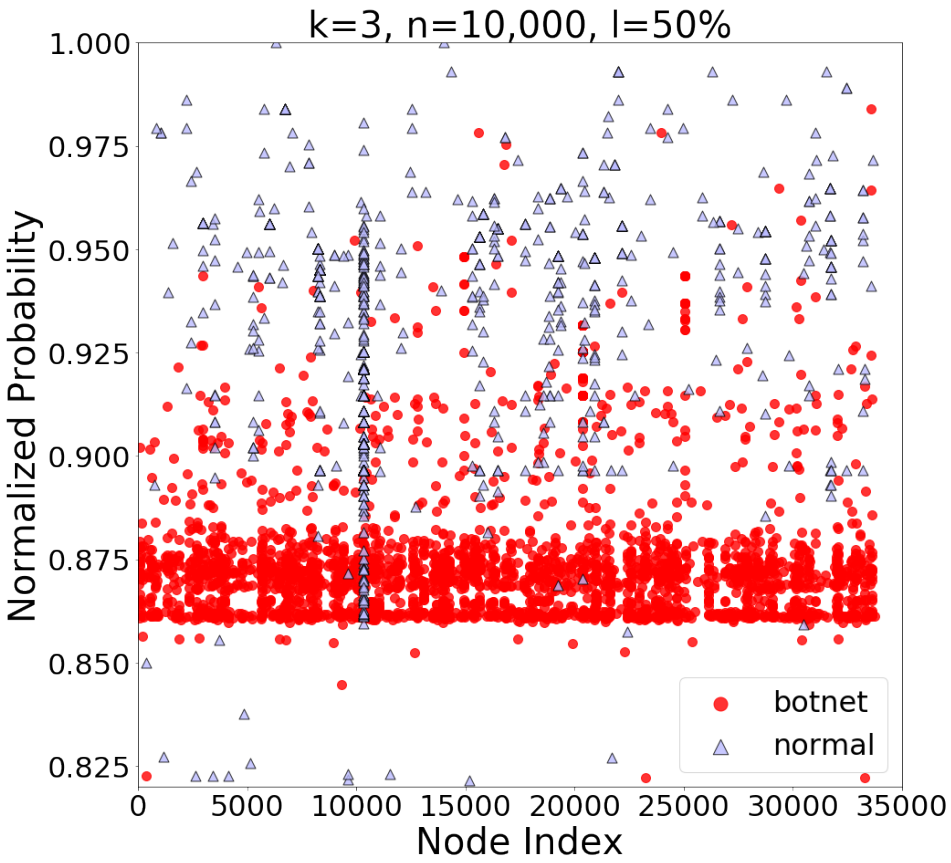
Probability Distribution

- $n=10{,}000$ walks
- Of length $k=3$



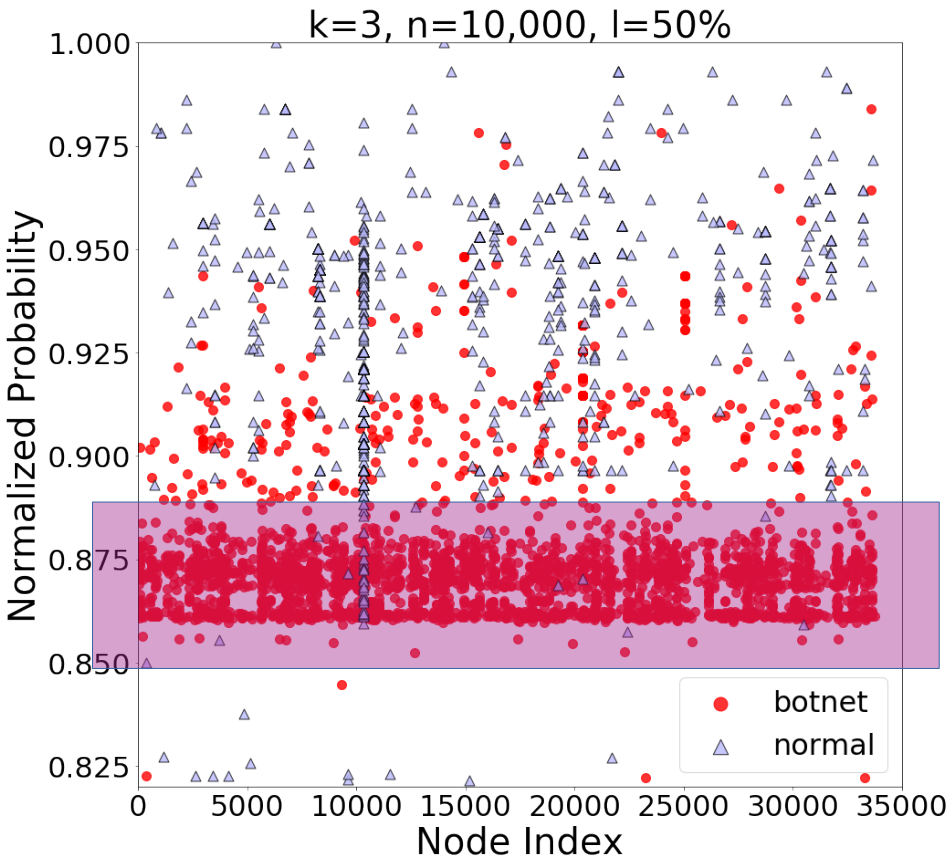
Probability Distribution

- $n=10{,}000$ walks
- Of length $k=3$
- With loss $l=0.5$



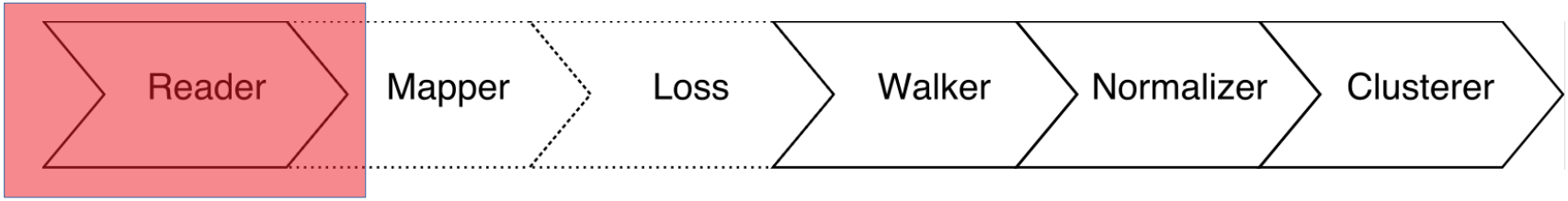
Probability Distribution

- $n=10{,}000$ walks
- Of length $k=3$
- With loss $l=0.5$
- Fast-mixing artifact



The Analysis Pipeline

The Analysis Pipeline



- Aggregate NetFlow data (Python 3.6, `networkx`)

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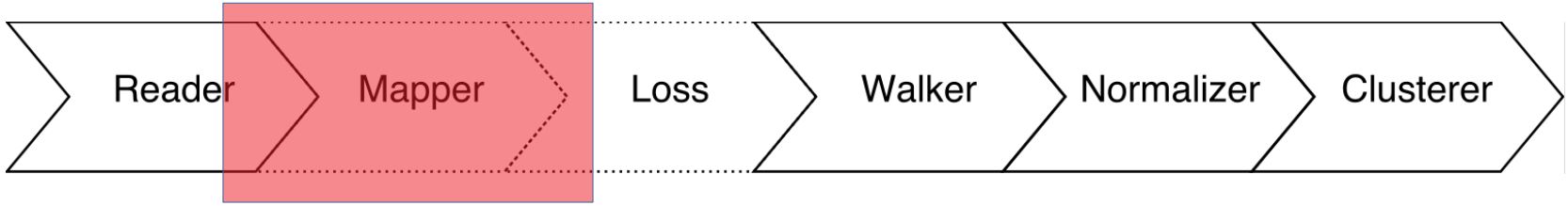

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- Evaluation steps:
  - Botnet node mapping

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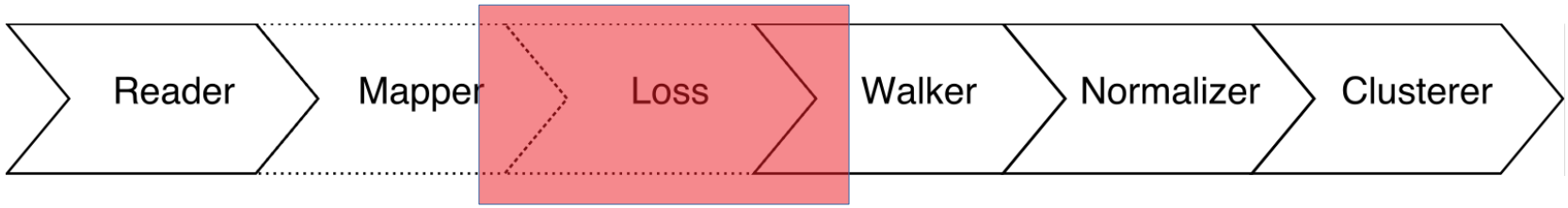

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  - Apply loss functions

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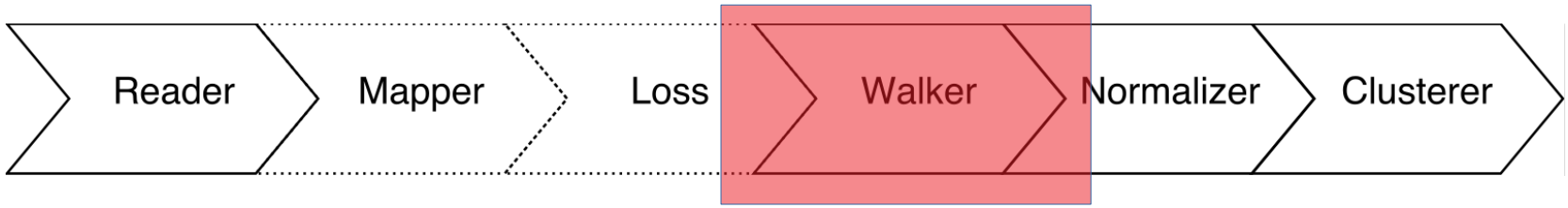

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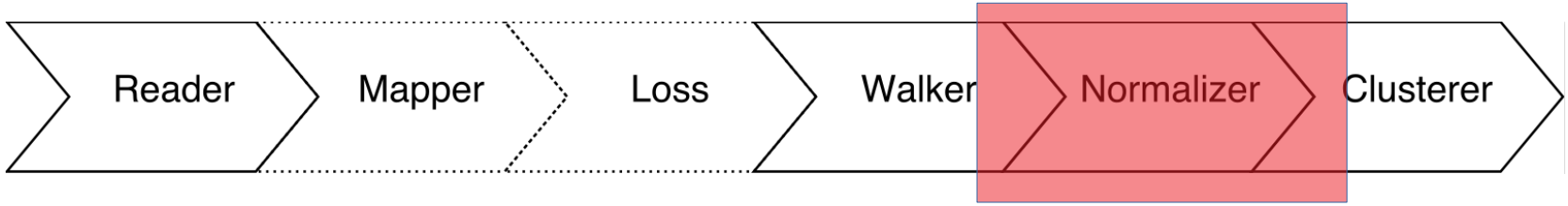

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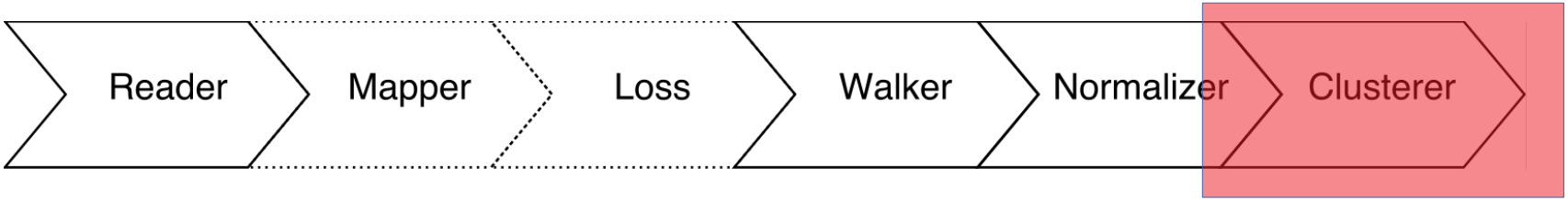

- Aggregate NetFlow data (Python 3.6, `networkx`)
- Evaluation steps:
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  - Apply loss functions
- Execute random walks (`numpy`)
- Normalize resulting probability distribution
- Cluster walk destinations (DBSCAN)

The Test Dataset

	Carrier Graphs		Botnet Graphs	
	TW07	CTU11	ZA24	SA25
Network Diameter	7	12	5	5
Number of Nodes	66 408	38 130	4805	1422
Average Node Degree	2.103	2.062	187.415	416.769
Number of Edges	139 628	78 626	734 010	592 646
Average Path Length	3.959	2.808	2.163	1.776
Average Clustering Coefficient	7×10^{-4}	3×10^{-3}	0.327	0.605

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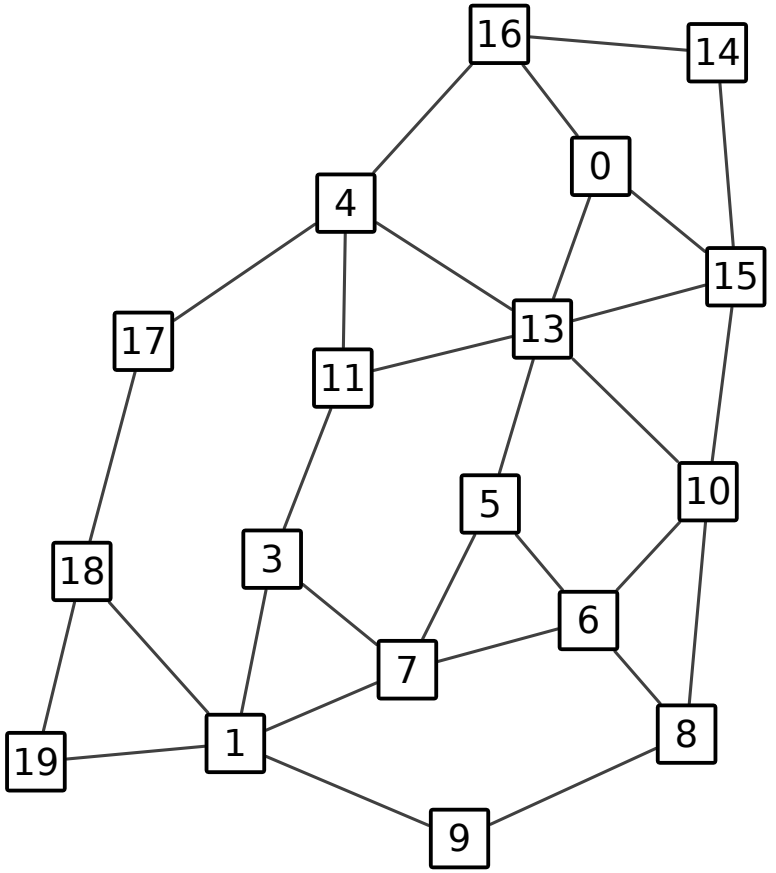
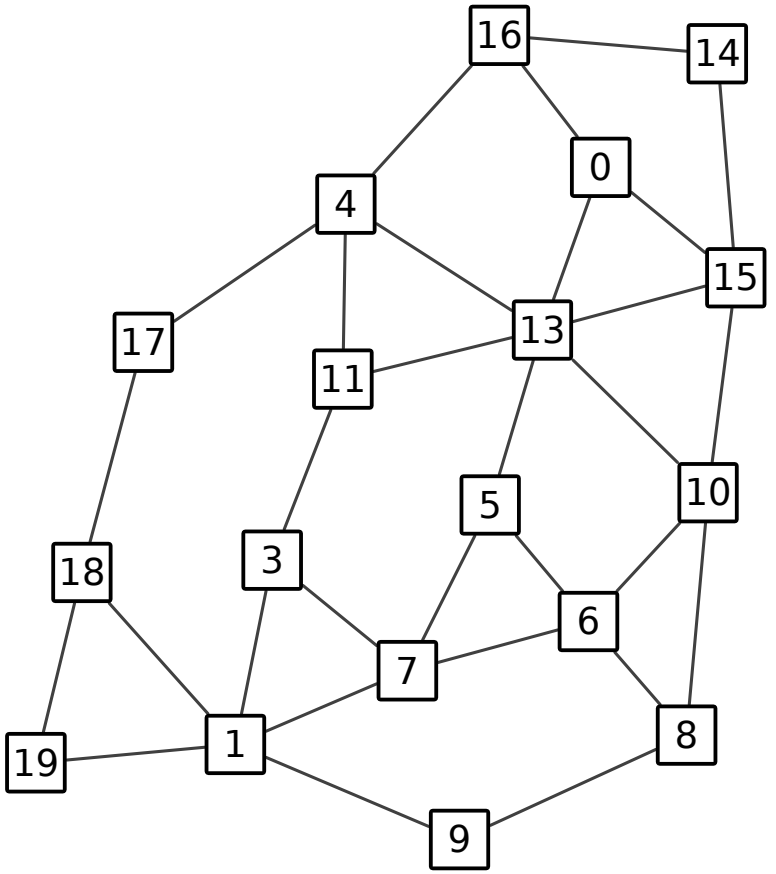
- CTU11 from Czech Technical University
- ZA24 ZeroAccess communication graph

Loss Strategies



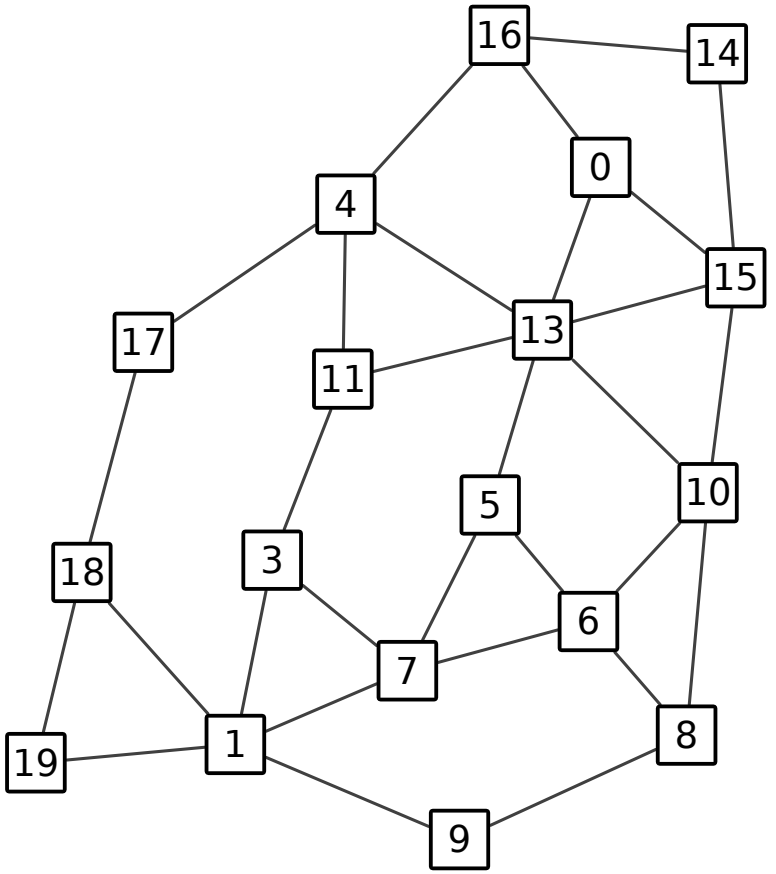
Loss Strategies

- Other approaches do not evaluate limited network view



Loss Strategies

- Other approaches do not evaluate limited network view
- Unrealistic assumptions:
  - All communication relationships captured



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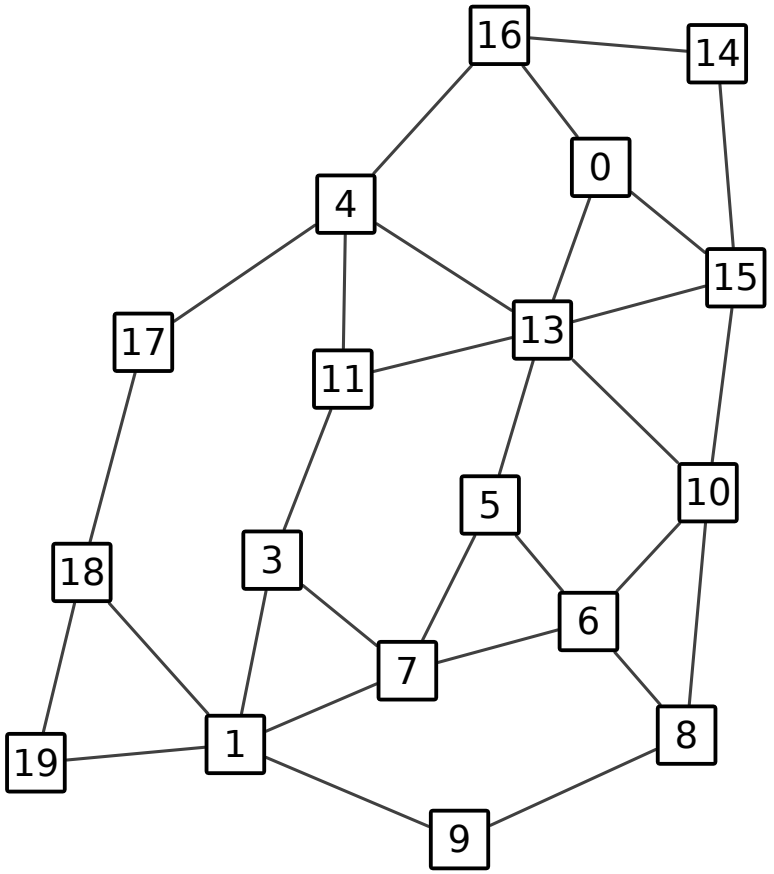
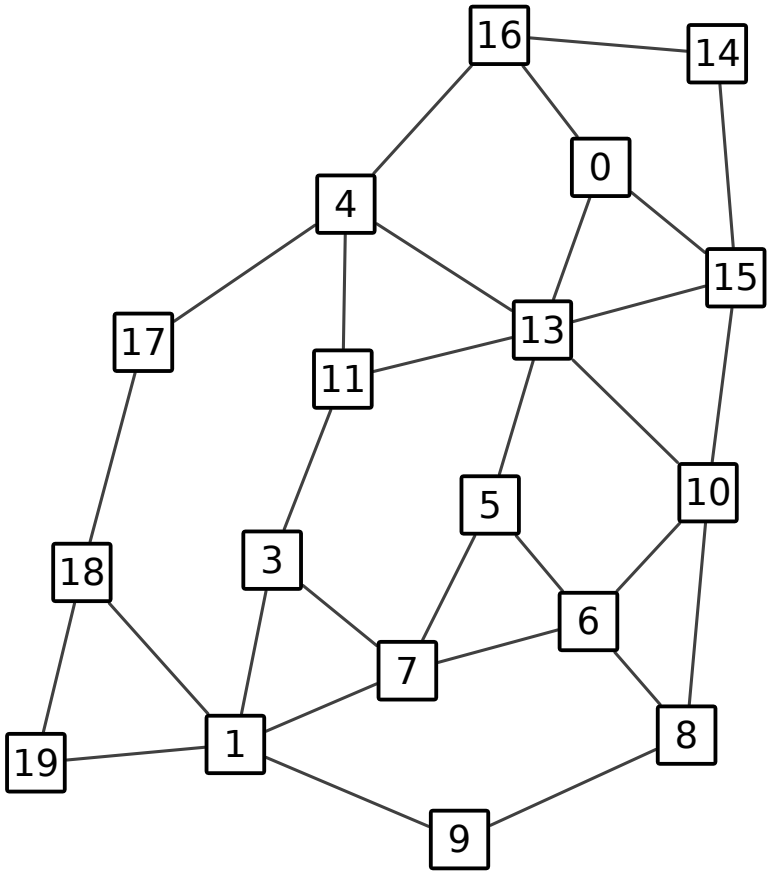
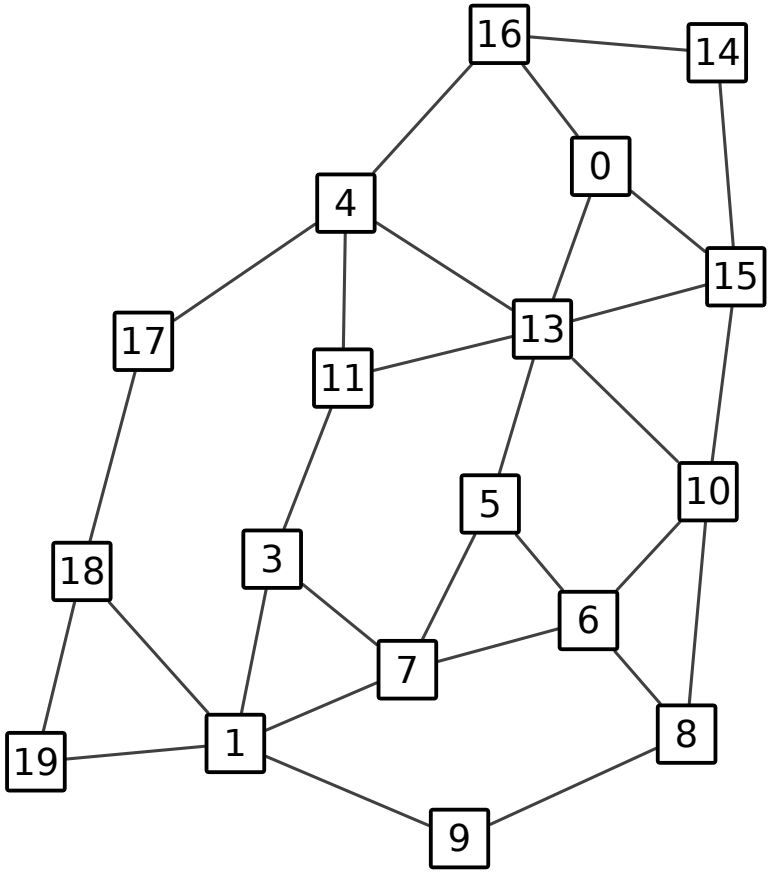


Loss Strategies

- Other approaches do not evaluate limited network view
- Unrealistic assumptions:
  - All communication relationships captured
  - Complete botnet in known network
- Solution: Simulate loss on communication graph

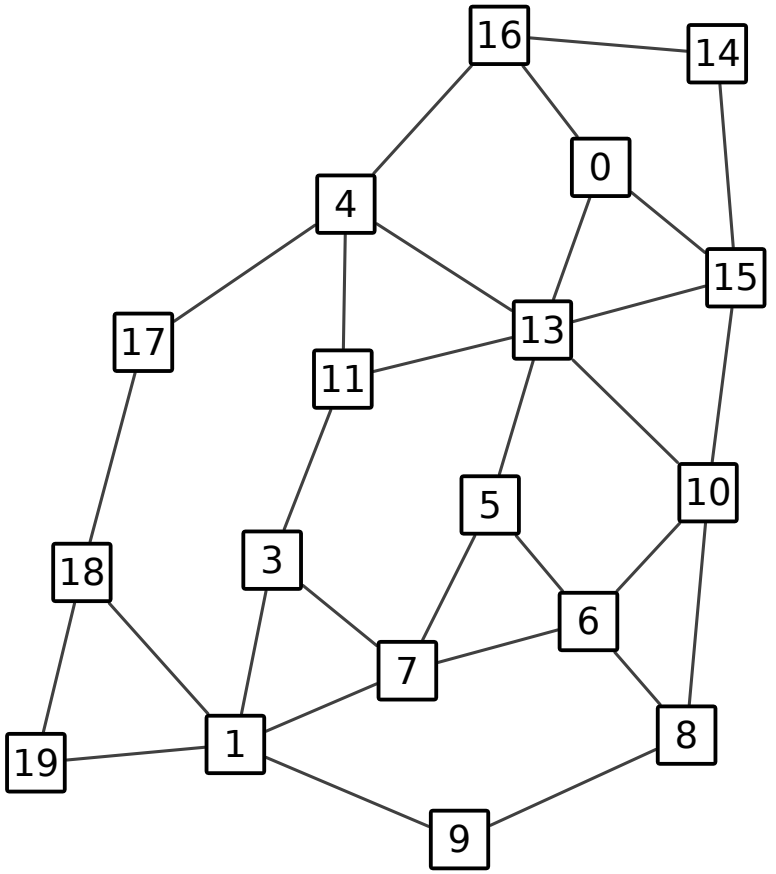


Random Botnet Edge Deletion



Random Botnet Edge Deletion

- Random subset of botnet edges



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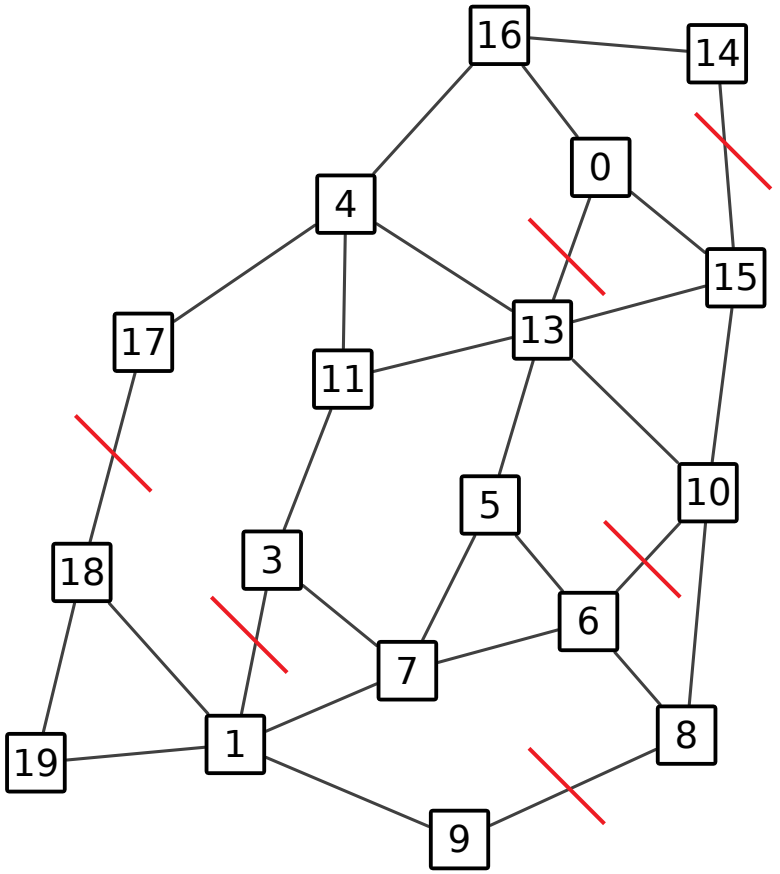
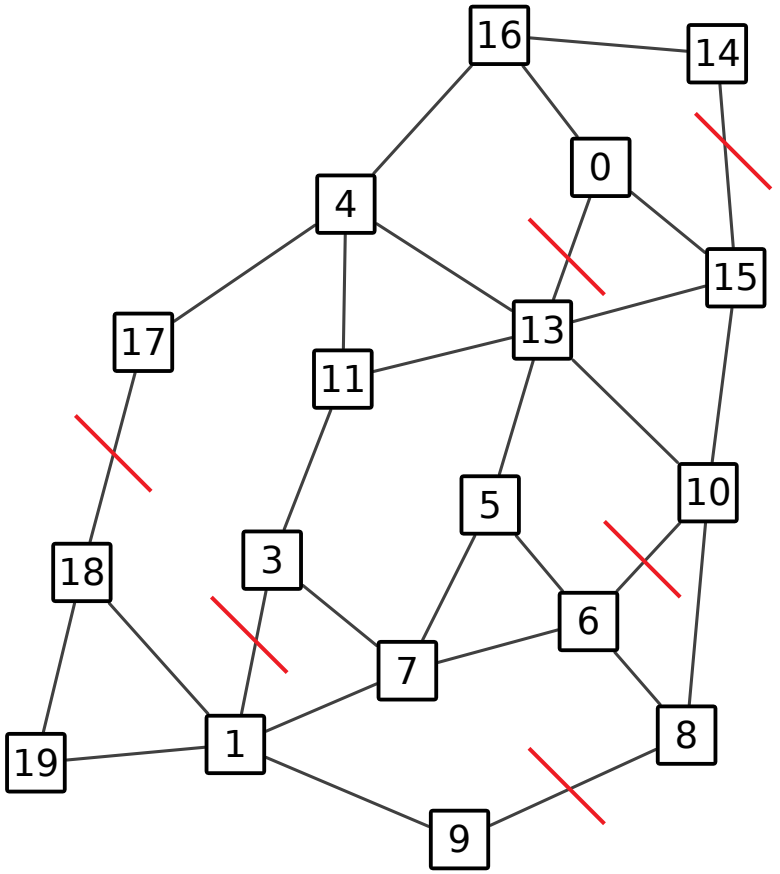


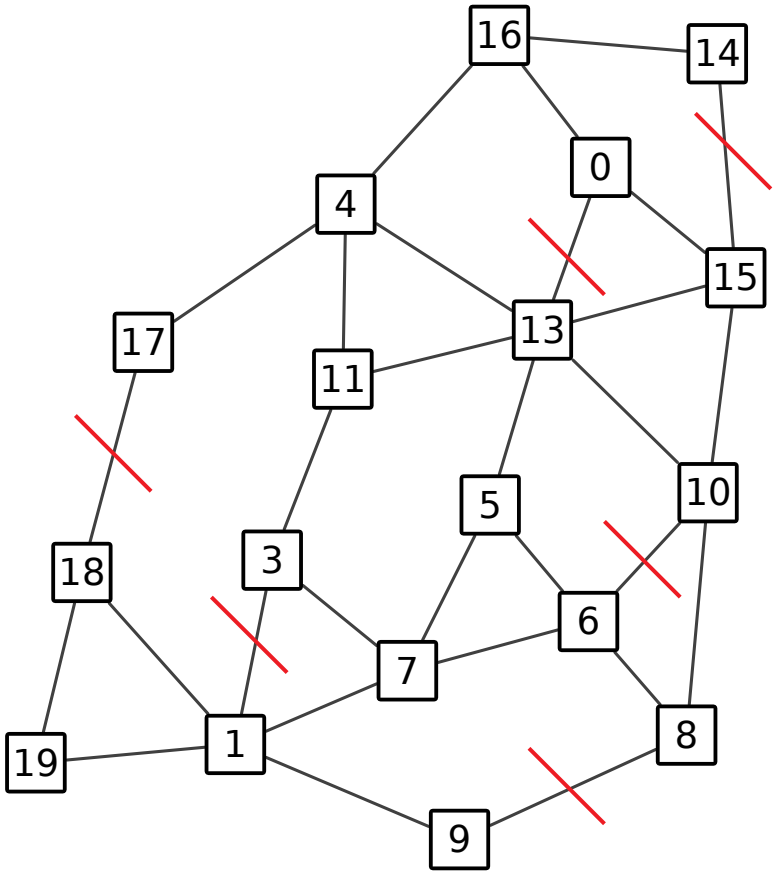
Random Botnet Edge Deletion

- Random subset of botnet edges
- Out-of-view connections



Random Botnet Edge Deletion

- Random subset of botnet edges
- Out-of-view connections
- ISP-related loss (e.g. 1:256 sampling)



RBED Robustness

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$$\text{Precision} = \frac{tp}{tp + fp}$$

$$\text{Recall} = \frac{tp}{tp + fn}$$

RBED Robustness

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$$\text{Precision} = \frac{tp}{tp + fp}$$

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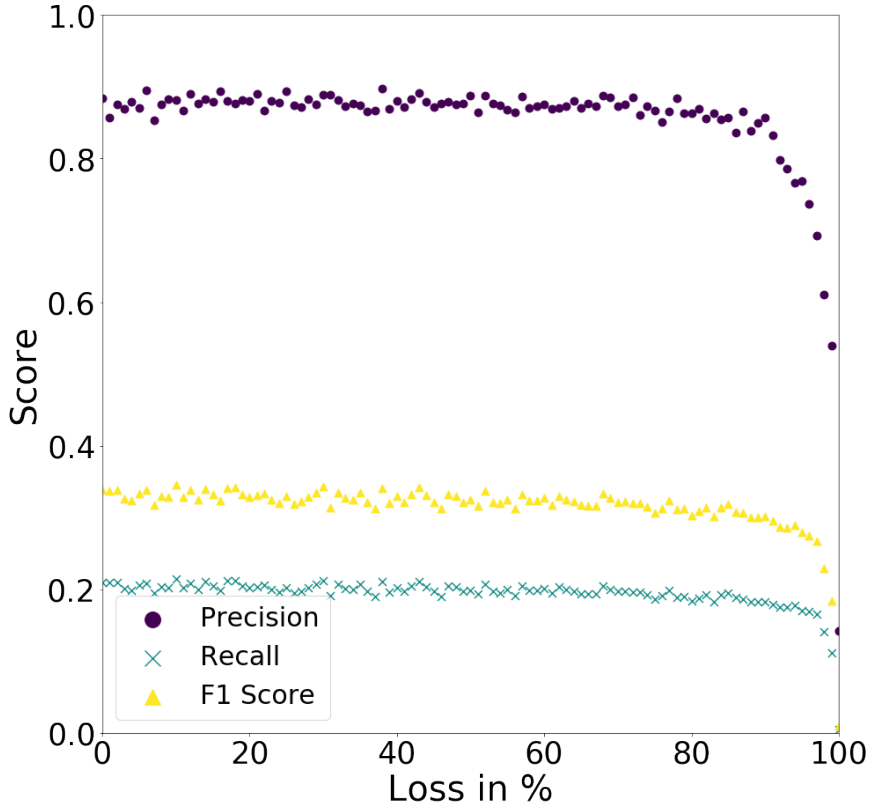

RBED Robustness

- Random Botnet Edge Deletion
- 90% loss – 83% precision

$$\text{Precision} = \frac{tp}{tp + fp}$$

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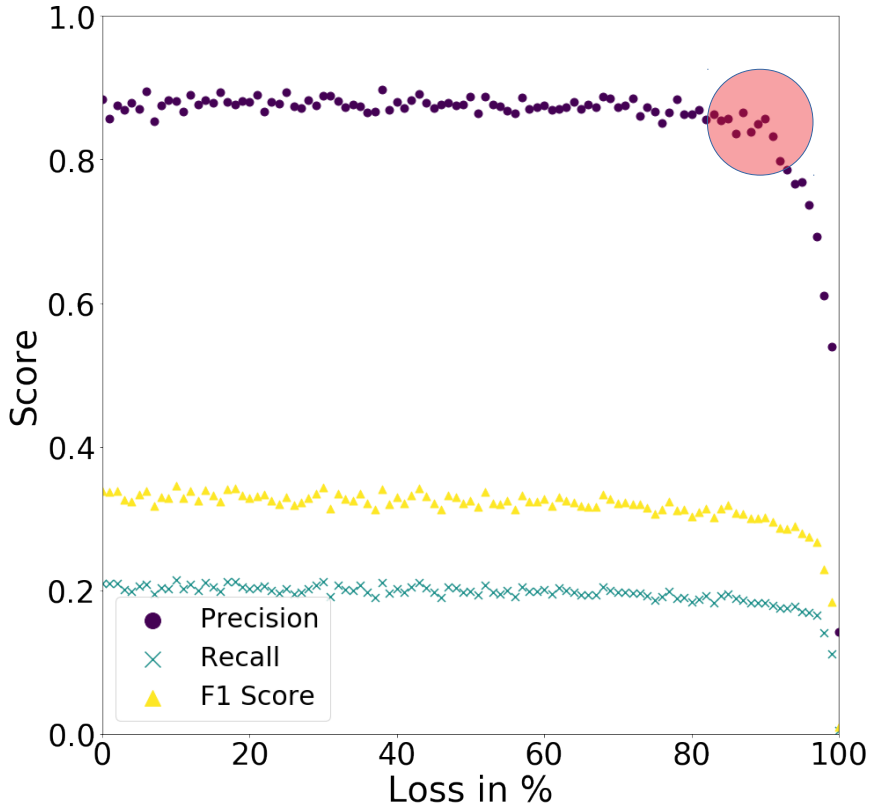
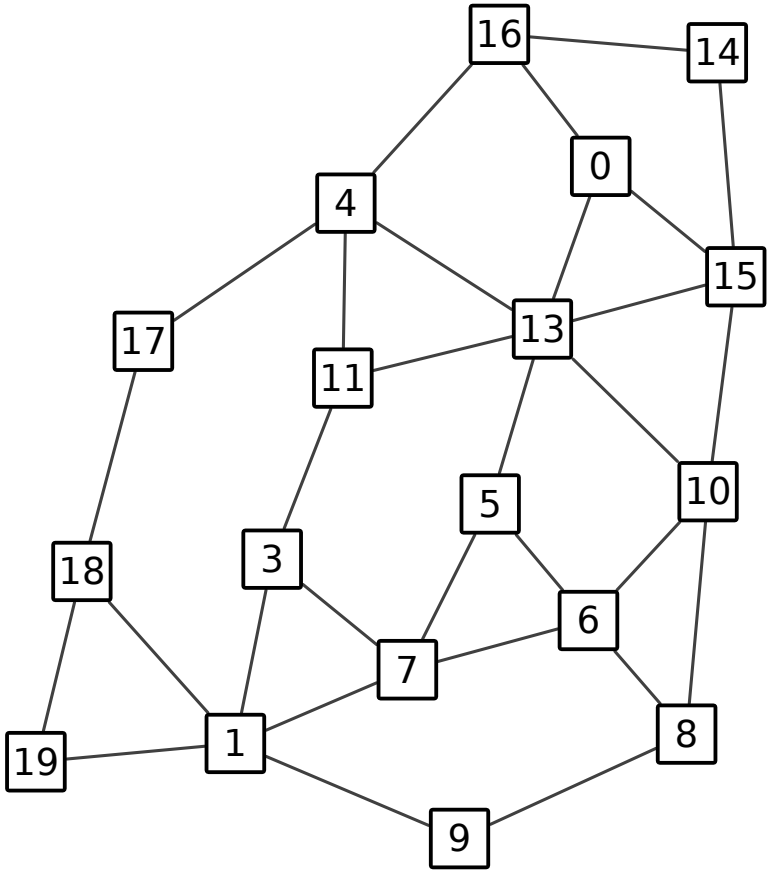
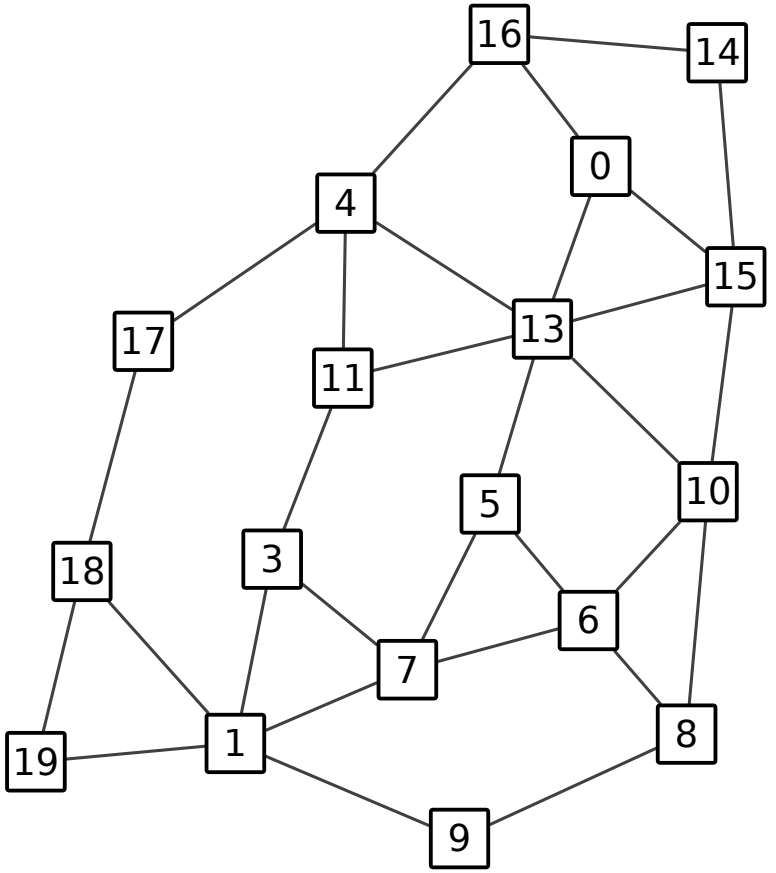


Host-based Visibility



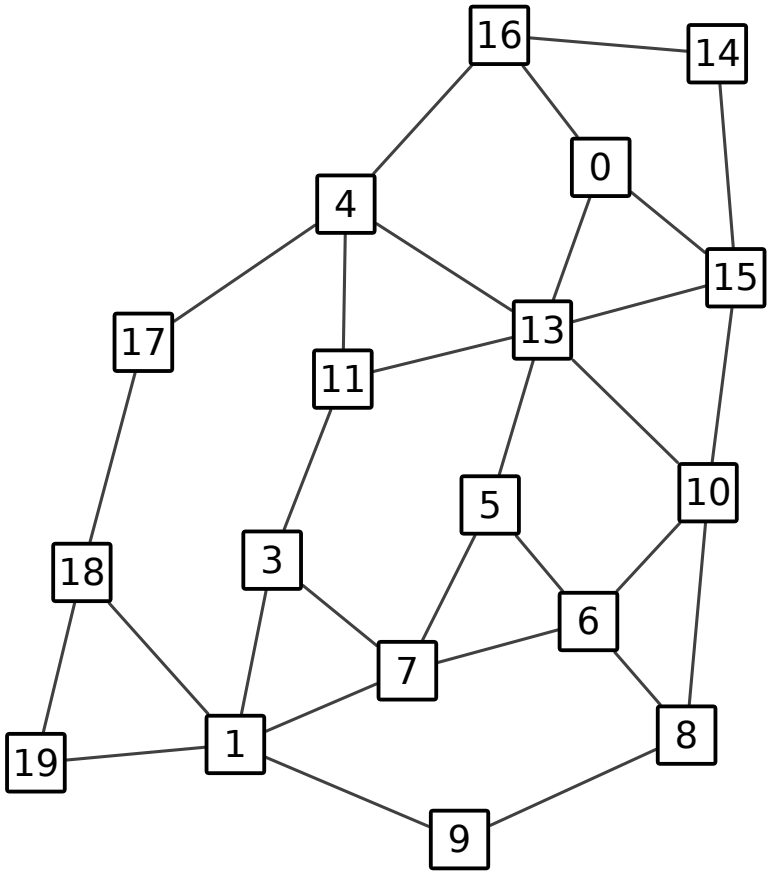
Host-based Visibility

- Sensor deployment



Host-based Visibility

- Sensor deployment
- Randomly chosen



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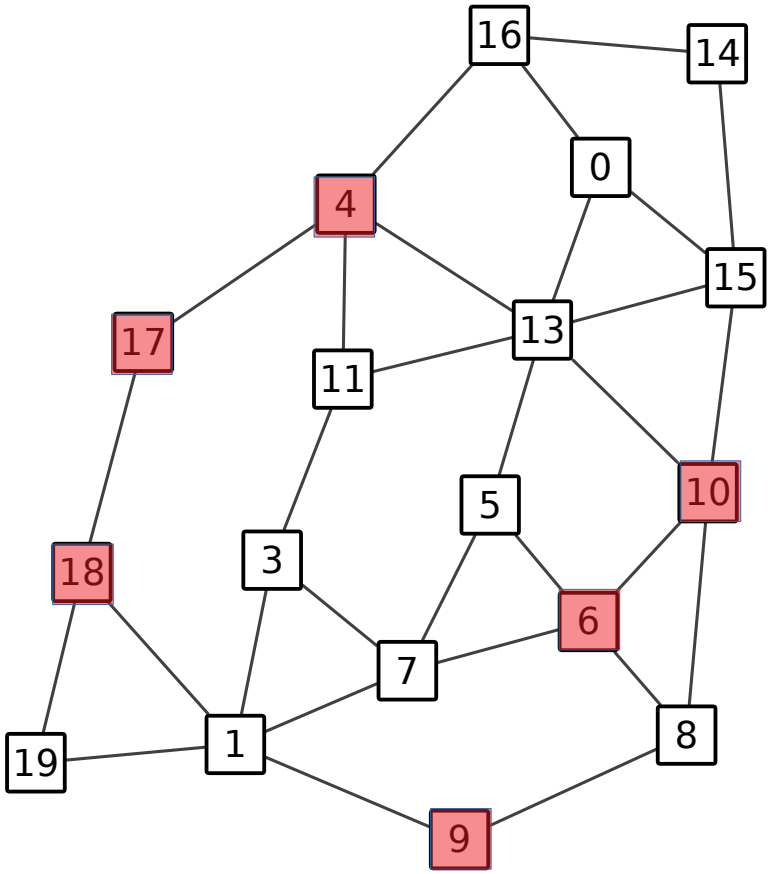
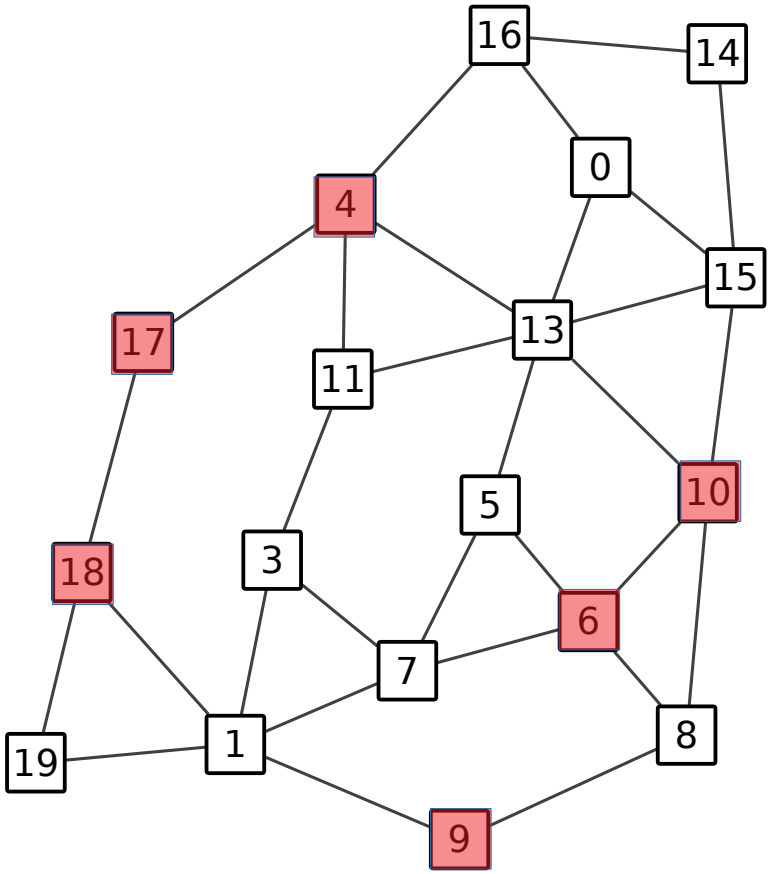


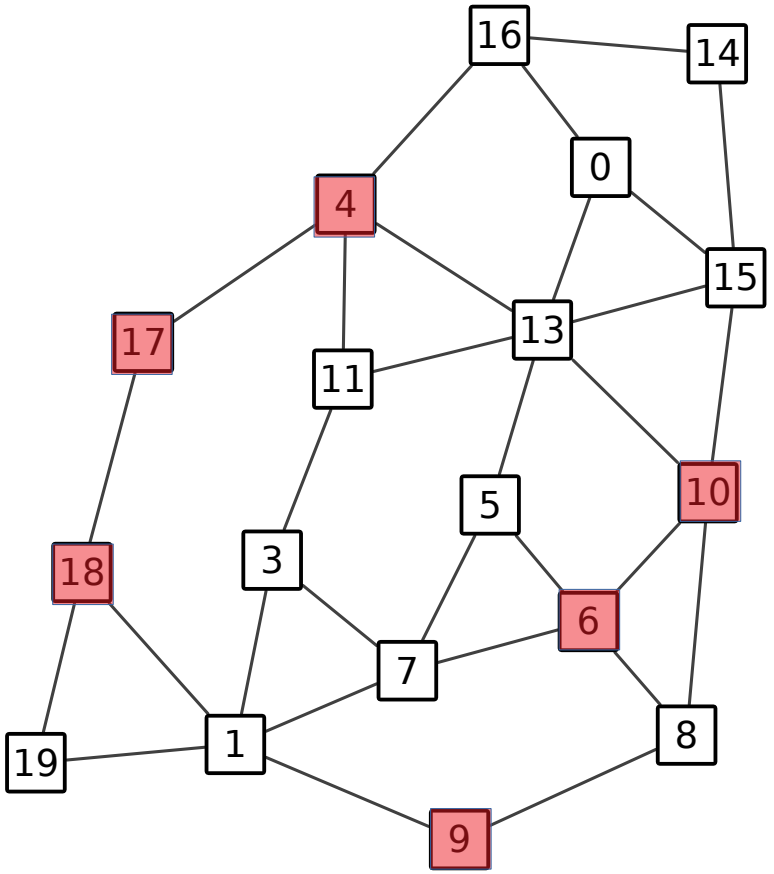
Host-based Visibility

- Sensor deployment
- Randomly chosen
- No communication between unmonitored hosts



Host-based Visibility

- Sensor deployment
- Randomly chosen
- No communication between unmonitored hosts
- Honeypot scenario

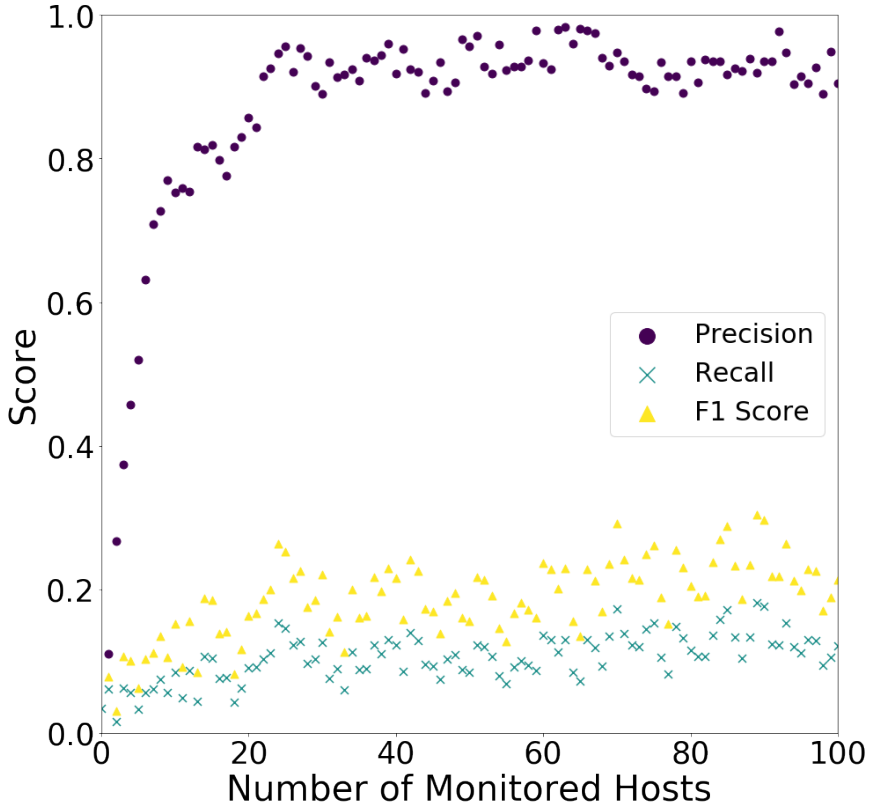


Sensor-Network Robustness

- Sensor deployment

Sensor-Network Robustness

- Sensor deployment

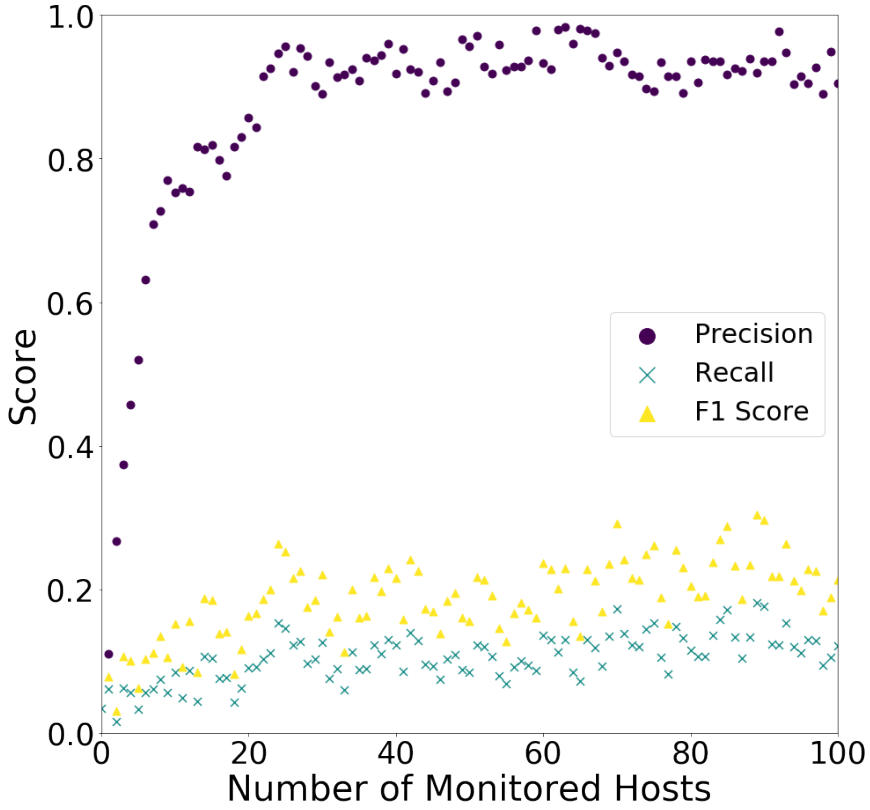


Sensor-Network Robustness

- Sensor deployment

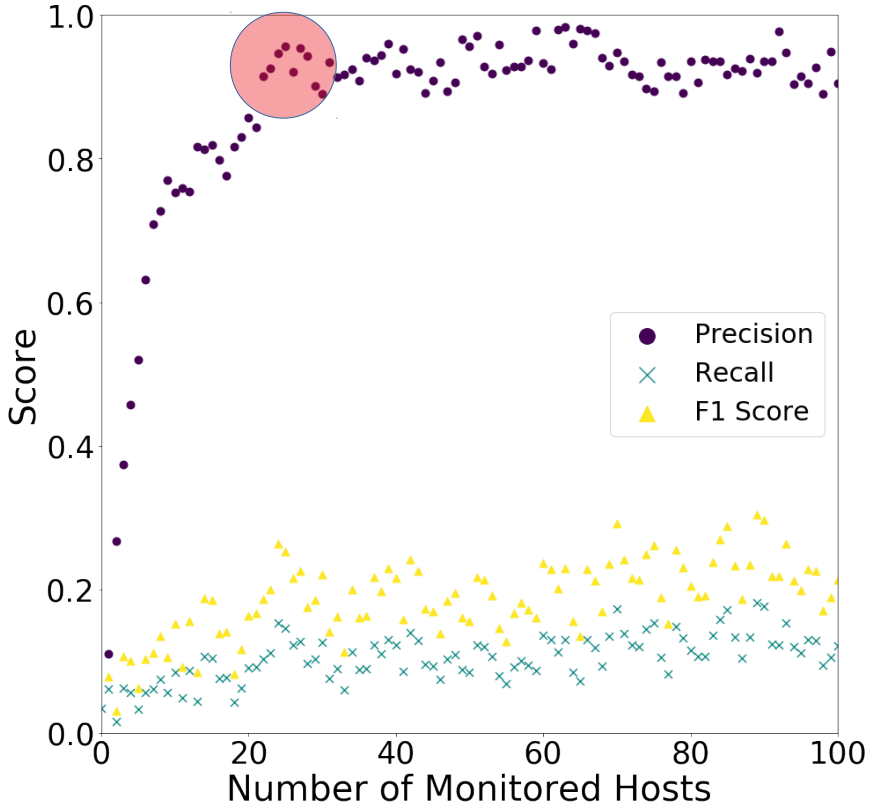
$$\text{Precision} = \frac{tp}{tp + fp}$$

$$\text{Recall} = \frac{tp}{tp + fn}$$



Sensor-Network Robustness

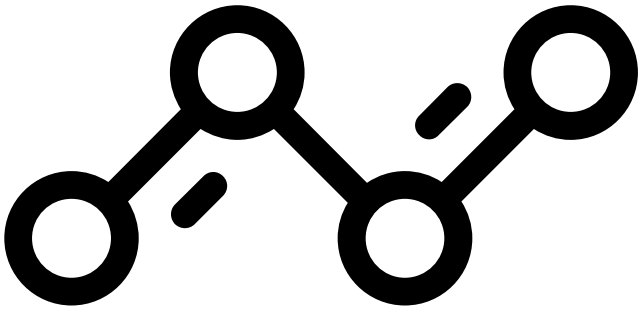
- Sensor deployment
- 25 sensors – 90% precision



$$\text{Precision} = \frac{tp}{tp + fp}$$

$$\text{Recall} = \frac{tp}{tp + fn}$$

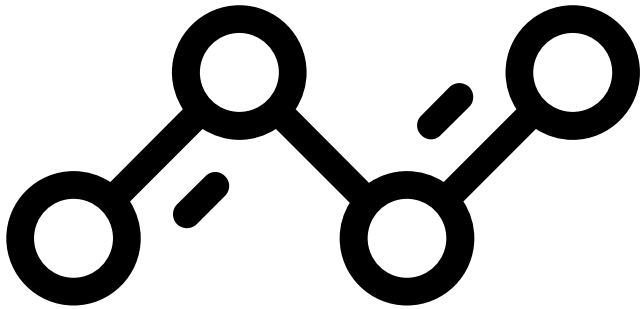
Conclusion



[7]

Conclusion

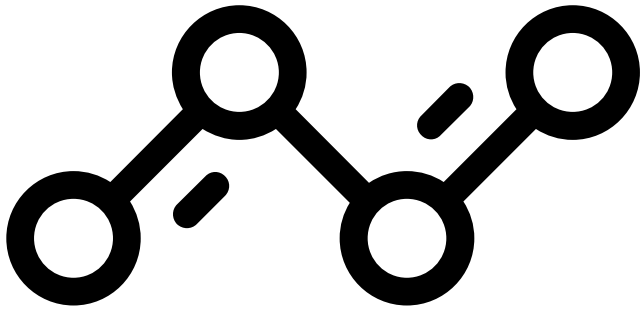
- Structured and unstructured botnets: fast-mixing



[7]

Conclusion

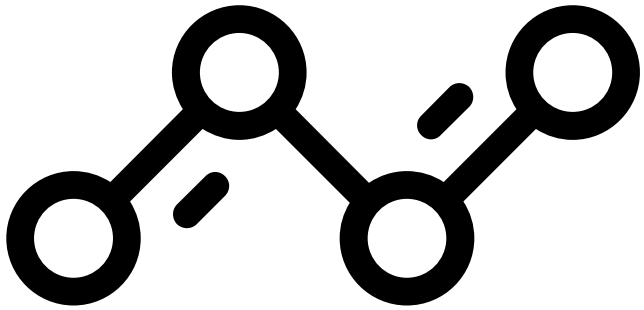
- Structured and unstructured botnets: fast-mixing
- High-precision detection
  - 83% precision



[7]

Conclusion

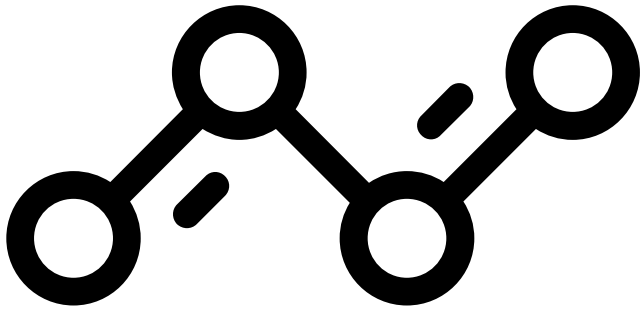
- Structured and unstructured botnets: fast-mixing
- High-precision detection
  - 83% precision
  - With 90% missing edges



[7]

Conclusion

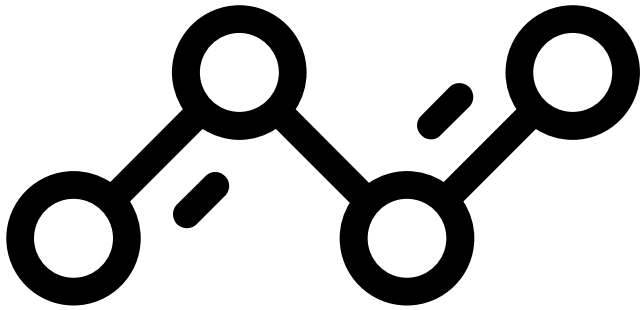
- Structured and unstructured botnets: fast-mixing
- High-precision detection
  - 83% precision
  - With 90% missing edges
- Simple architecture



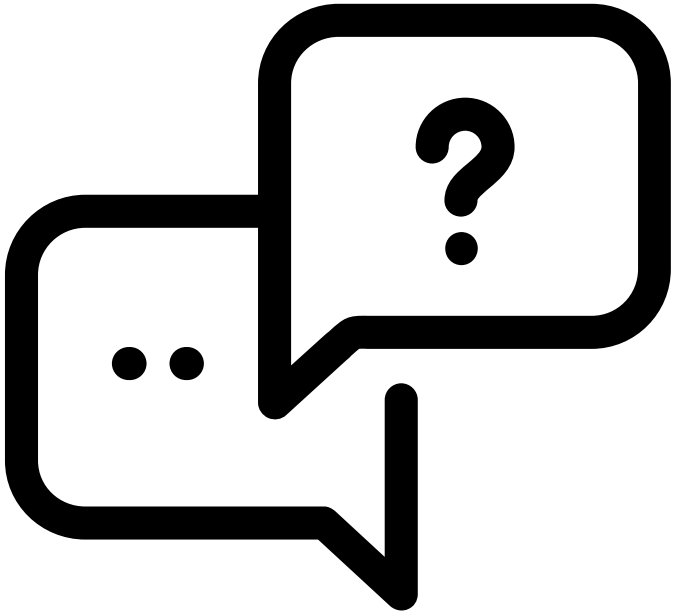
[7]

Conclusion

- Structured and unstructured botnets: fast-mixing
- High-precision detection
  - 83% precision
  - With 90% missing edges
- Simple architecture
- Only open-source algorithms



[7]



[7]

Thanks!

Questions?

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[7] Icon made by Freepik from https://www.flaticon.com/

[8] Icon made by dDara from https://www.flaticon.com/

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