Up-and-Down Routing in Mobile Opportunistic Social Networks with Bloom-Filter-Based Hints

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Introduction

Mobile opportunistic social networks (MOSN)

- Opportunistic contacts
- Intermittent connectivity
- Instantaneous end-to-end paths may not exist

A scenario

- People walk around with phones that communicate with each other via Bluetooth or WiFi

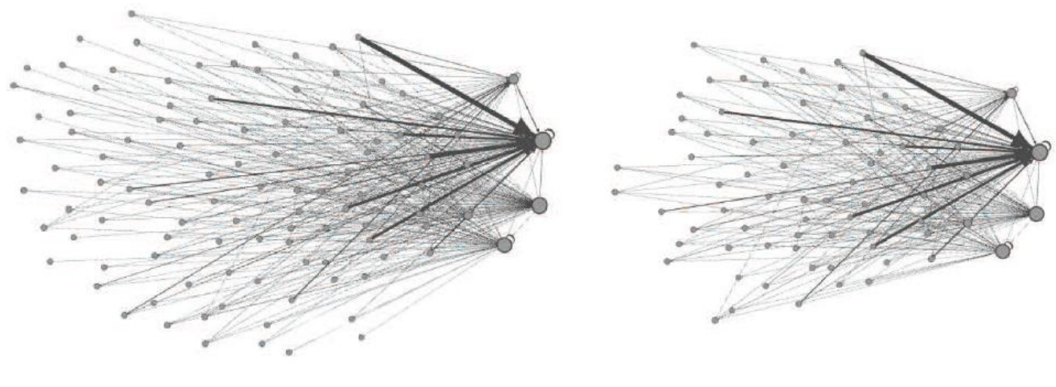
Introduction

Contact and state information

- Contact information
  - local, but large volume (per node vs. per destination)
- State information
  - costly due to the iterative process

Network structure information of MOSNs

- Nested core-periphery structures (nested hierarchy)
- MIT trace

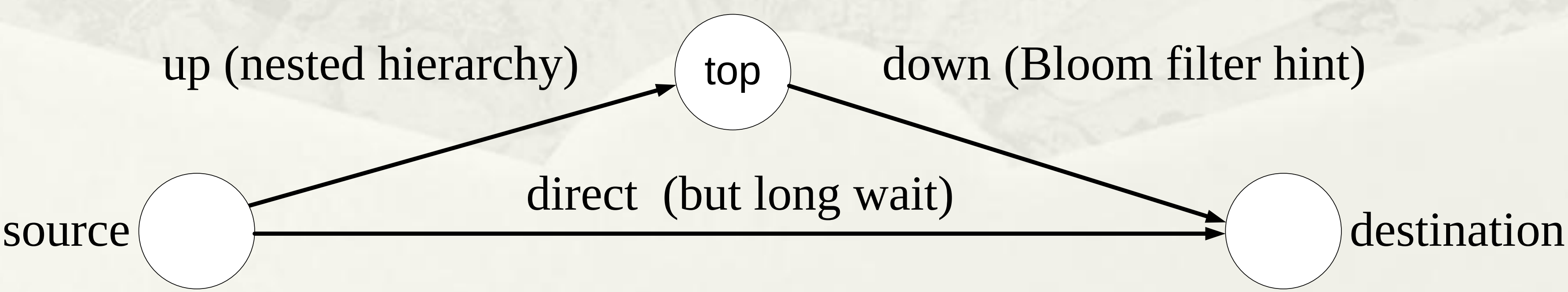


(a) Complete trace. (b) 30% removed.

Introduction

Up-and-down routing based on nested hierarchy: per node contact with limited state information

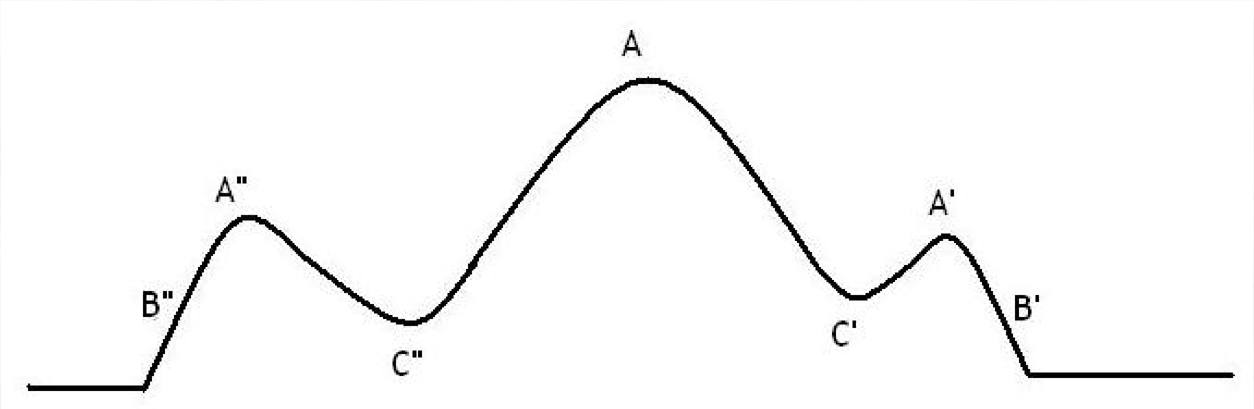
- Up phase
  - Single-copy routing from source to network core
  - Nested hierarchy
- Down phase
  - Multi-copy routing from network core to destination
  - Bloom filter as the routing hint



Introduction

Challenges for traditional hierarchical routings

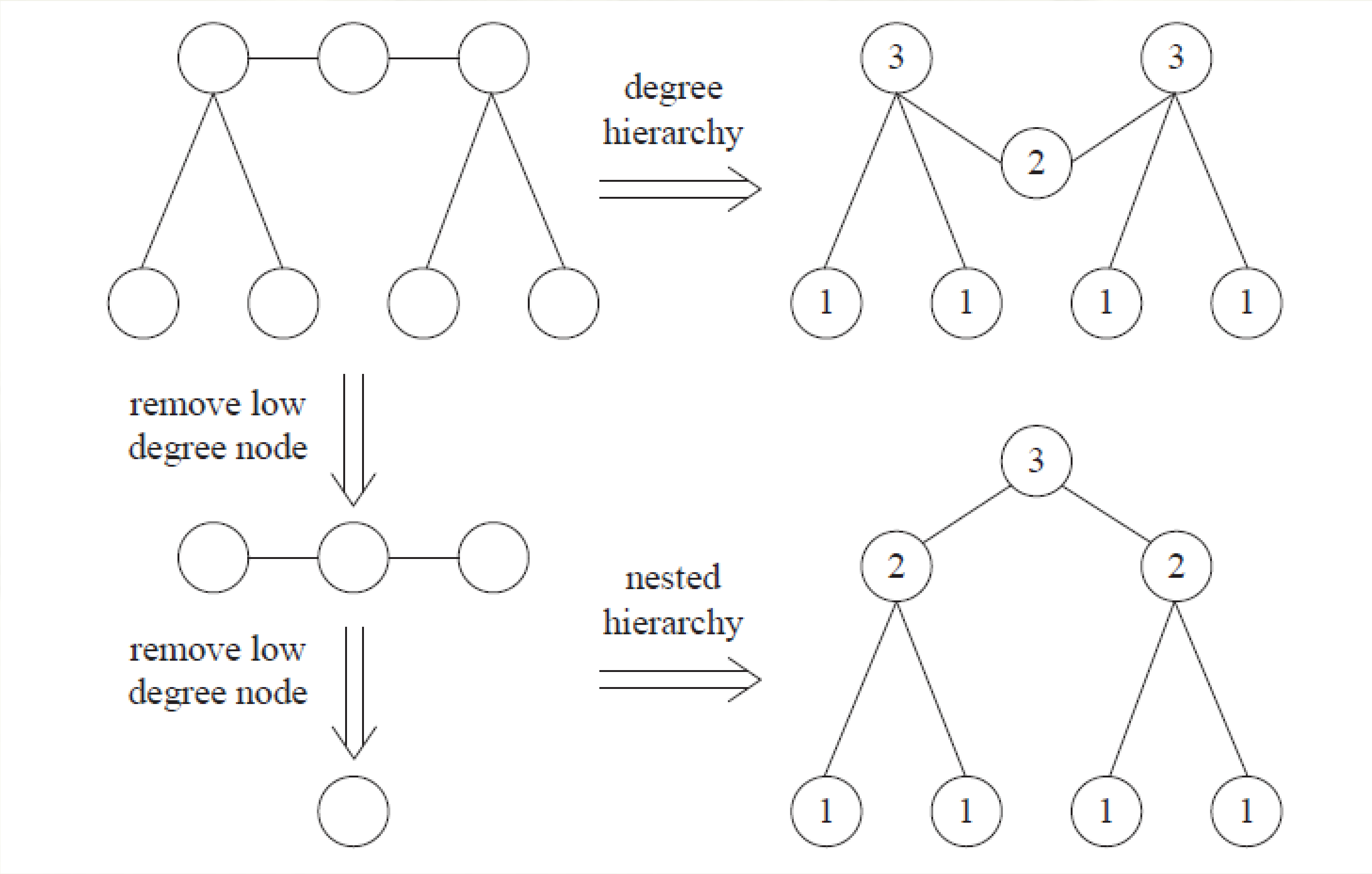
- Trap in local maximums when moving up



- Cannot find the down path efficiently
  - High storage space for descendants: each node tracks its child nodes and their child nodes.

Up Phase

Degree hierarchy vs. nested hierarchy



Local Maximum

Local maximums in real dataset

(Stanford Large Network Dataset Collection)

AS-733 (autonomous system dataset)

- 6,747 nodes
- 1 local maximum in nested hierarchy (17 levels)
- 8 local maximums in degree hierarchy

p2p-Gnutella08 (Gnutella peer-to-peer network)

- 20,777 nodes
- 3 local maximums in nested hierarchy (20 levels)
- 76 local maximums in degree hierarchy

Nested hierarchy has fewer local maximums!

Local Maximum

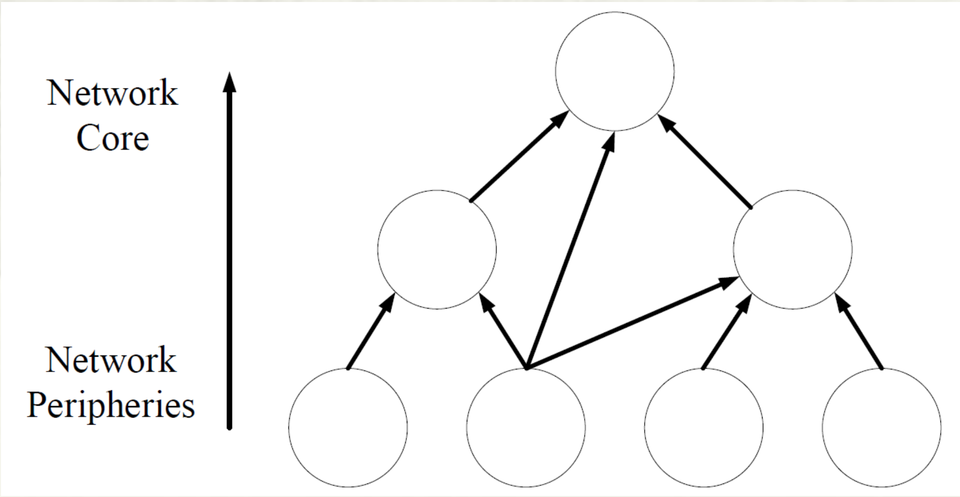
CRAWDAD Trace	The Fraction of Contacts Hold by The Most-active 20% Nodes	Total Number of of Root Nodes
Cambridge/Haggle/Imote/Intel	30.72%	1 node
Cambridge/Haggle/Imote/Cambridge	51.27%	1 node
Cambridge/Haggle/Imote/Infocom	29.83%	1 node
Thlab/Sigcomm2009/Mobiclique/Proximity	43.64%	1 node
ST_Andrews/Sassy/Mobile	55.14%	1 node

Up Phase

- Weighted degree of a node: sum of weights of adjacent links (total contact frequency)
- Effective weighted degree of a node: weighted degree to unlabeled neighbors
- Labeling scheme for nested hierarchy
  - A node labels itself when it has the lowest effective weighted degree among unlabeled neighbors
  - The label is set to be the largest label among its labeled neighbors plus one

Up Phase

- The message is routed towards the root along a DAG
- Single-copy routing to save the forwarding cost
- Switch to the down phase, when first reaching a node that matches (in Bloom filter)

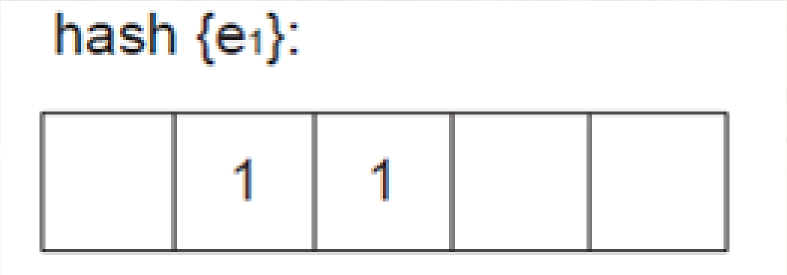


Down Phase

- Each node uses the Bloom-filter-based routing hint to record its descendants
- Existence of false positive (i.e., a false match)
- The size of Bloom-filter-based routing hint being bounded based on a given false positive rate

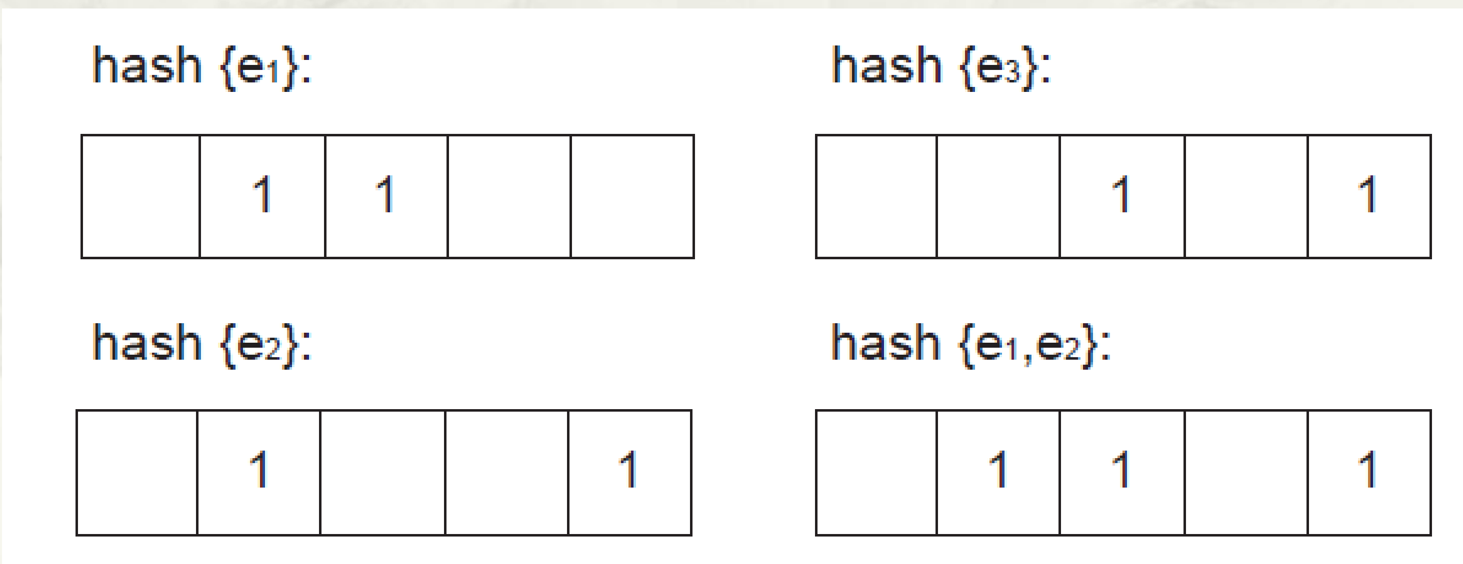
Bloom Filters

- Used to test whether an element is a member of a set or not
- A Bloom filter is a bit array of m bits
- k hash functions are used to map an element
- An example (m=5, k=2) of mapping element e_1

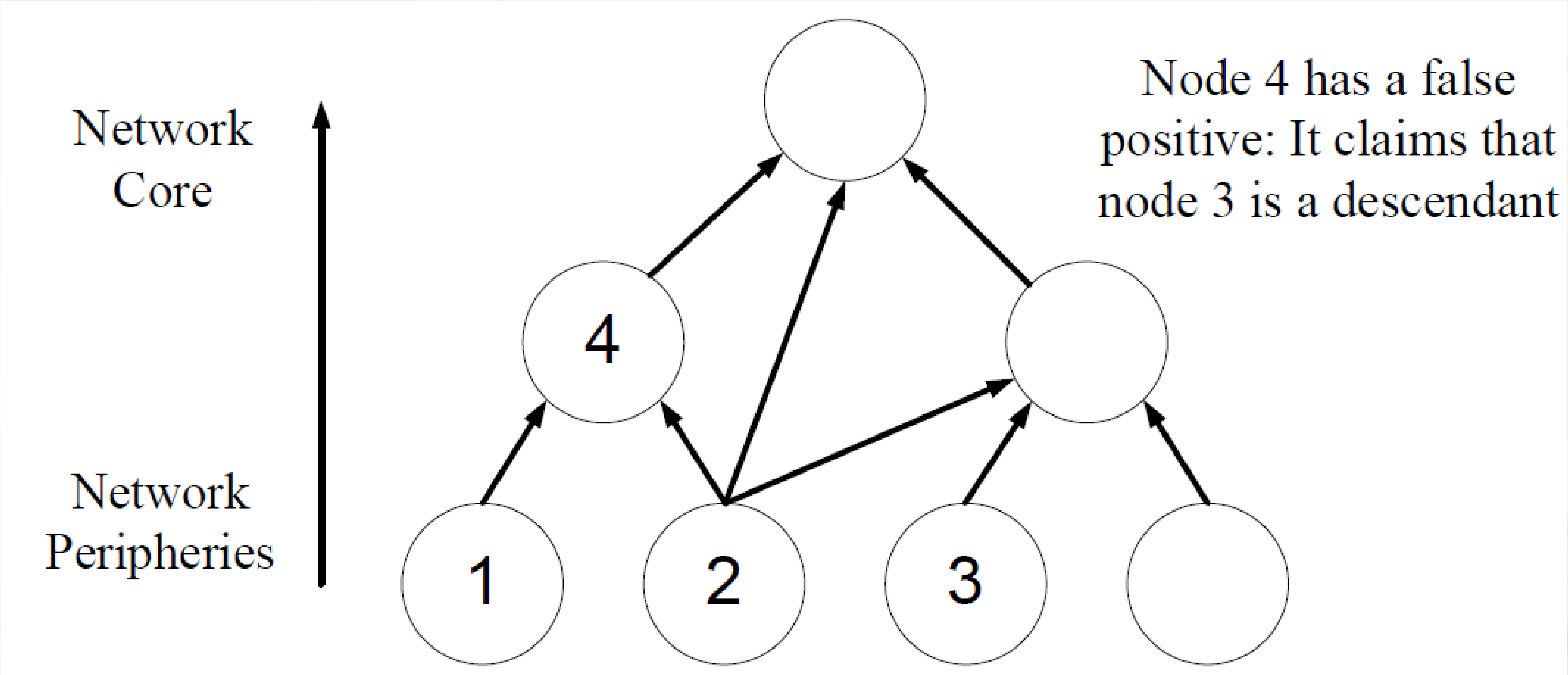


Bloom Filters

- Space-efficient at the cost of false positives
- An example of false positive for e_3 in $\{e_1, e_2\}$



False Positive



False positive rate reduces as the level goes up: all child nodes have false positives

Multi-Copy

- Multi-copy routing serving two objectives
  - Improving delivery ratio by mitigating false positive
  - Reducing down phase delay
- Distributing multiple copies
  - Binary split of copies whenever there is a match
- Bloom filter robustness ratio
  - Ratio of Bloom filter size to number of descendants $d(\alpha-1)^{d-2}$ (α: network parameter, d: node degree)
  - Keeping robustness level constant at each level

Evaluation Setting

Traces

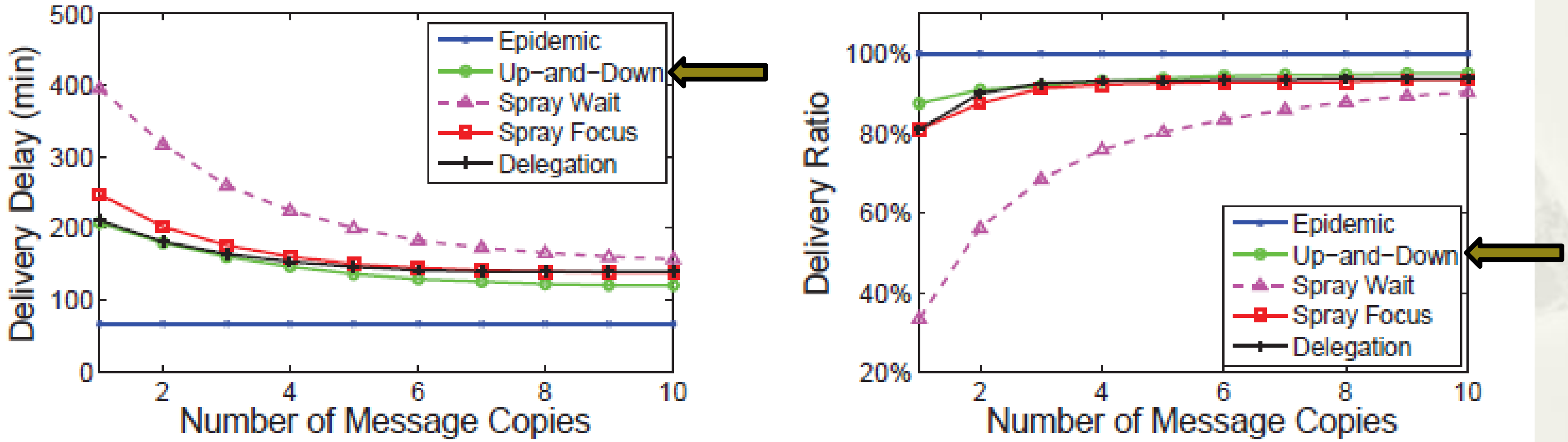
- Sigcomm trace (76 nodes with α=2.5)
- Synthetic trace (100 nodes with average d=10, by Barabasi-Albert's preferential attachment with α=2.1, edge weights: 0-0.1)

Algorithms in comparison

- Epidemic (no contact info. with unlimited copies)
- (Binary) Spray and Wait (contact info. per dest.)
- (Binary) Spray and Focus (contact info. per dest.)
- (Modified) Delegation Forwarding (info. per dest. with bounded copies)

Sigcomm Trace

- Data delivery delay and ratio
  - deadline: 500 mins
  - no delivery: deadline as delay

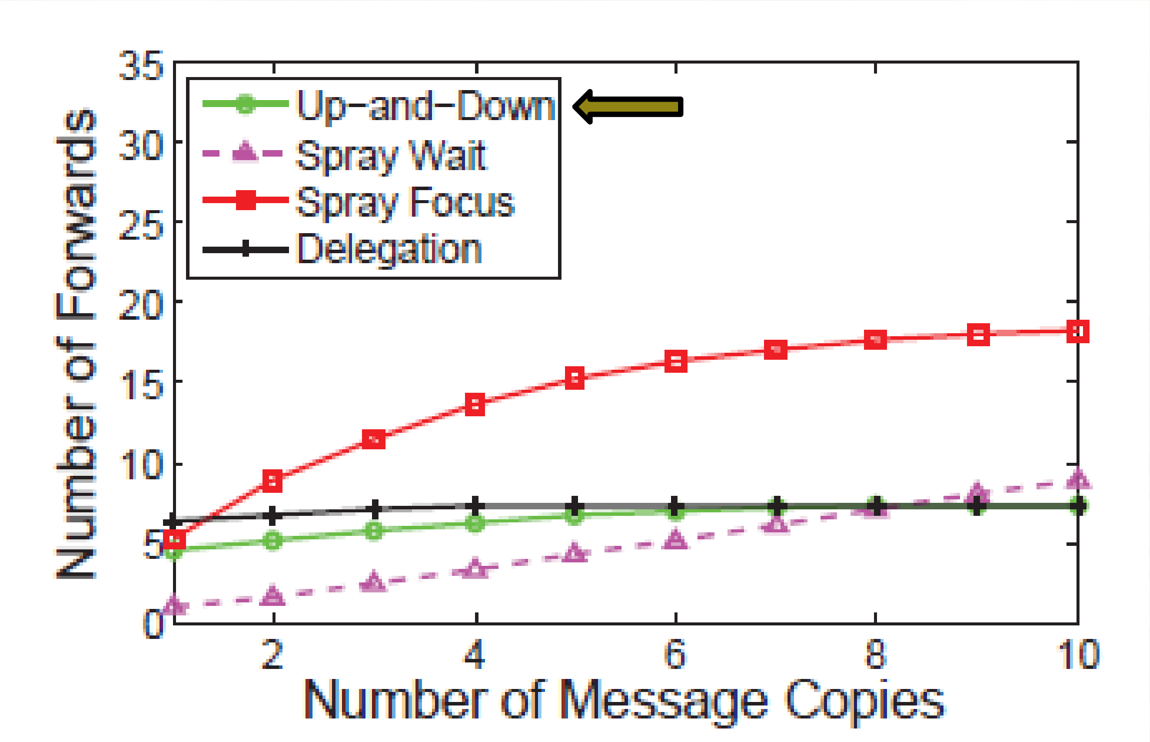


(a) Data Delivery Delay

(b) Data Delivery Ratio

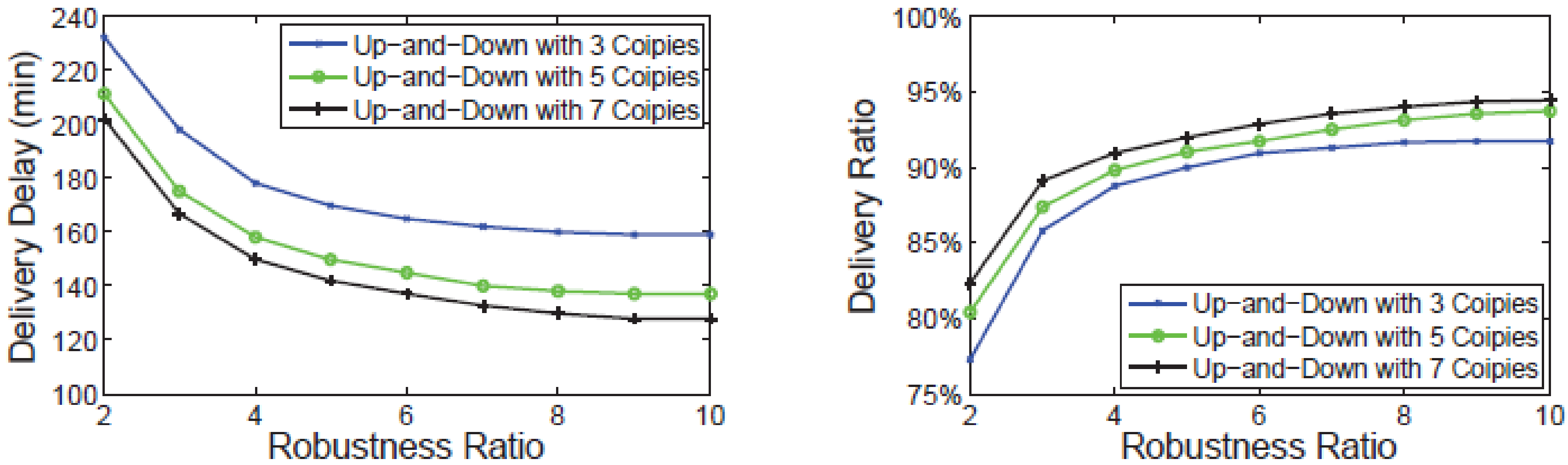
Sigcomm Trace

- Number of forwards



Sigcomm Trace

- Robustness ratio



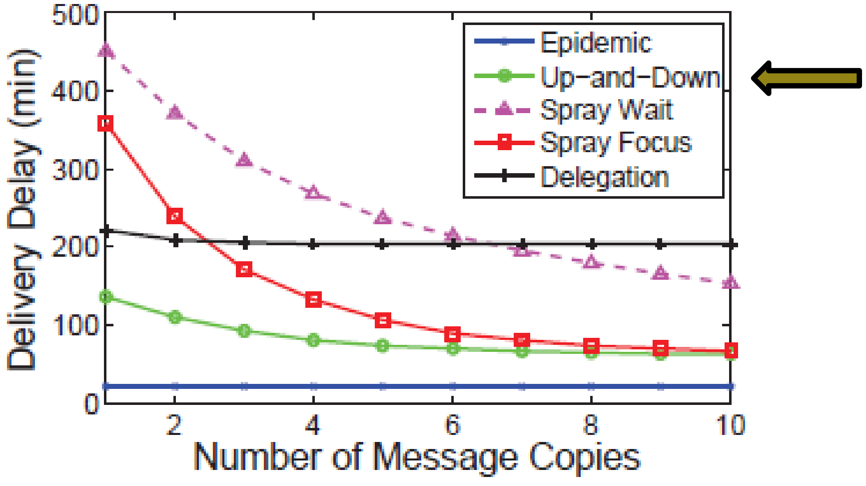
(g) Robustness of Delivery Delay

(h) Robustness of Delivery Ratio

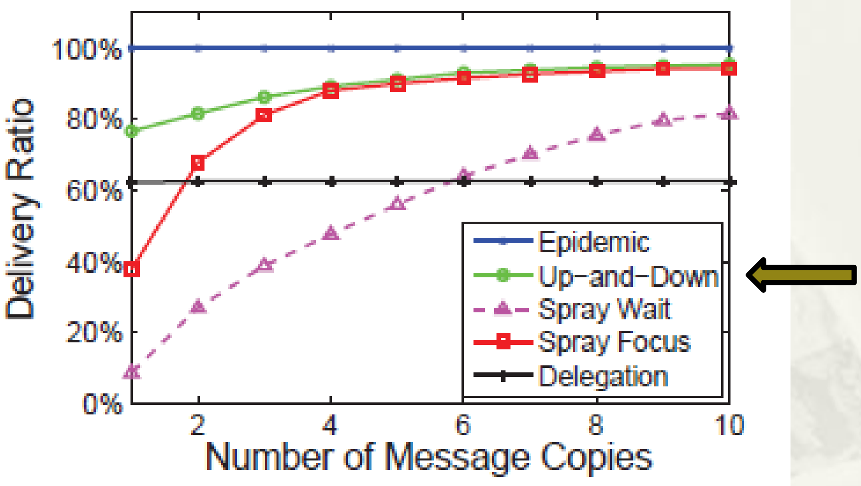
Overall false positive rate: 38%, 28%, 17%, 10%, 06%, 03%, 02%, 01%, 0.7%
Storage saving percentage: 81%, 72%, 62%, 53%, 44%, 31%, 21%, 10%, 0%

Synthetic Trace

- Data delivery delay and ratio



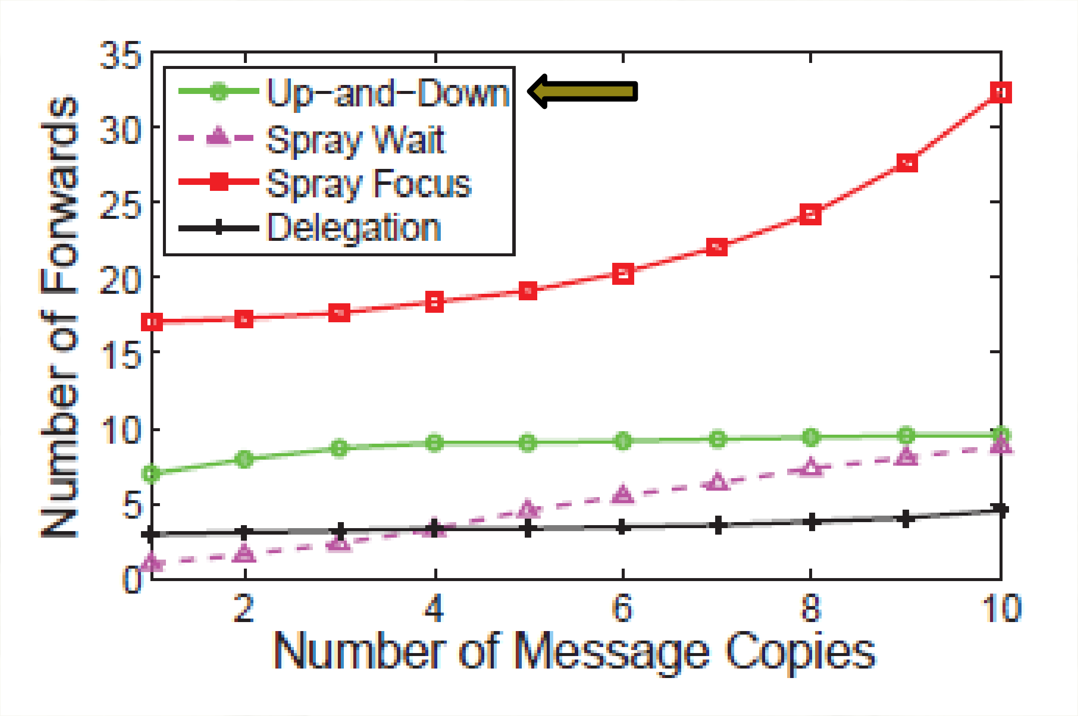
(a) Data Delivery Delay



(b) Data Delivery Ratio

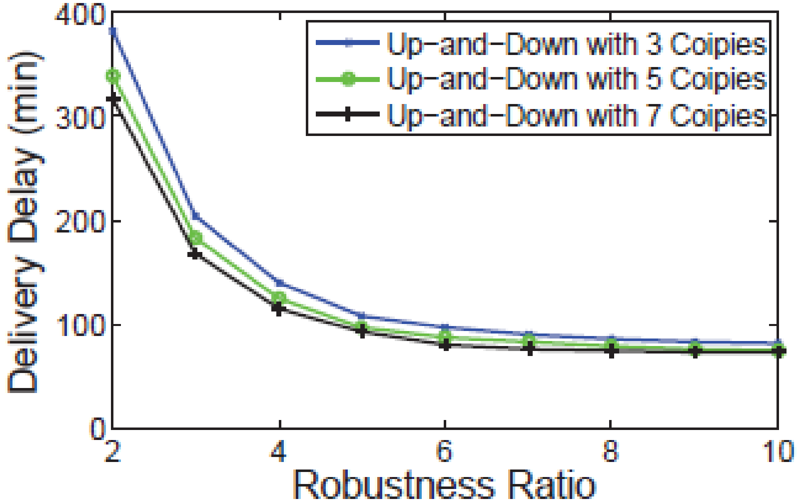
Synthetic Trace

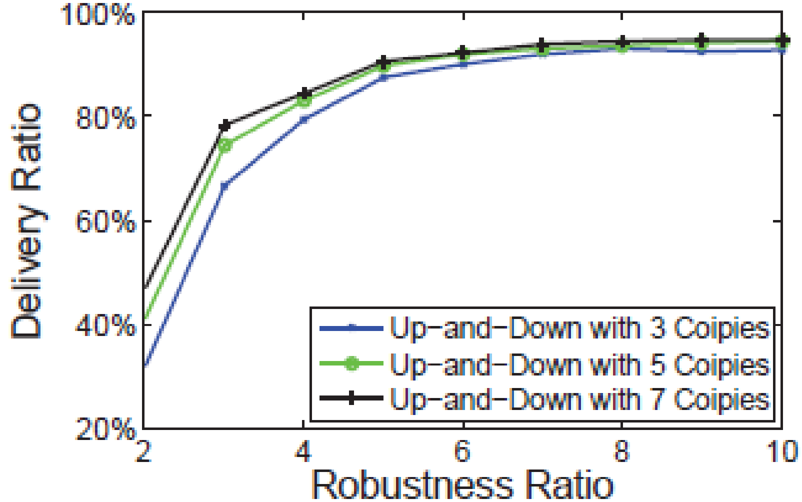
- Number of forwards



Synthetic Trace

- Robustness ratio





Overall false positive rate: 39%, 24%, 15%, 09%, 06%, 04%, 02%, 01%, 0.8%
Storage saving percentage: 83%, 74%, 65%, 57%, 48%, 39%, 30%, 22%, 13%

Evaluation Summary

- A competitive performance on the data delivery delay and ratio
- Real vs. synthetic traces
  - Real: clustering with more parallel paths
  - Synthetic: multi-hop with fewer parallel paths
- A small diameter does not guarantee a short delay!

Conclusions

Up-and-down routing

- Single-copy up phase and multi-copy down phase
- Nested core-periphery property (nested hierarchy)

Future work

- Bound the number of copies in the down phase
- Coarse grain level
- Deal with multiple local maximums