Botnet detection revisited:
Theory and Practice of Finding Malicious P2P Networks via Internet Connection Graphs

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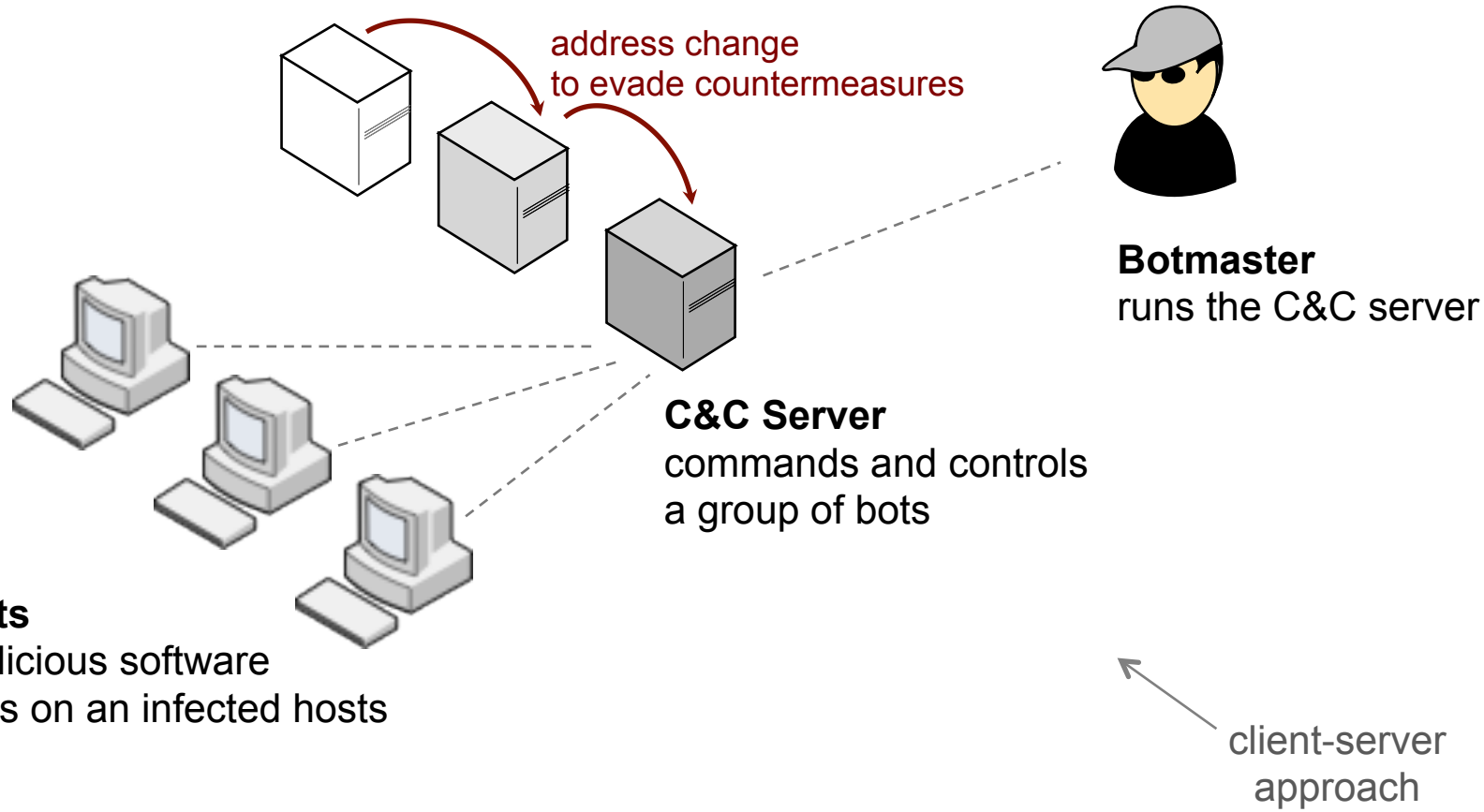
Outline

1. **Introduction and Motivation**
   - P2P Botnets from an operators point of view
   - Graph-based botnet detection:
     Revealing P2P structures in Traffic Dispersion Graphs
2. **Recent approaches**
   - PageRank and Clustering
   - Finding Friend-of-a-friend structures
3. **Experimental results**
   - Limitations of existing approaches
   - Suggestions on improvements
4. **Conclusion**

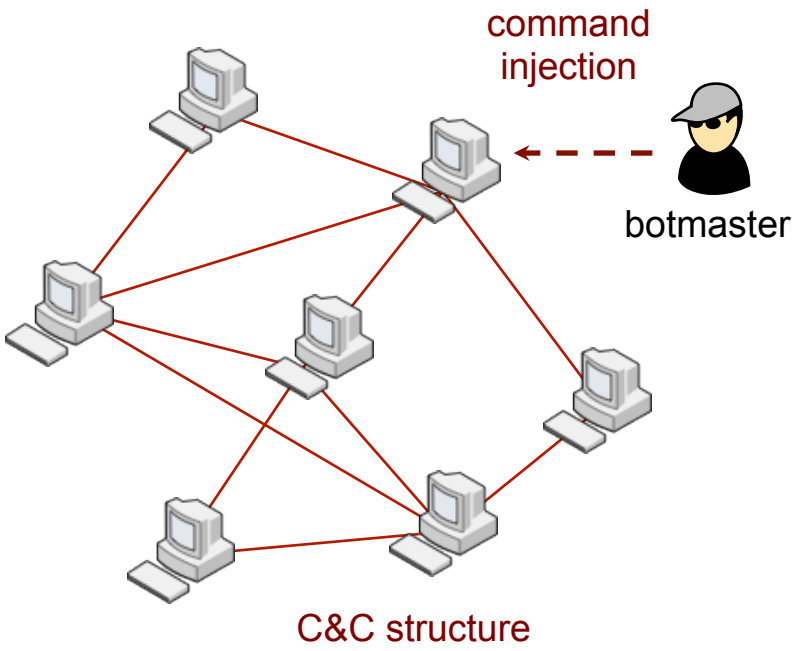
What is a botnet?



P2P Botnets

→ Use of peer-to-peer (P2P) overlay networks already observed in practice

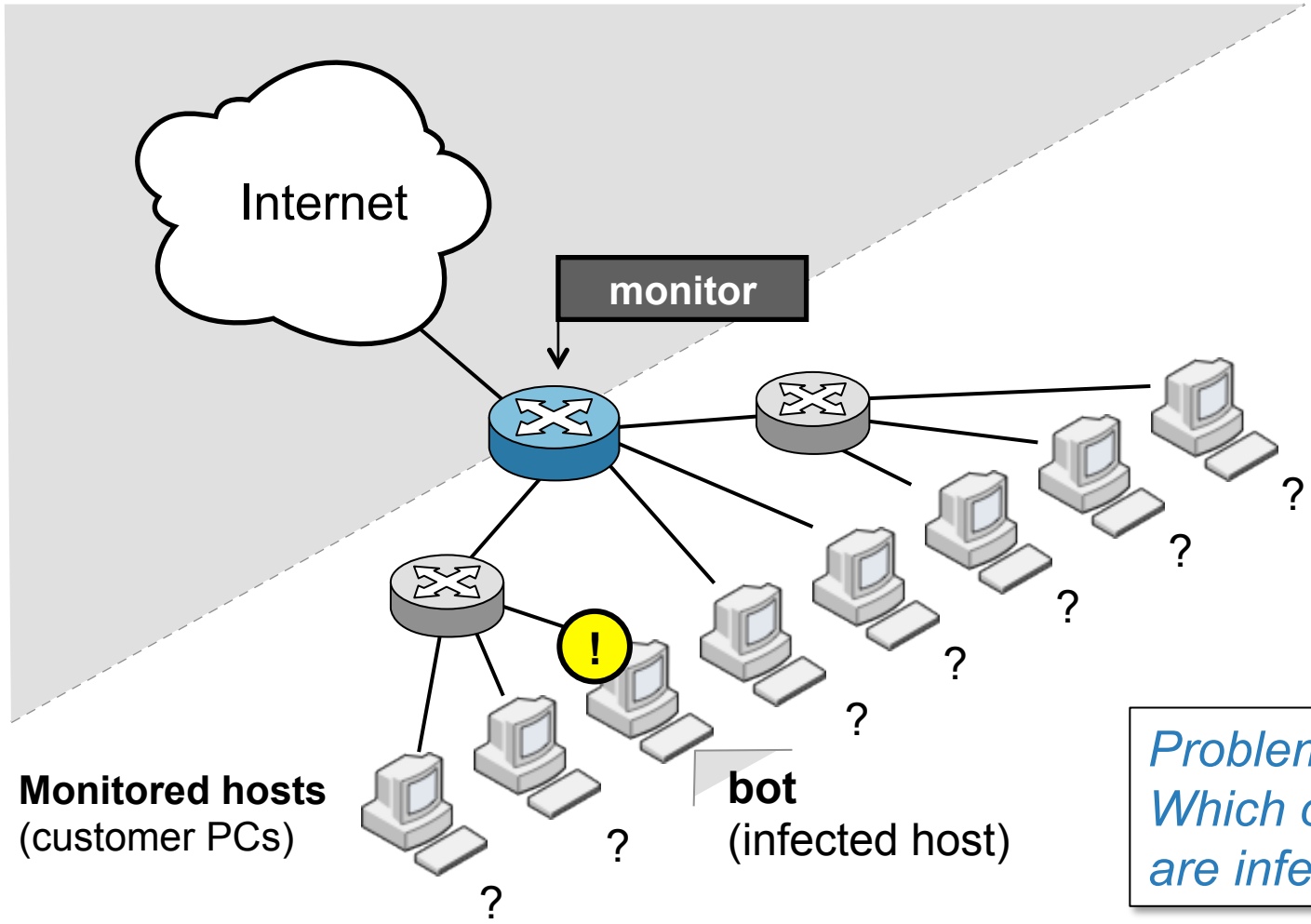
→ Example: Storm botnet
- peak activity in 2007
- millions of infected hosts
- uses Overnet P2P network (based on Kademlia) in the setup phase



→ No central point of failure, but command dissemination slow

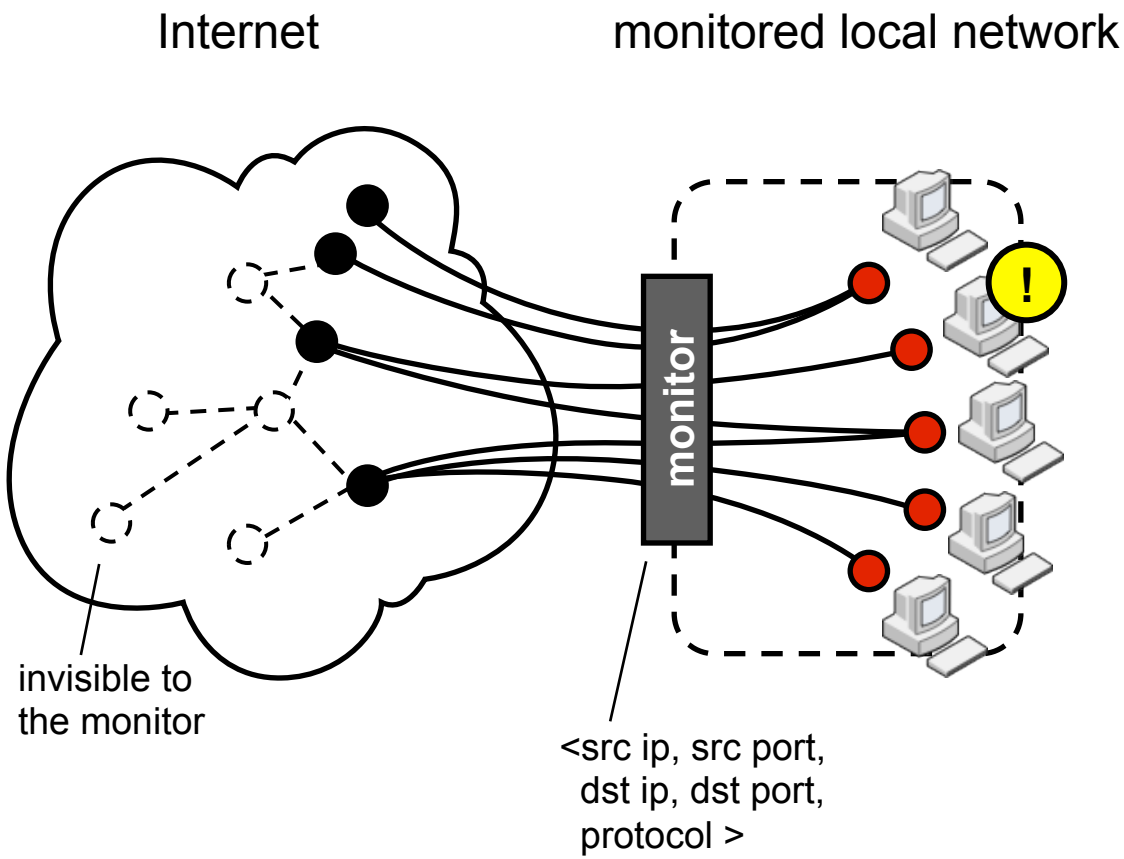
→ Theory: P2P networks form observable structures

What the network operator observes:



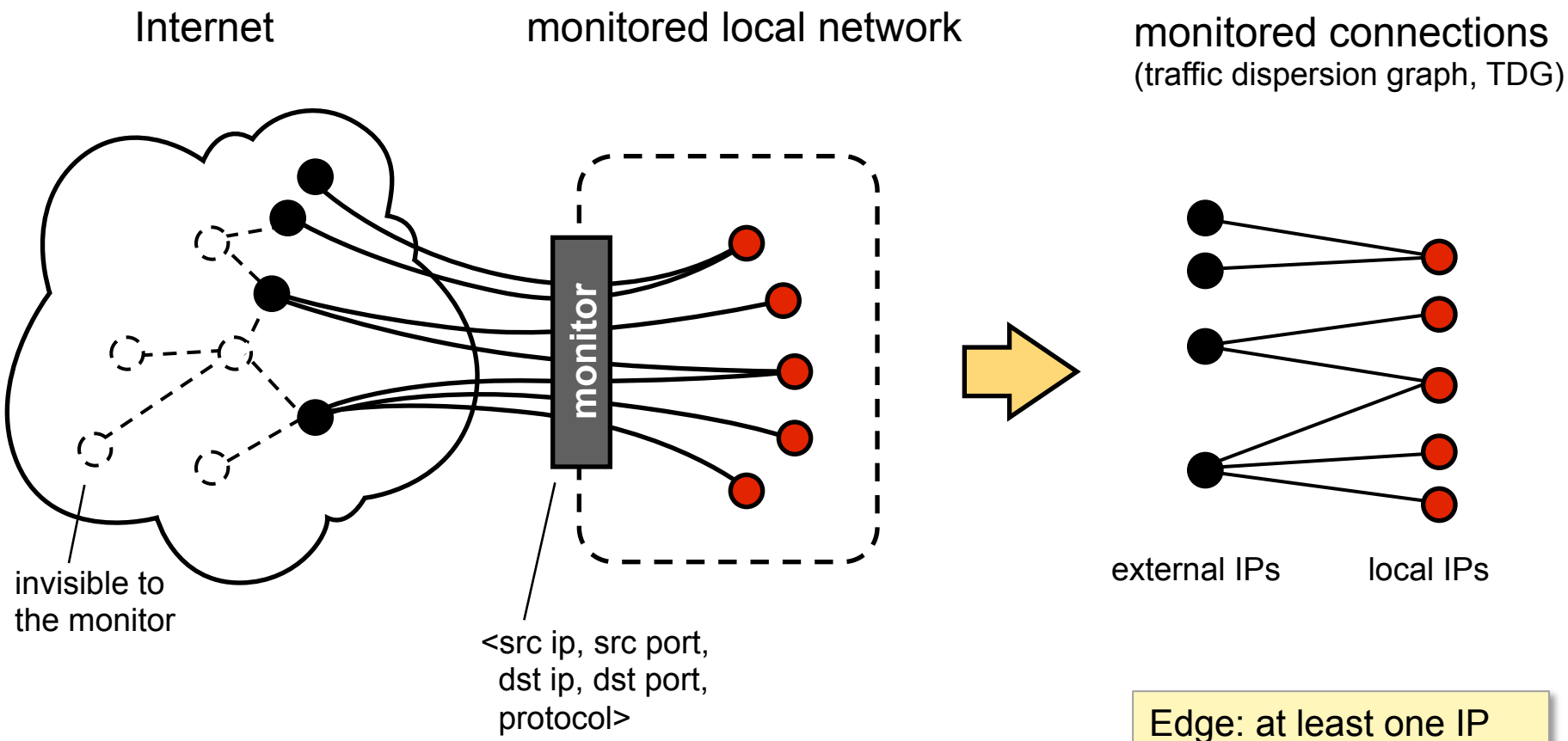
Problem:
Which other hosts are infected?

Observable connections



Goal: identify potential bots for further analysis

Traffic dispersion graph



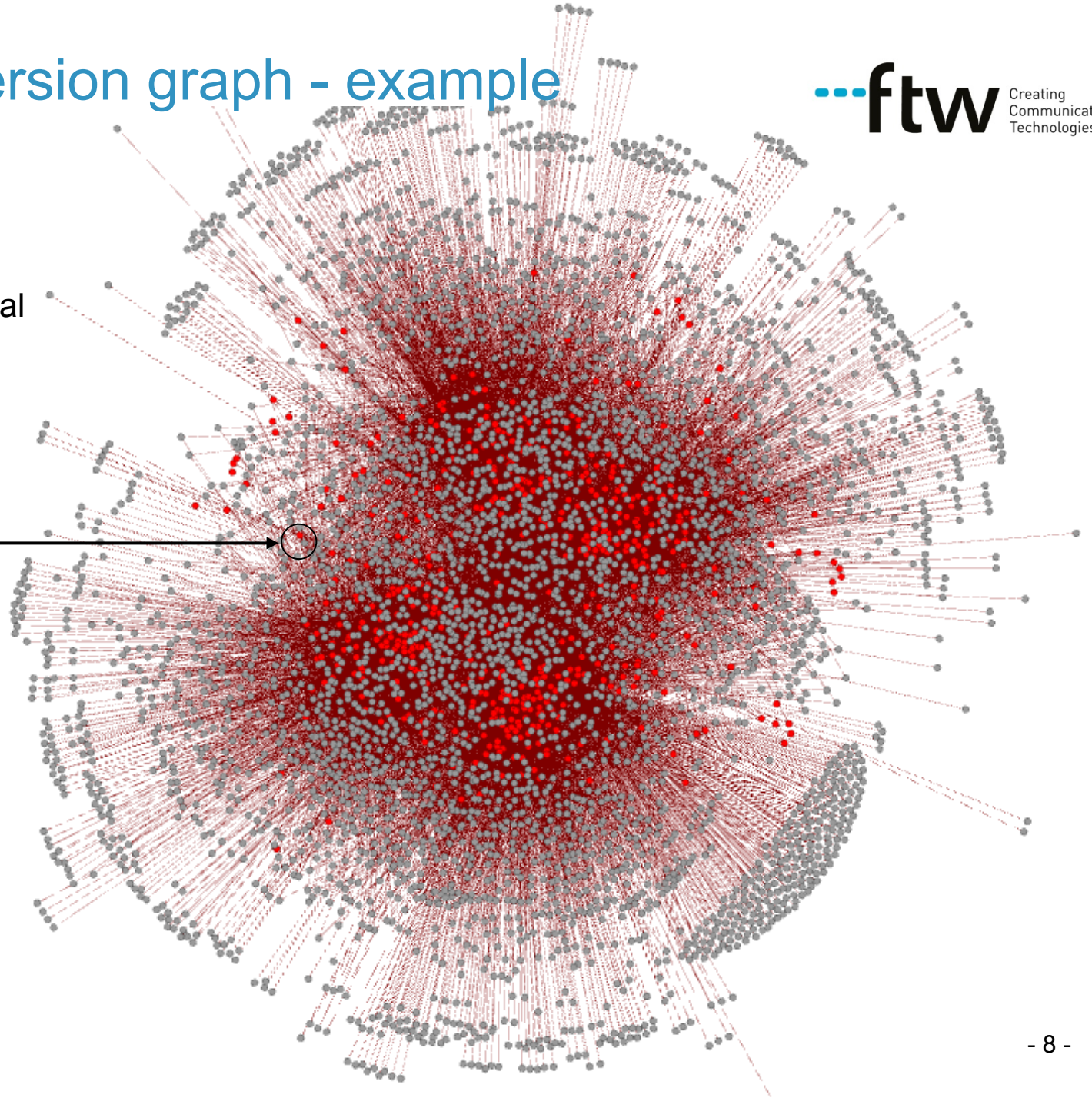
Edge: at least one IP packet transferred

Traffic dispersion graph - example

TDG with
~ 4000 nodes
thereof 500 internal
~ 20.000 edges

Known bot

How to find others?



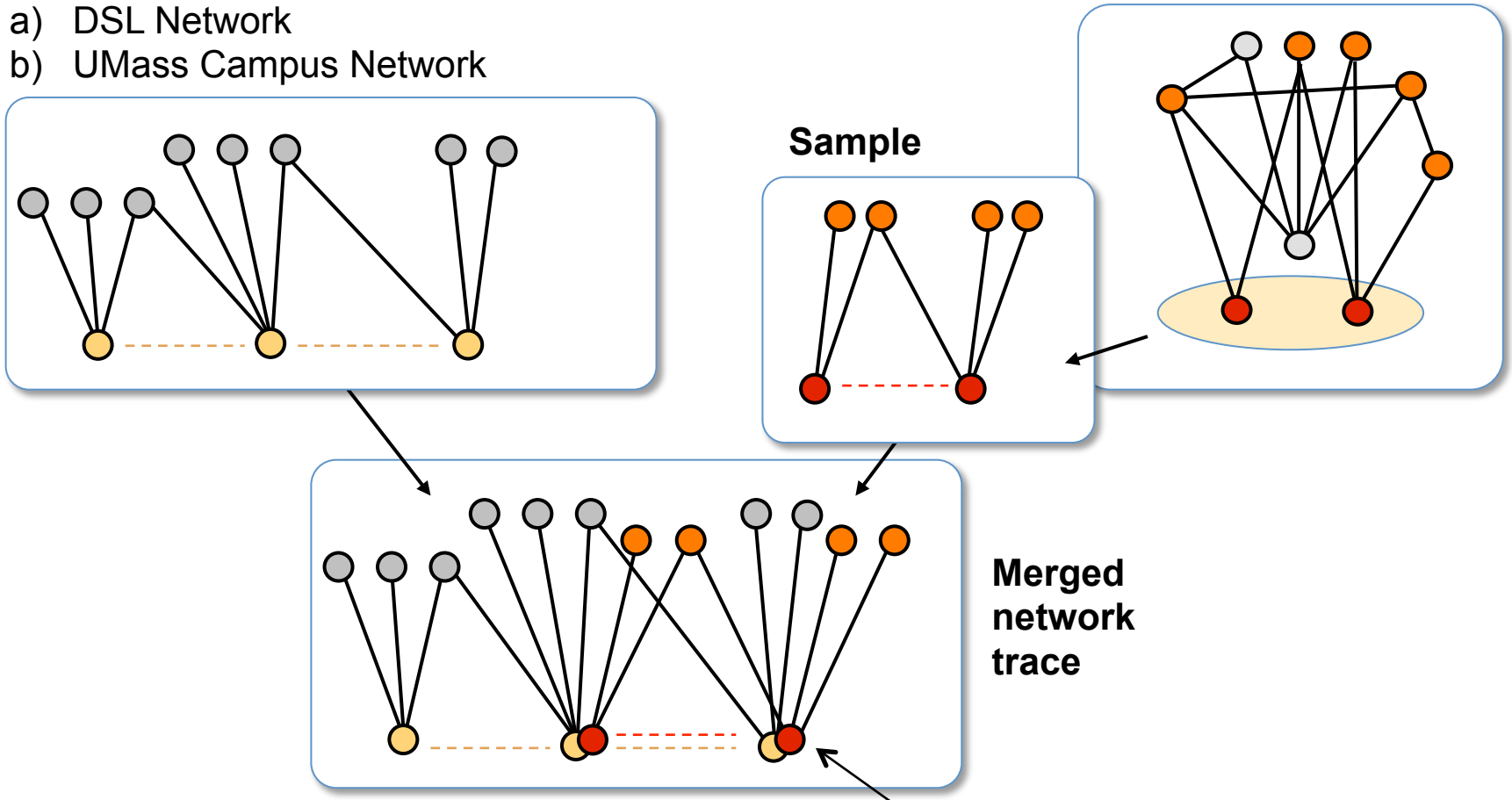
Experimental setup

Traffic dispersion graph (TDG) from a network trace

a) DSL Network

b) UMass Campus Network

P2P botnet topology from a synthetic Kademlia P2P network



Recent approaches to Botnet Detection

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→ Finding fast mixing components by
random walks in traffic dispersion graphs
BotGrep: Finding P2P bots with structured graph analysis
by Nagaraja, Mittal, Hong, Caesar, Borisov. USENIX Security 2010

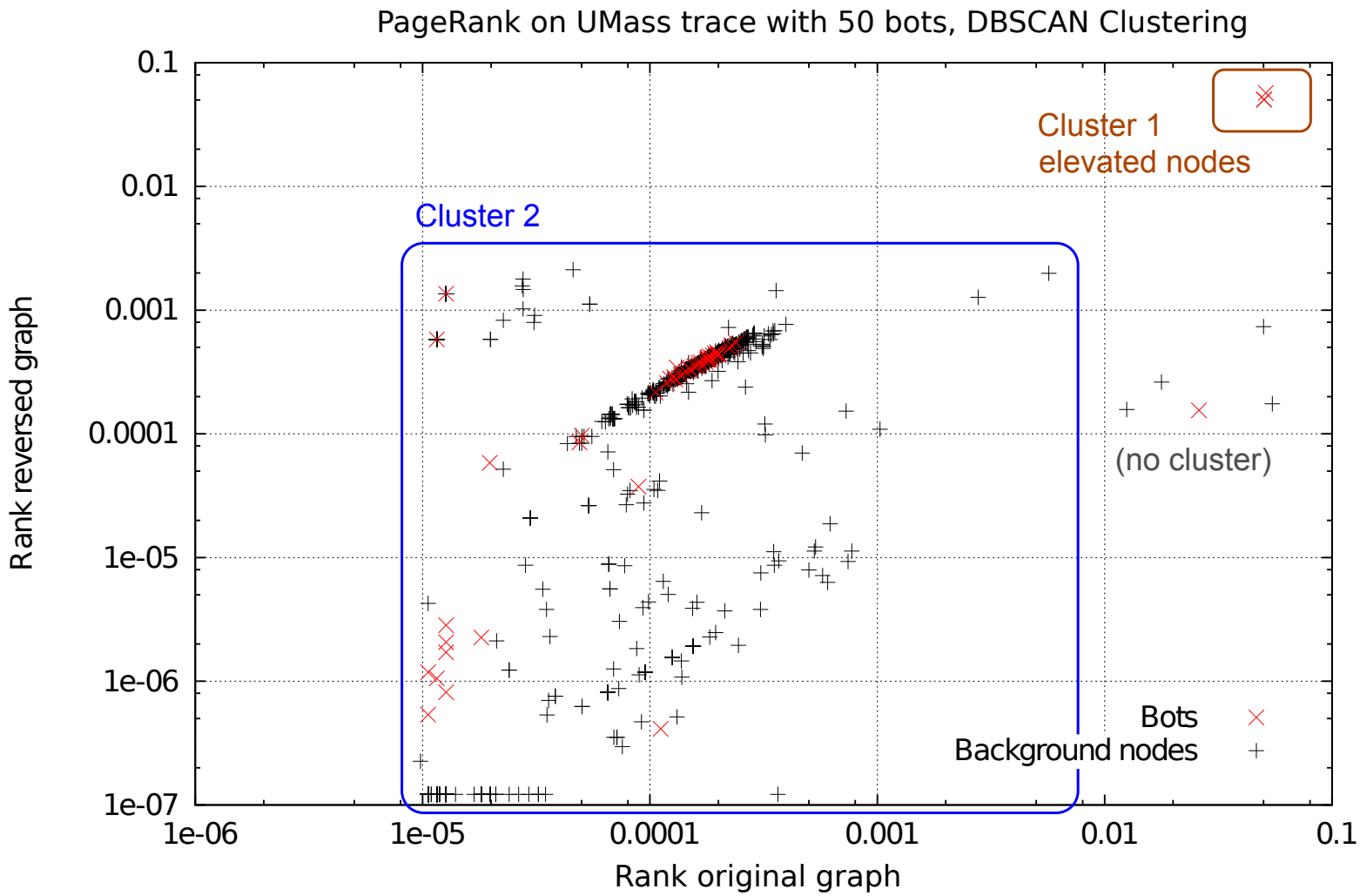
→ Clustering hubs/authorities by
pagerank on traffic dispersion graphs
BotTrack: Tracking botnets using netflow and pagerank.
by François, Wang, State, Engel. NETWORKING 2011

complete knowledge of the network is assumed (holistic view)

→ **Finding friends-of-a-friend** in traffic disperson graphs
Friends of an enemy: identifying local members of peer-to-peer botnets using mutual contacts
by Coskun, Dietrich, Memon. ACSAC ’10

only partial knowledge is assumed (edge router’s view)

Hubs vs Authorities – results of BotTrack

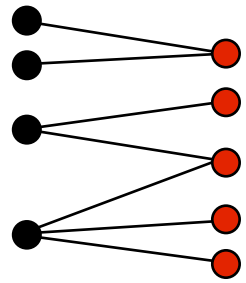


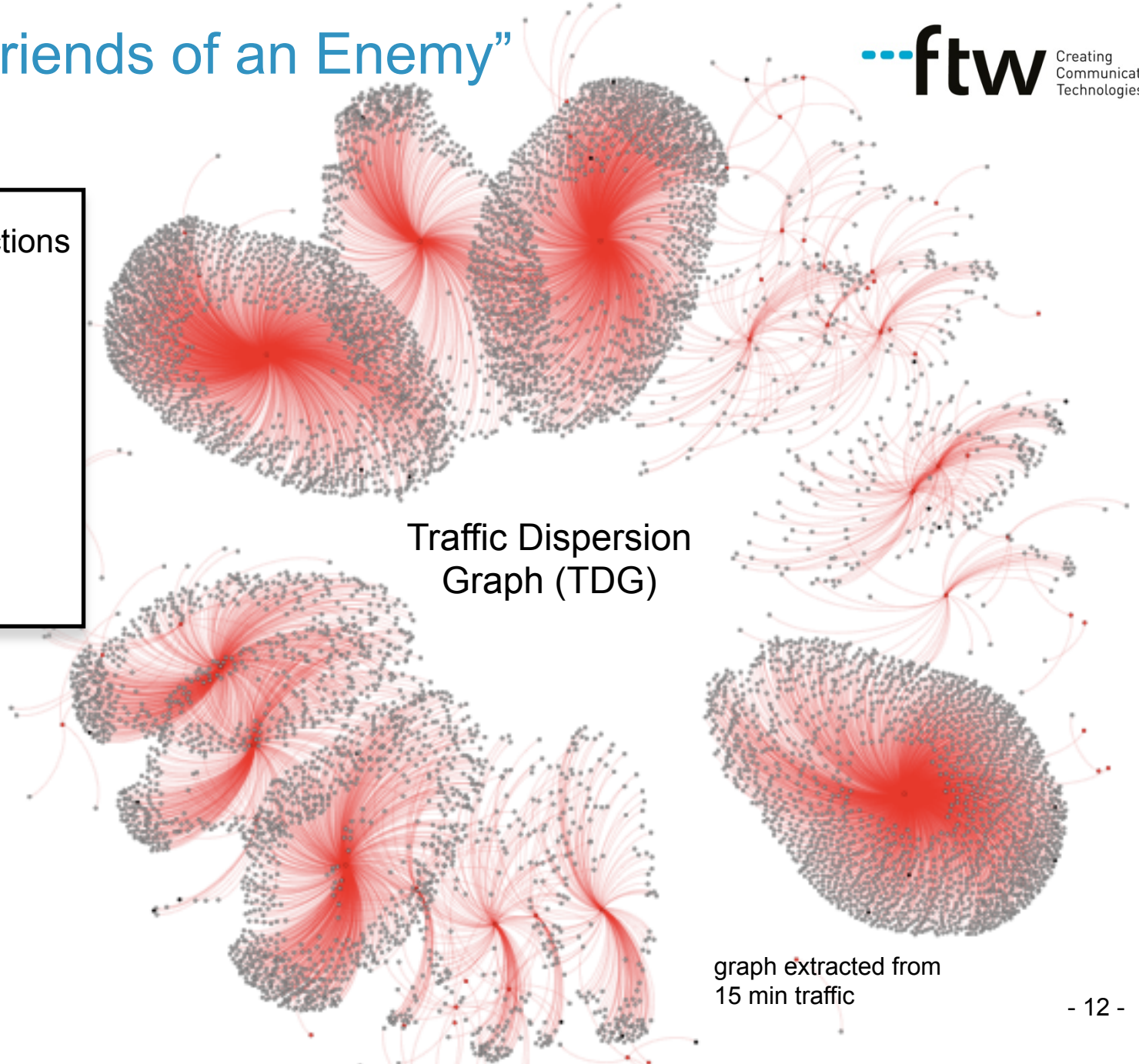
Finding “Friends of an Enemy”

[Coskun et al. 2010]

1

monitored connections (full TDG)



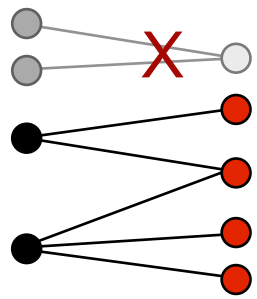


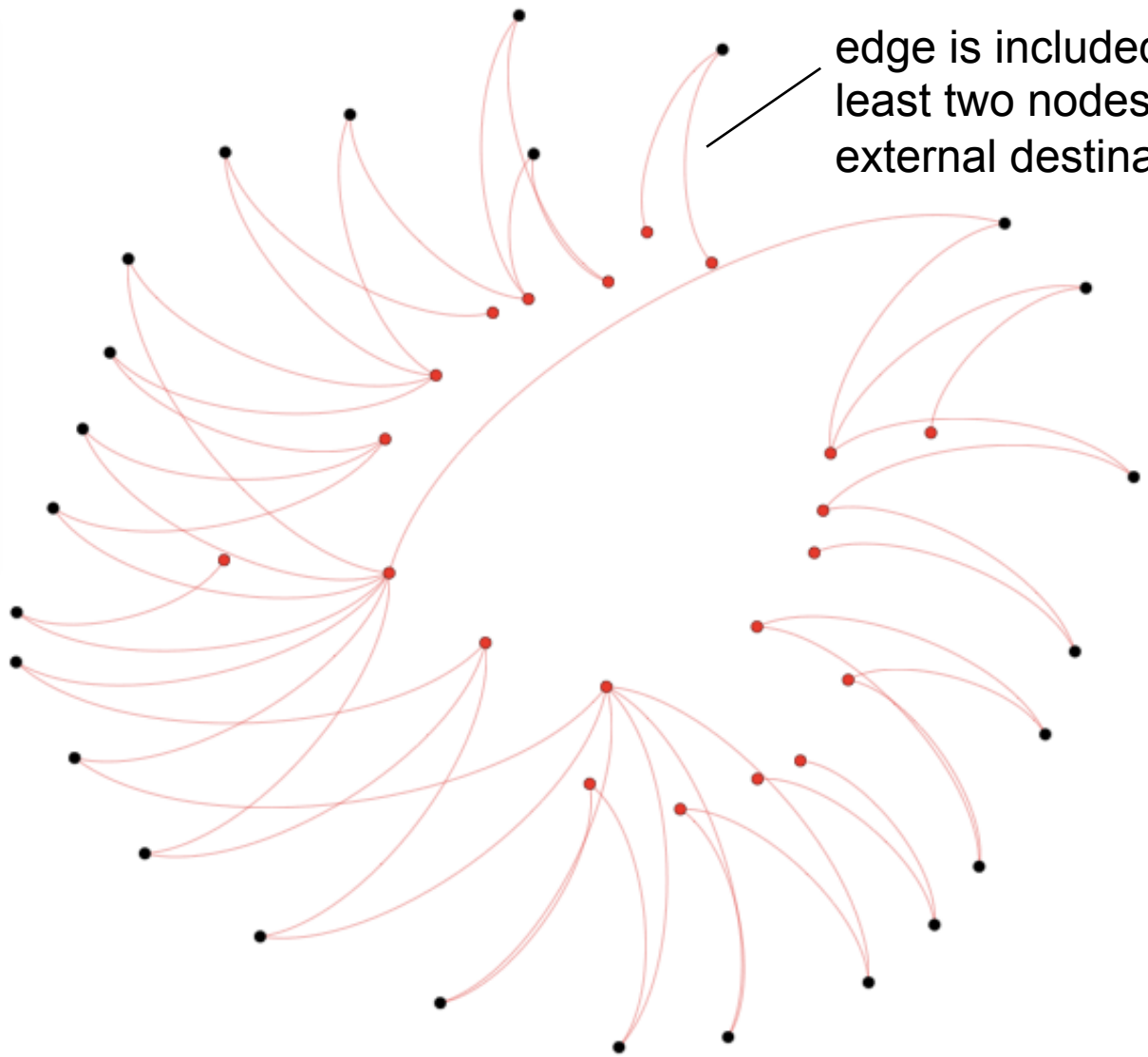
graph extracted from 15 min traffic

TDG with “mutual contacts” only

2

only connections with mutual contacts



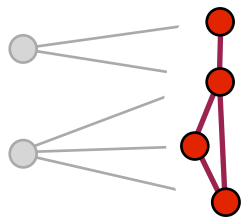


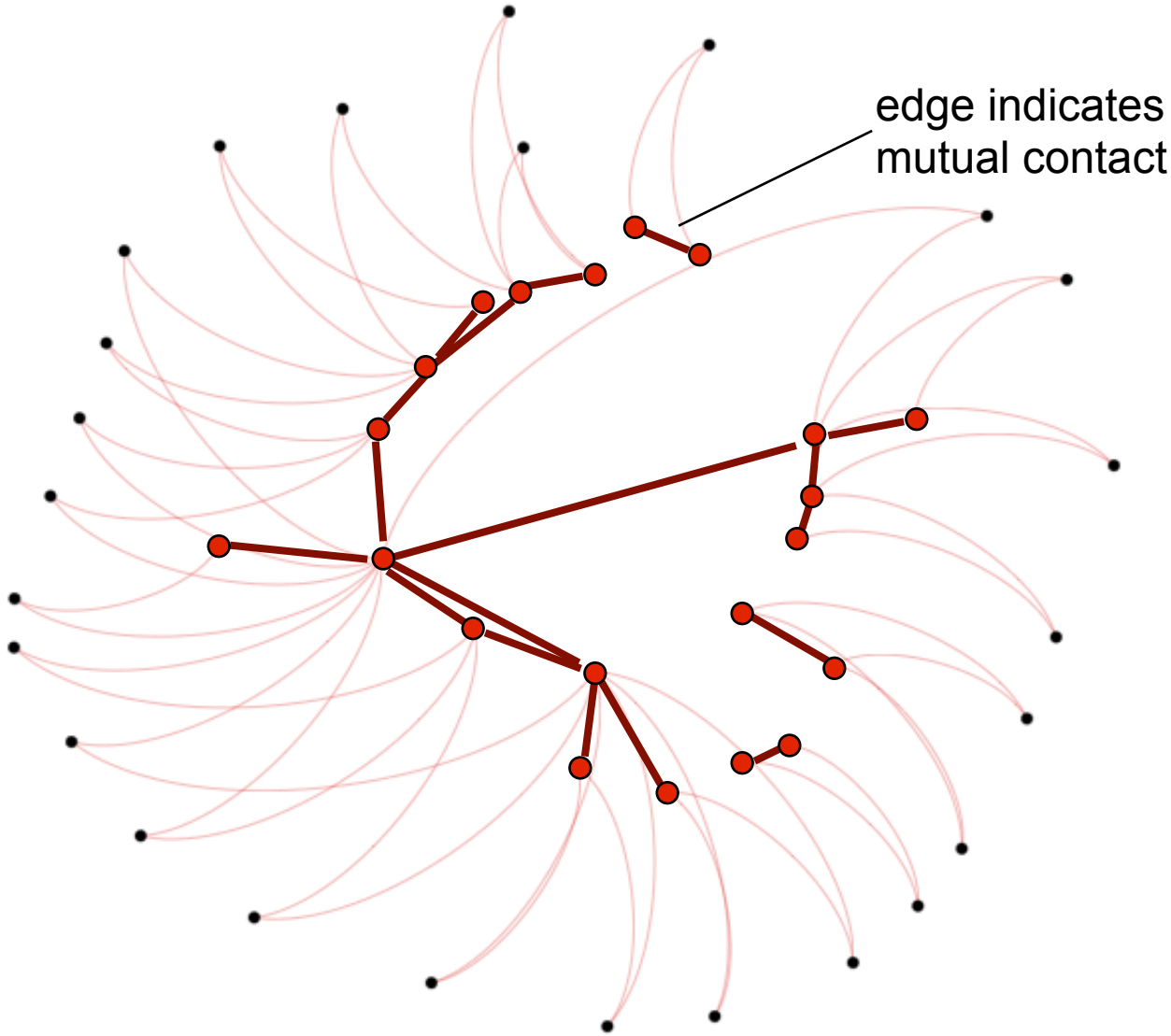
edge is included only if at least two nodes share an external destination

... and the resulting MCG

3

mutual contacts graph (MCG)





“Dye pumping”

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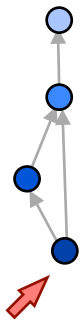
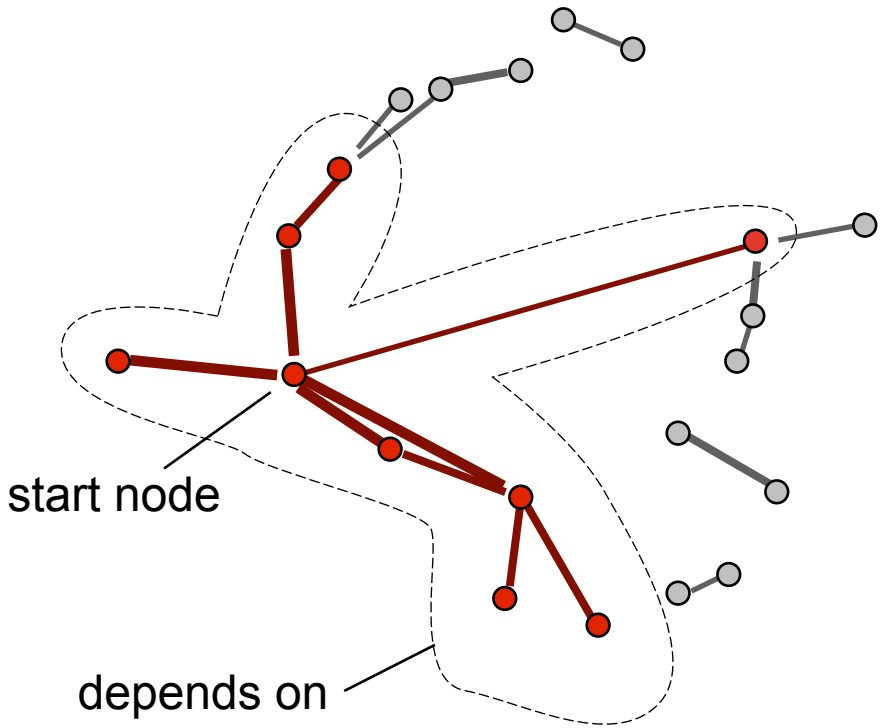
Dye pumping



start node (known infected host)



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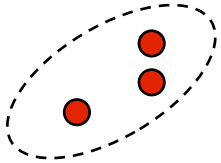
Result

set of nodes that likely belong to the same p2p network



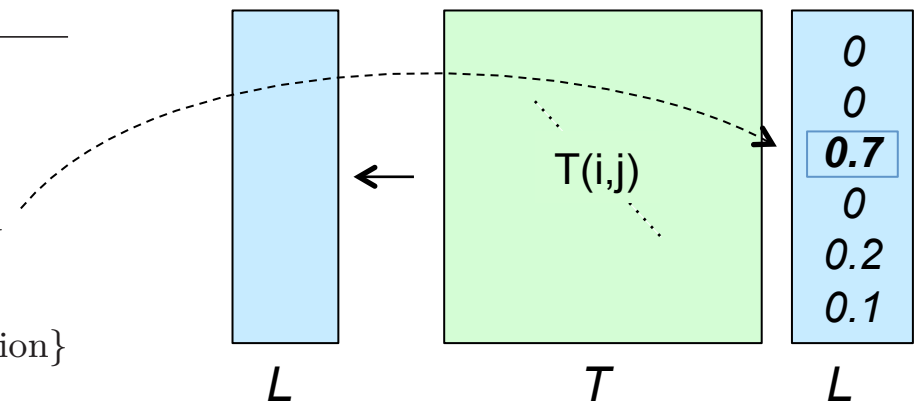
Dye Pumping details

- → Algorithm as proposed by Coskun et al. 2010
- → Compute transition matrix T

  T(i,j) = edge weight of (i,j) over weighted degree of i
- → Multiply iteratively with Dye level vector L
- → „Refresh“ dye level of the start node before each iteration

Algorithm 1 $Dye\_Pumping(\mathbf{E}, s, maxIter)$

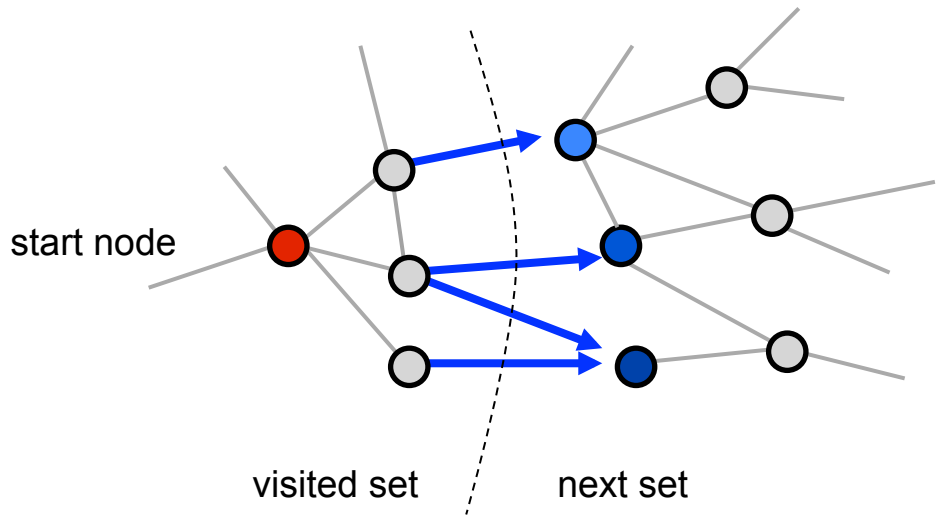
$\mathbf{T} \leftarrow computeTransitionMatrix(\mathbf{E})$
$\overline{\mathbf{T}} \leftarrow normalize(\mathbf{T})$
$L \leftarrow [0, 0, ..., 0]^{tr}$ {initialize L as a zero vector}
for $iter = 1$ to $maxIter$ **do**
  $L(s) \leftarrow L(s) + 1$ {Pump dye from the seed node}
  $L \leftarrow \frac{L}{\sum L(i)}$ {Normalize dye level vector}
  $L \leftarrow \overline{\mathbf{T}} L$ {Distribute dye in network for one iteration}
end for
output L



Alternative to dye pumping

→ **MCG Search**: breadth-first search (limited by depth or dye)

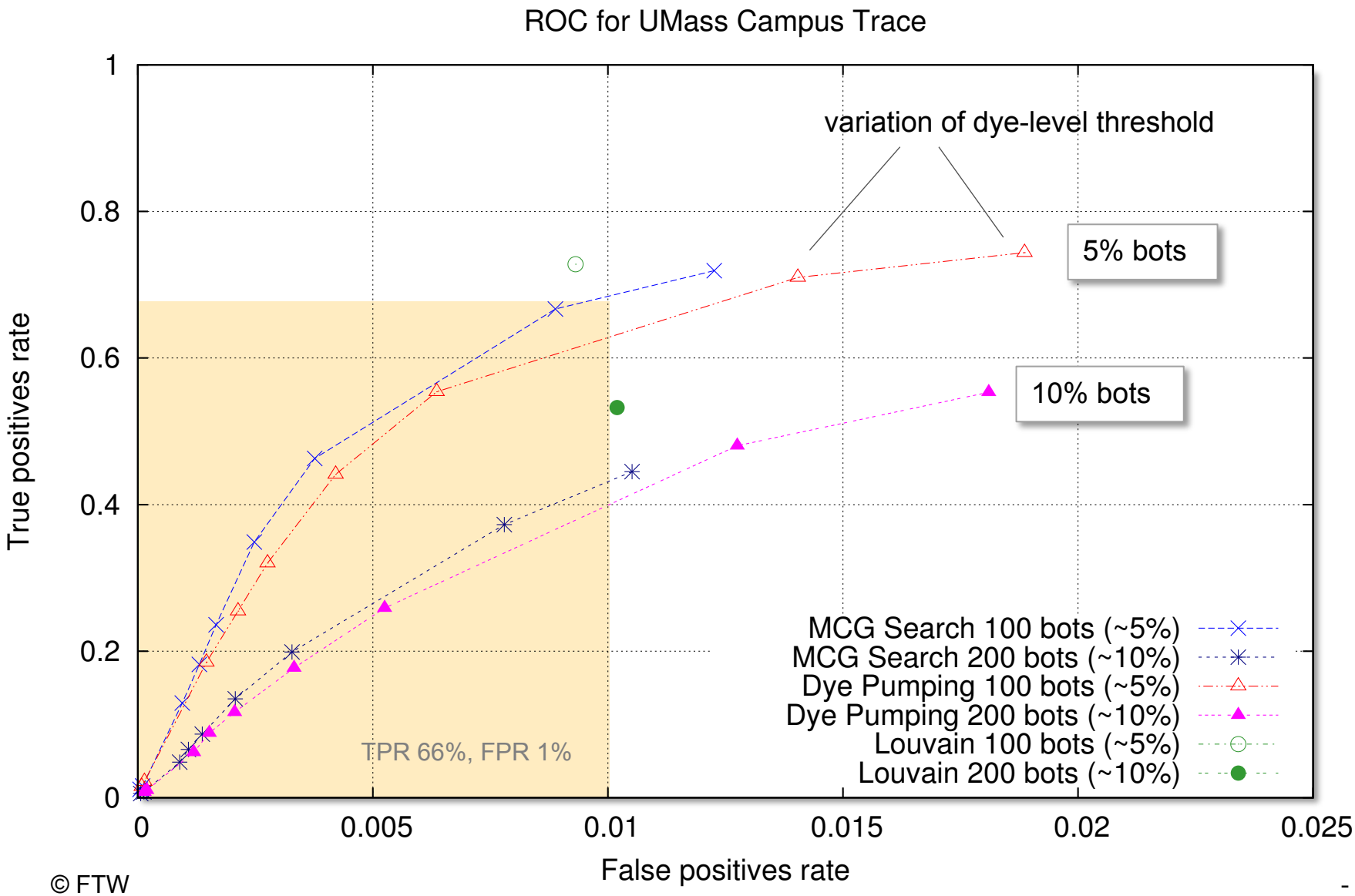
- each node in the visited set gives half of its dye
- this dye is spread to unvisited nodes according to edge weight.



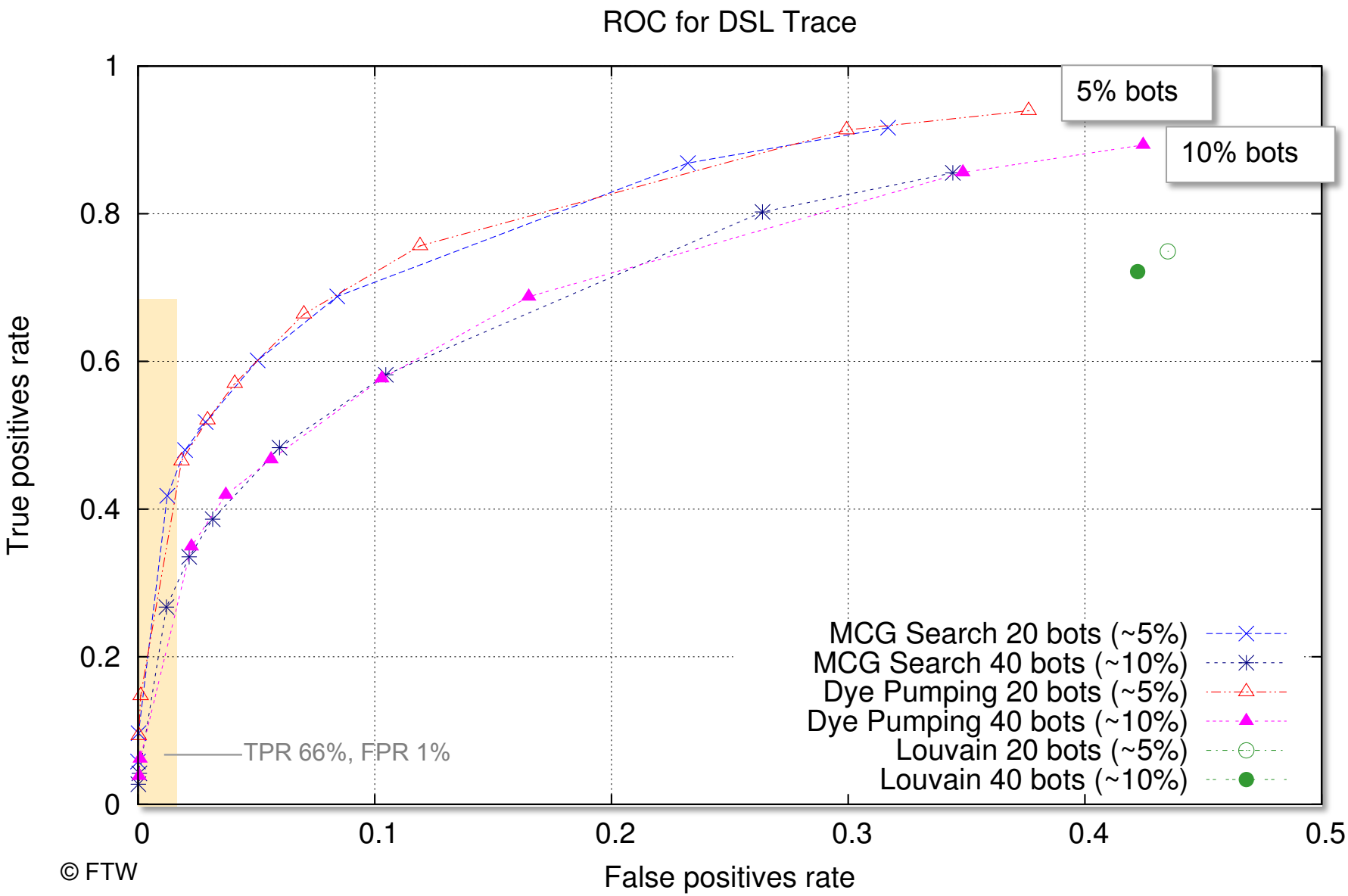
→ Similar detection rate to Dye Pumping

→ Saving matrix multiplications gives significant speed-up.

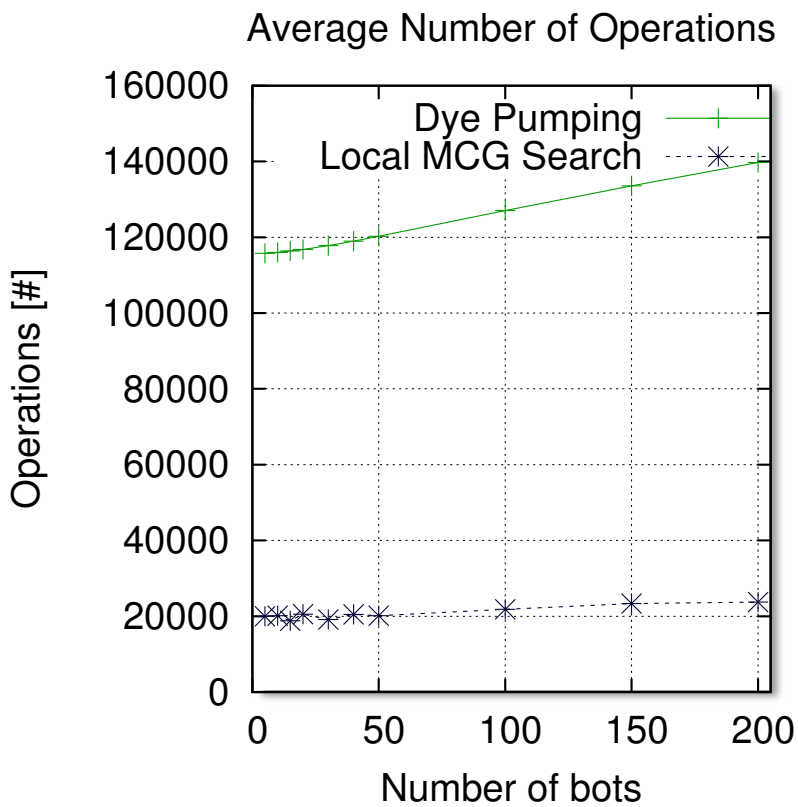
Results for campus network

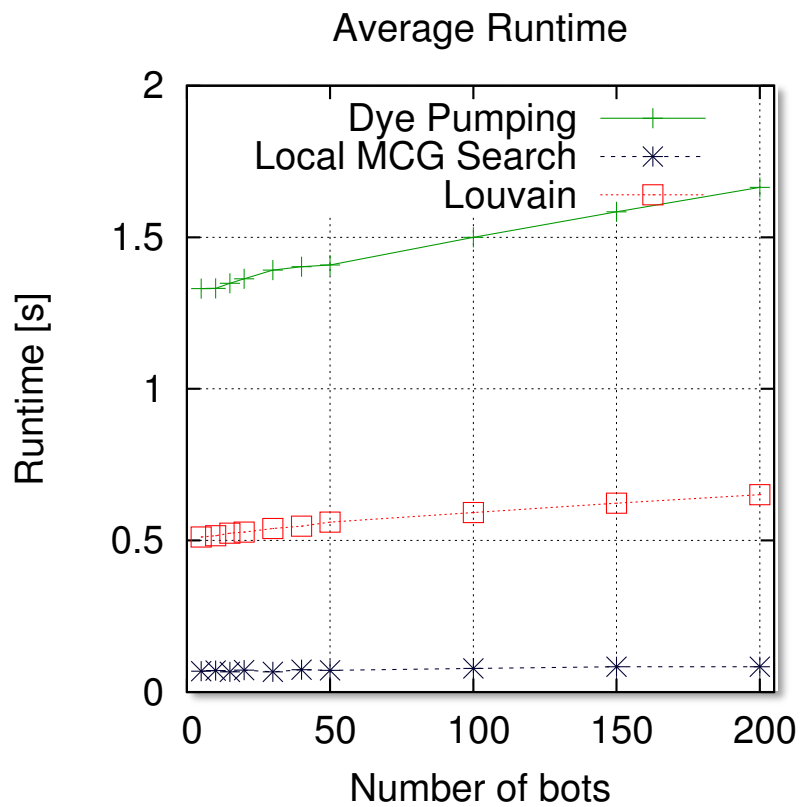


Results for DSL network



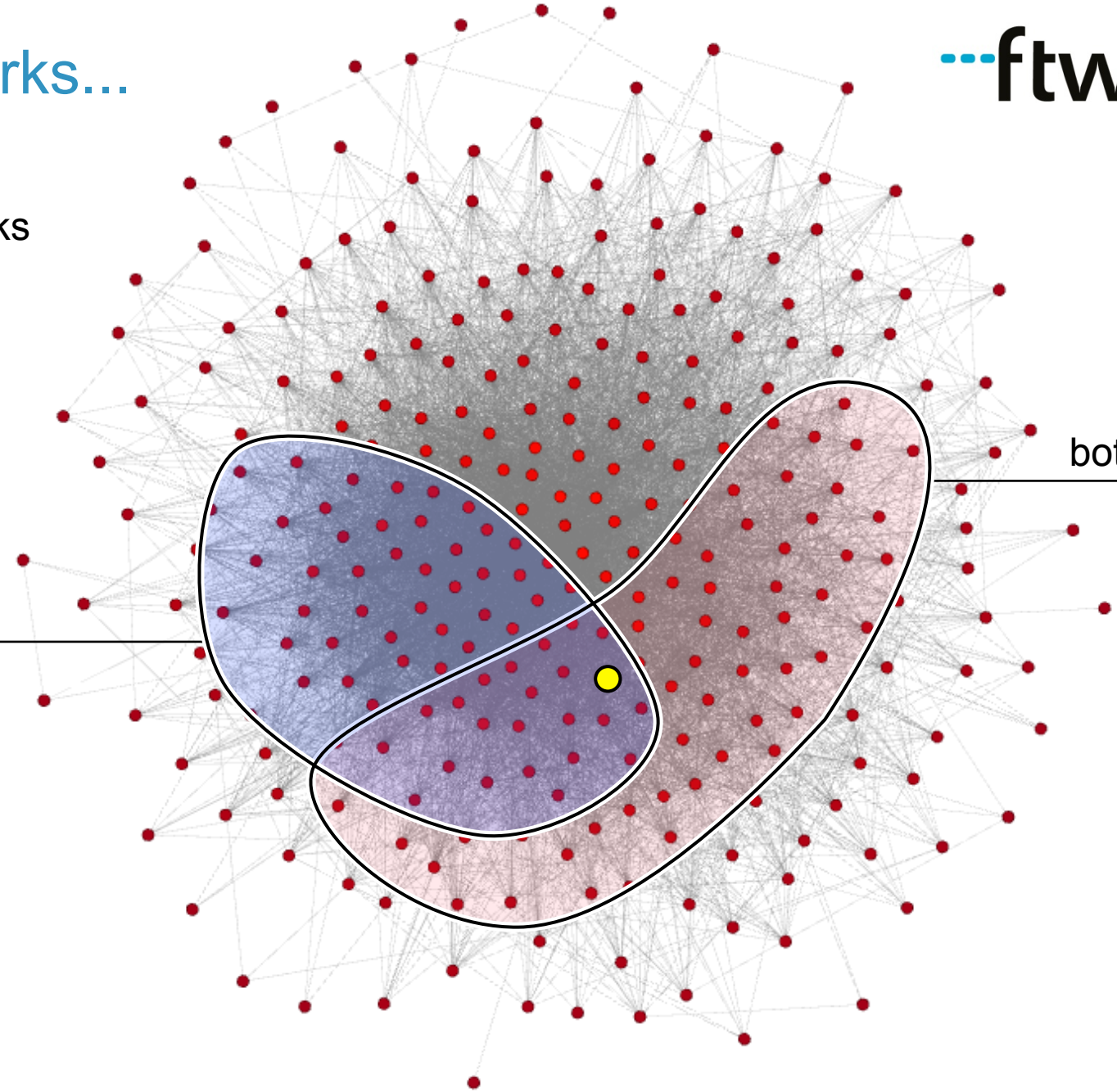
Runtime comparison





Some remarks...

on the impact of
other P2P networks



Conclusion and open questions

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→ Structured P2P networks form densely connected topologies

→ They can be found in Traffic Dispersion Graphs (TDG)
- Only IP contacts needed (works also for encrypted c&c traffic)
- Problem: nodes participate in botnet *and* legitimate communication

→ P2P networks with high interconnectivity can be separated
- Performance depends on background traffic
- Experiments: Local heuristics better than targeting high degree, page rank, ...

→ Network graph analysis on its own cannot detect botnets
- but help to identify further bots, if some infected hosts are known

Thank you very much!

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