Gossip protocols for large-scale distributed systems

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Gossip definition

- **In a recent workshop on the future of gossip**
  - many attempts to formally define gossip
  - we failed!
    - either too broad
    - or too strict
- **Gossip best described with a prototypical gossip scheme**
  - "I cannot define gossip, but I can recognize it when I see it"

A generic gossip protocol - executed by process p

Init: initialize my local *state*

Active thread

do once every δ time units

q = getPeer(*state*)

s_p = prepareMsg(*state*, q)

send (REQ, s_p, p) **to** q

A "cycle" of length δ

Passive thread

do forever

receive (t, s_q, q) **from** *

if (t = REQ) **then**

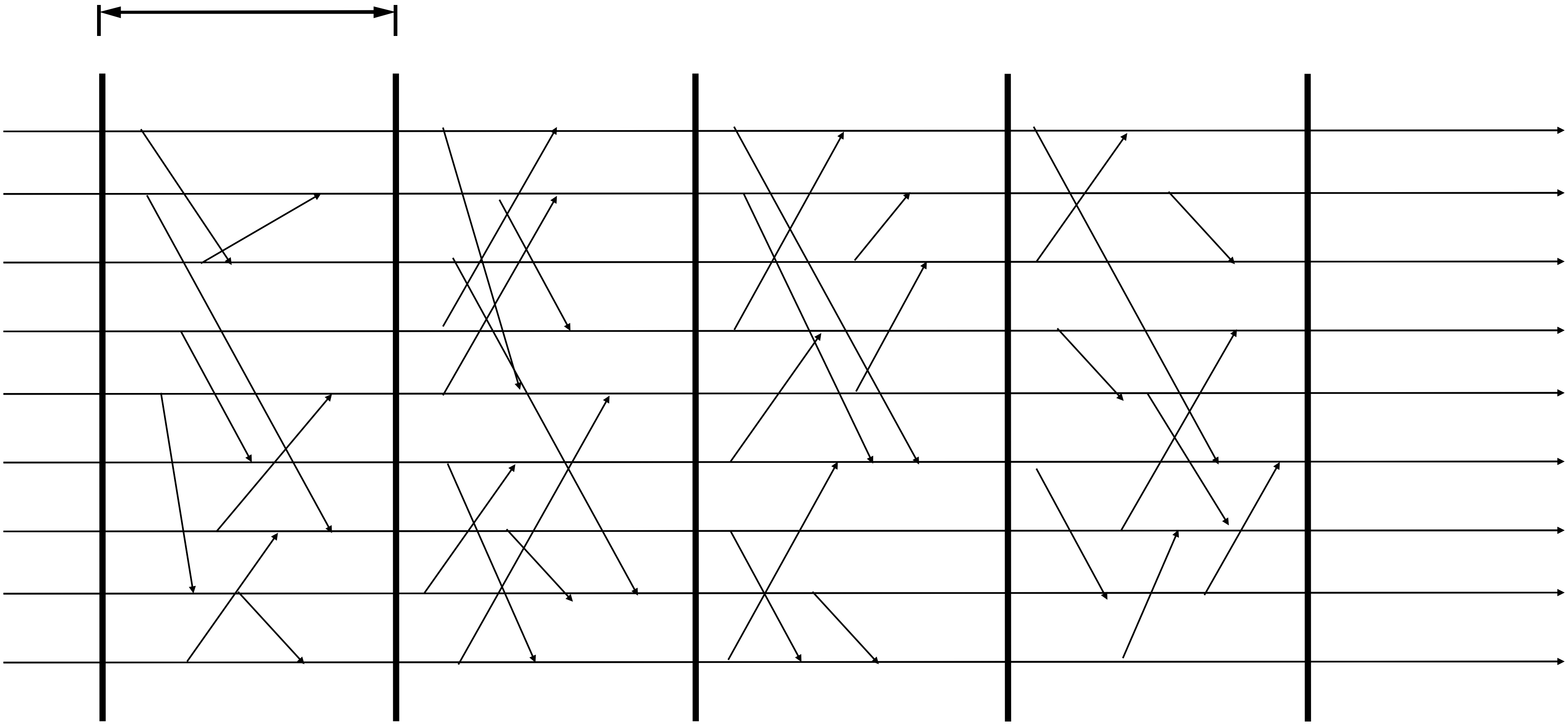
s_p = prepareMsg(*state*, q)

send (REP, s_p, p) **to** q

state = update(*state*, s_q)

Epidemic cycle

- **During a cycle of length δ, every node has the possibility of contacting one random node**



A generic gossip protocol

- **Generic scheme is... too generic!**
- **Gossip “rules of thumb”**
  - peer selection must be random, or at least guarantee enough *peer diversity*
  - only *local* information is available at all nodes
  - communication is *round-based* (periodic)
  - transmission and processing capacity per round is *limited*
  - all nodes run the *same* protocol

A bit of history

- **1987**
  - Demers et al. introduced the first gossip protocol, for information dissemination
- **'90s**
  - Gossip applied to solve communication problems
- **'00s**
  - Gossip revival: beyond dissemination
- **2006**
  - First workshop on the future of gossip, Leiden (NL)

What is going on?

- **In the last decade, we have seen dramatic changes in the distributed system area**
- **Shift in the scale of distributed systems**
  - larger
  - geographically more dispersed
- **Traditional failure model do not hold any more**
  - "let $p_1 \dots p_n$ be a set of processes..."
  - $f < 3n+1$, $f<n/2$ anyone?
  - dynamic membership: "churn"

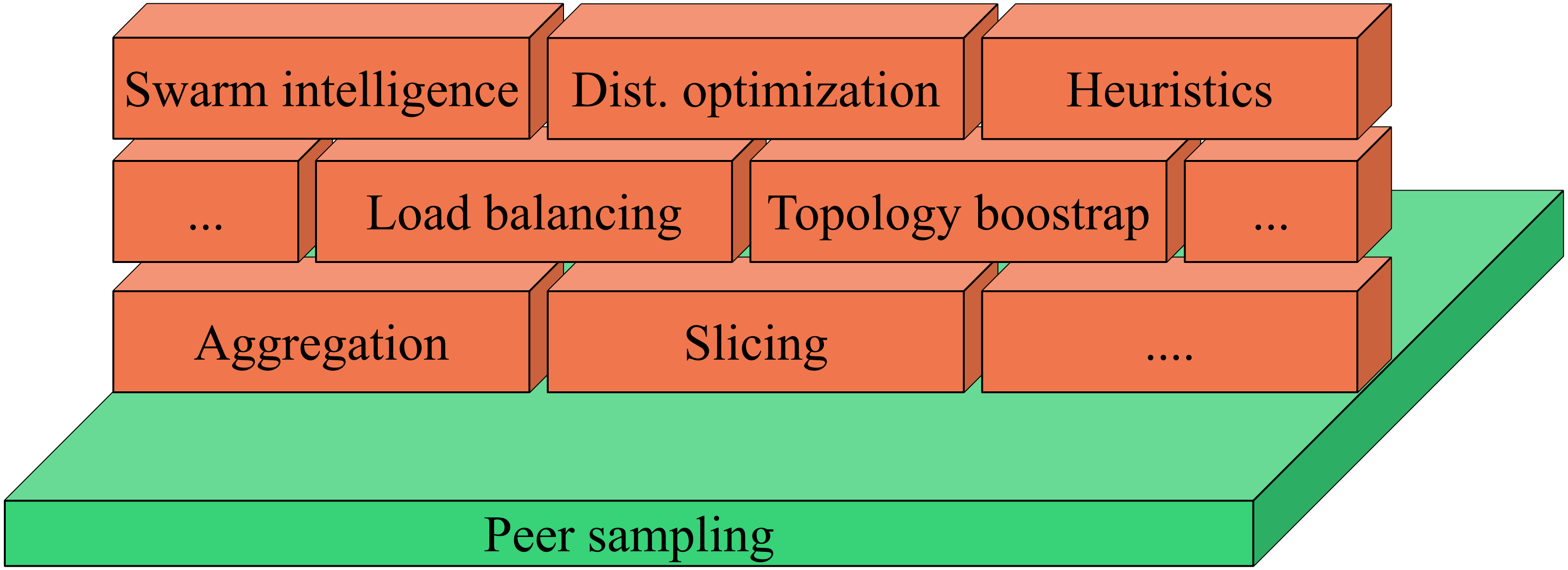
What is going on?

- **We need to re-think our solutions**
  - Focus on behavior under continuous change
  - Focus on large-scale
  - Focus on convergence, maintenance
- **The laid-back approach of gossip is the right answer**
  - gossip protocols are indifferent to changes in the group of communicating nodes, single nodes are not important
  - nodes act based on local knowledge, they are only aware of a small (constant/ logarithmic size) portion of the global state
  - convergence is quick (often logarithmic in size)

The plan

- **Introduce gossip ✓**
- **Let's start from the beginning**
  - Information dissemination
- **Beyond dissemination**
  - Peer sampling
  - Aggregation
    - Average computation
    - Size estimation
  - Topology management
  - Slicing
  - ....

- Gossip solves a diverse collection of problems
- Solutions can be combined to solve more complex problems
- Toward Gossip Lego?



- **Bibliography**

  - Alan Demers et al. *Epidemic algorithms for replicated database maintenance*. In Proc. of the 6th ACM Symposium on Principles of Distributed Computing (PODC'87), 1–12, ACM Press.

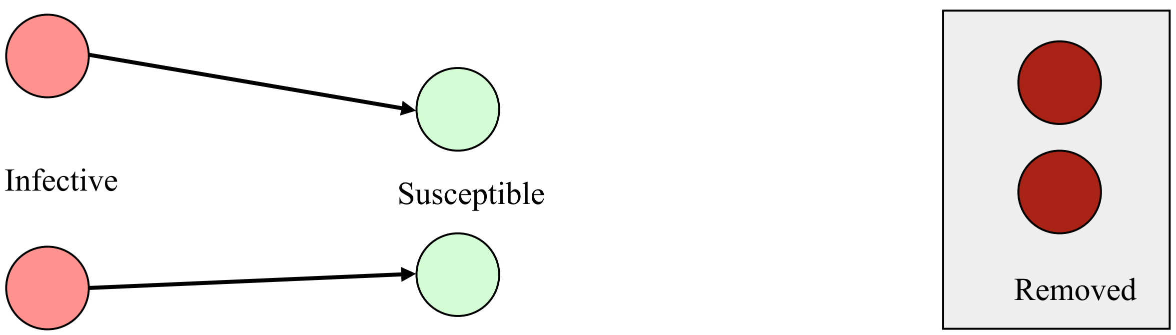
Setting the stage

- **XEROX Clearinghouse Servers**
  - Database replicated at *thousands of nodes*
  - Heterogeneous, *unreliable* network
  - *Independent* updates to single elements of the DB are injected at multiple nodes
  - Updates must propagate to all other nodes or be supplanted by a later updates of that same element
  - Replicas become consistent after no more new updates
  - Assuming a reasonable update rate, most information at any given replica is “current”

Model of epidemics

- ***Epidemics*** **study the spread of a disease or infection in terms of populations of infected/uninfected individuals and their rates of change**

- **Following the epidemiology literature, we will name a node *p* as:**
  - ***Susceptible*** if *p* has not yet received an update
  - ***Infective*** if *p* holds an update it is willing to share
  - ***Removed*** if *p* has the update but is no longer willing to share it



Model of epidemics

- **How does it work?**
  - Initially, a single individual is infective
  - Individuals get in touch with each other, spreading the update
- **Rumor spreading, or gossiping, is based on the same principles**
- **Can we apply the same ideas to distributed systems?**
  - Our goal is to spread the “infection” (update) as fast as possible!

System model

- **A database that is replicated at a set of *n* nodes $S = \{ s_1, \ldots, s_n \}$**
- **The copy of the database at node *s* can be represented by a time-varying partial function:**
  - $s.value: K \rightarrow V \times T$
    - K set of keys
    - V set of values
    - T set of timestamps
- **In the following slides**
  - We will omit the key and we will consider only a single key,value pair

System model

- **For simplicity we will assume a database that stores value and timestamp of a single entry at each node s**
  - $s.value = (v, t)$
- **To indicate a deletion at time *t***
  - $s.value = (\textbf{deleted}, t)$
- **The update operation is formalized as**
  - $s.value \leftarrow (v, now())$
  - It is assumed by this work that *now()* is a function returning a globally unique timestamp (no details)
- **So, a pair with a larger timestamp is considered "newer"**

The goal

When a database is replicated at many sites, maintaining consistency in the presence of updates is a significant problem.

Eventual Consistency: If no updates take place for a long time, all replicas will gradually become consistent (i.e., the same)

$$\forall r,s \in S : r.value = s.value$$

Several algorithms for distributing updates

- **Best effort**
- **Anti-entropy (simple epidemics)**
  - Push
  - Pull
  - Push-pull
- **Rumor mongering (complex epidemics)**
  - Push
  - Pull
  - Push-pull
- **Eager epidemic dissemination**

Best effort (Direct mail)

- **How it works?**
  - Notify *all* other nodes of an update soon after it occurs.
  - When receiving an update, check if it is “news”

- **Node *s* executes:**

upon *s.value* ← *(v, now())* **do**
  foreach $r \in S$ **do**
    send <UPDATE, s.value> **to** *r*

upon receive <UPDATE, (v, t)> **do**
  if *s.value.time* < *t* **then**
    s.value ← *(v, t)*

- **Not an epidemic algorithm: just the simplest**
  - What happens if the sender fail “in between”?
  - What happens if messages are lost?
  - What is the load of the sender?

Init: initialize my local *state*

Active thread

do once every δ time units

q = getPeer(*state*)

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if (t = REQ) **then**

s_p = prepareMsg(*state*, q)

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state = update(*state*, s_q)

Anti-entropy - Simple epidemics

- **With respect to a single update (identified by its timestamp), all nodes are either**
  - *susceptible* (they don't know the update), or
  - *infective* (they know the update)
- **Every node regularly chooses another node at random and exchanges database contents, resolving differences**
  - Method *getPeer*()
    - Select a random member from *S-{p}*
  - Method *prepareMsg*()
    - Simple version: **return** *s.value*
    - In most cases: prepare a digest of new updates
  - Method *update*()
    - Simple version: see next page
    - In most cases: ask for other data

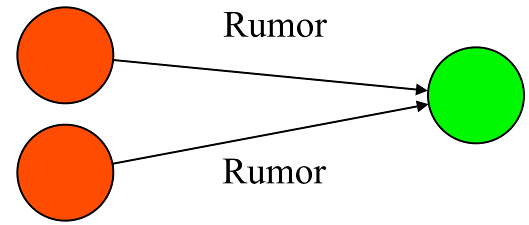
Implementation of *update*()

Susceptible node
Infective node

- **Push**

  if $p.value.time > r.value.time$ **then**

  $r.value \leftarrow p.value$



- **Pull**

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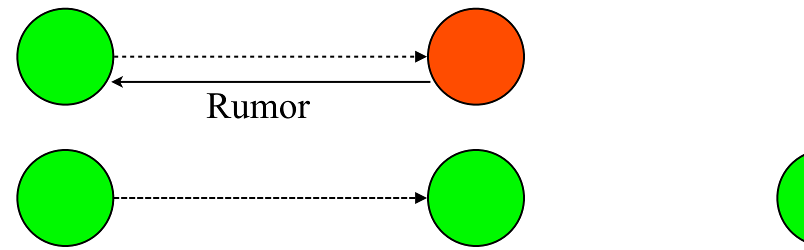


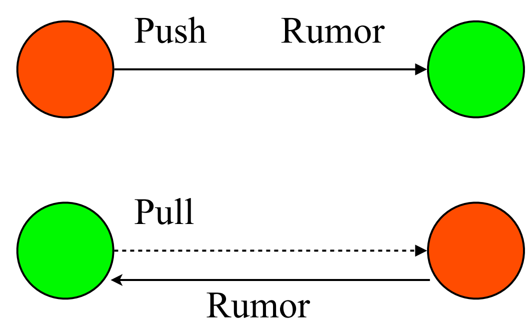
- **Push-pull**

  if $p.value.time > r.value.time$ **then**

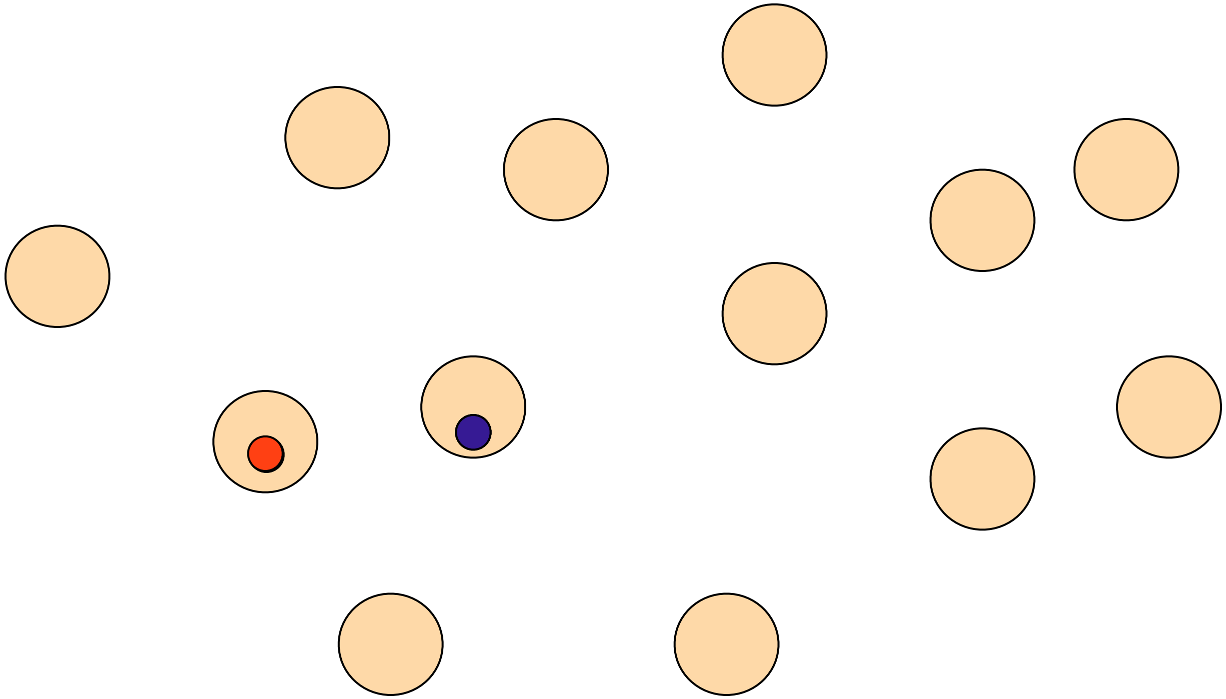
  $r.value \leftarrow p.value$

  else

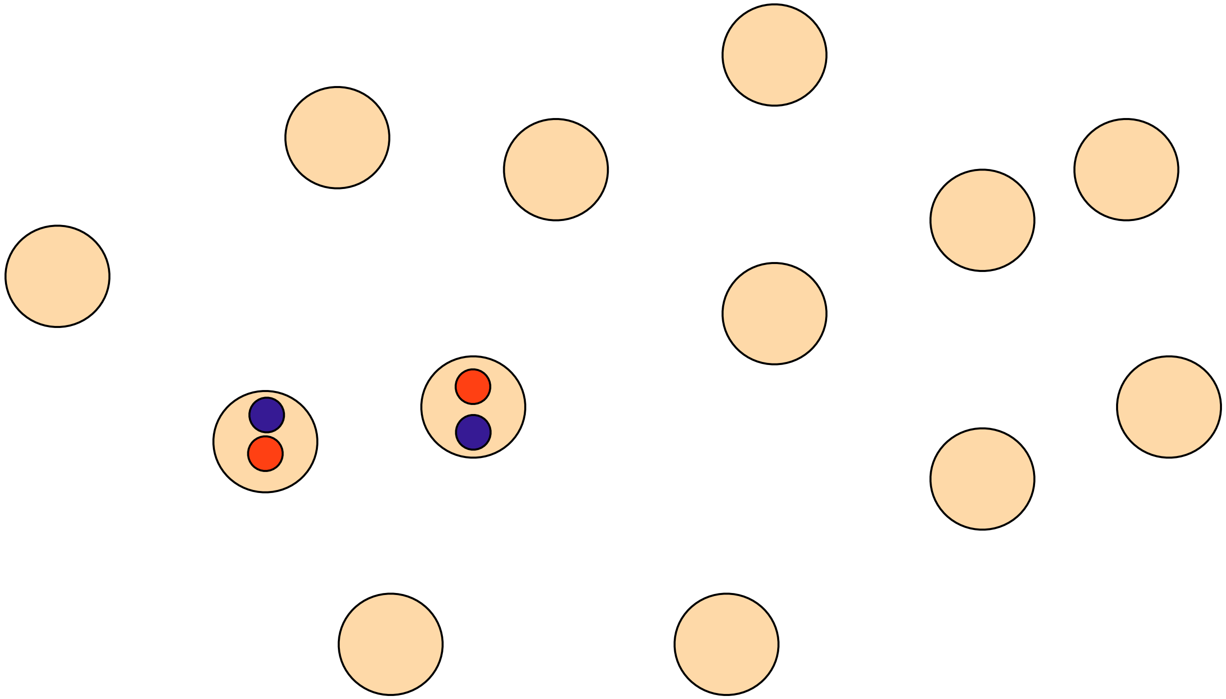
  $p.value \leftarrow r.value$



Anti-entropy



Anti-entropy



Anty-entropy: Convergence

Anty-entropy: Convergence

- **To analyze convergence, we must consider what happens when only a few nodes remain susceptible**
  - Let *p(i)* be *the probability of a node being (remaining) susceptible after the i-th anti-entropy cycle*.
    - *Pull*:

Anty-entropy: Convergence

- **To analyze convergence, we must consider what happens when only a few nodes remain susceptible**
  - Let $p(i)$ be *the probability of a node being (remaining) susceptible after the i-th anti-entropy cycle*.
    - *Pull*:
      - $p(i+1) = p(i)^2$
    - *Push*:

Anty-entropy: Convergence

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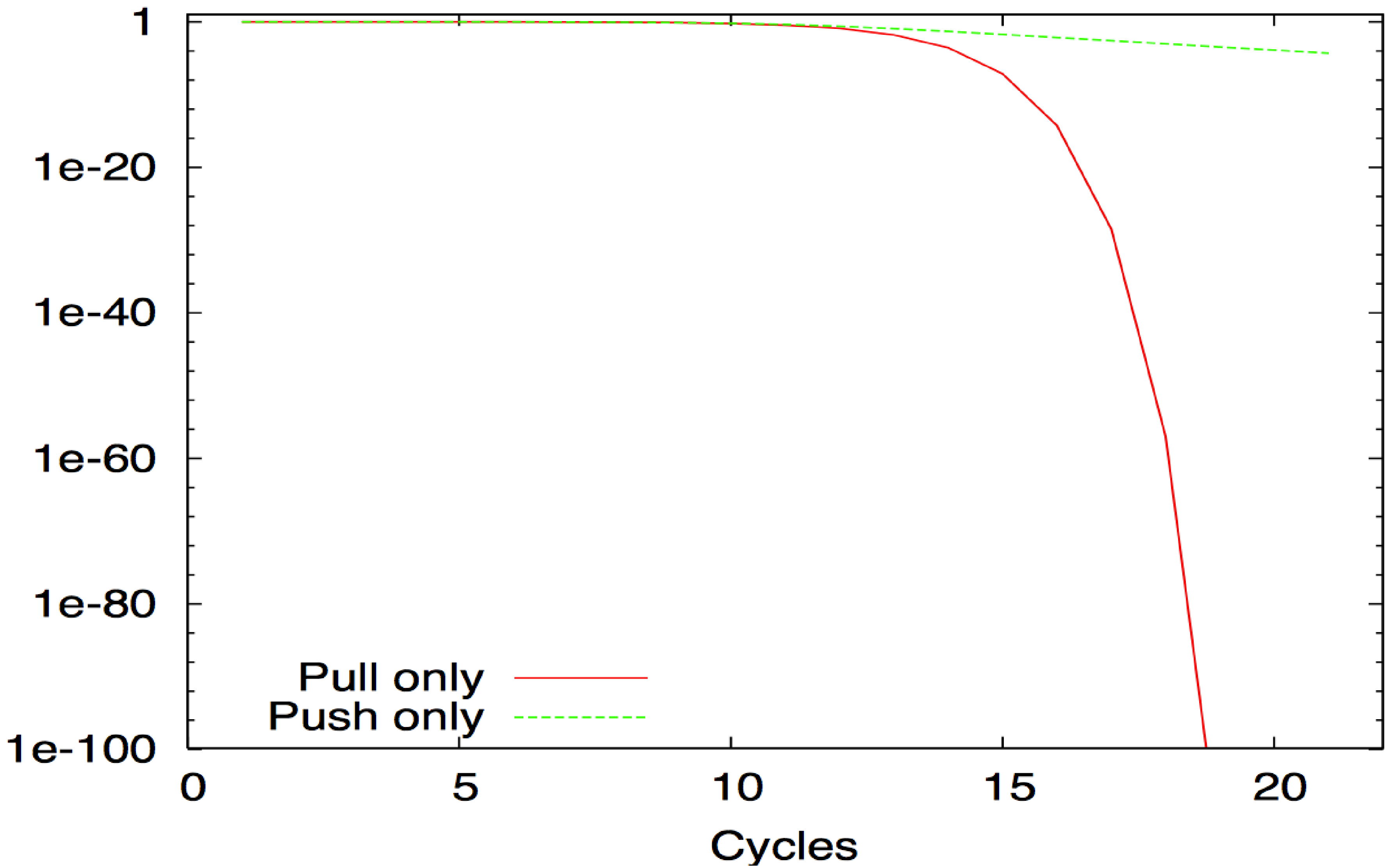
  - Let $p(i)$ be *the probability of a node being (remaining) susceptible after the i-th anti-entropy cycle*.
    - *Pull*:
      - $p(i+1) = p(i)^2$
    - *Push*:
      - $p(i+1) = p(i)(1 - 1/n)^{n(1-p(i))}$
        For small $p(i)$, $p(i+1) \sim p(i)/e$
    - *Push-pull*:
      - both mechanisms are used, convergence is even more rapid
  - All converge to 0, but pull is more rapid than push, so in practice pull (or push-pull) is used

Push vs pull


1
1e-20
1e-40
1e-60
1e-80
1e-100
0
5
10
15
20
Cycles
Pull only
Push only

Anti-entropy: Comments

- **Benefits:**
  - Simple epidemics eventually "infect" all the population
  - For a push implementation, the expected time to infect everyone is $log_2(n) + ln(n)$
- **Drawbacks:**
  - Propagates updates much slower than best effort
  - Requires examining contents of database even when most data agrees, so it cannot practically be used too often
- **Normally used as support for best effort, i.e. left running in the background**

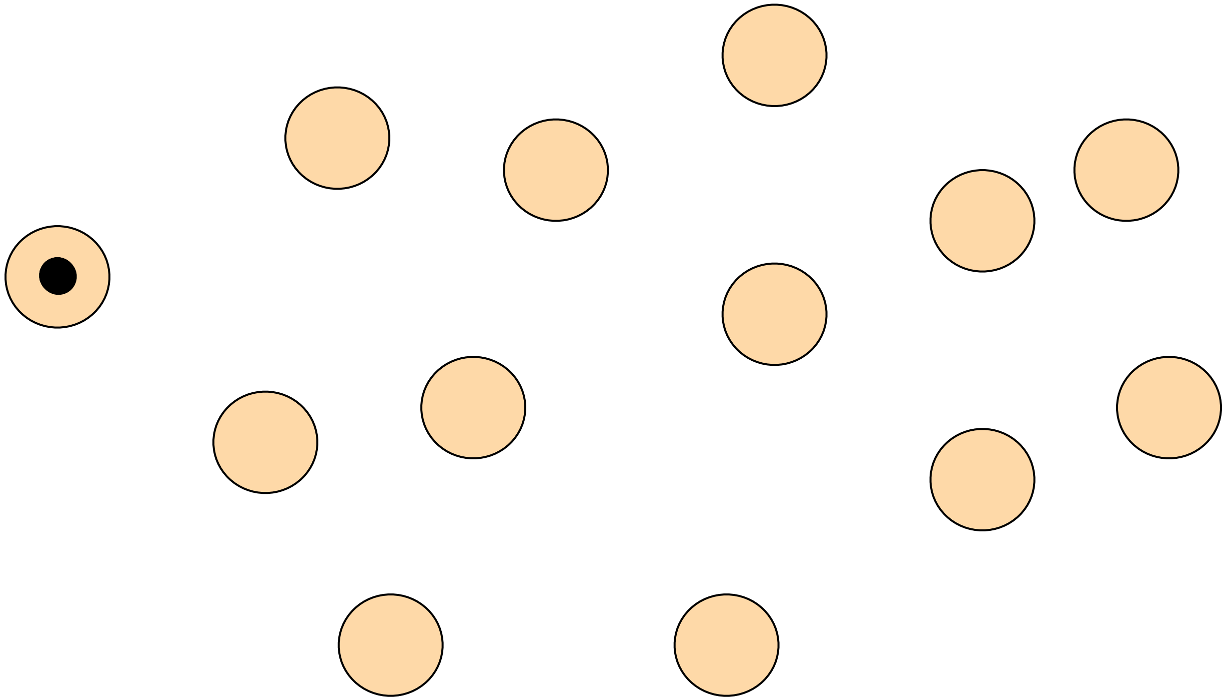
Anti-entropy: Optimizations

- **To avoid expensive databases checks:**
  - Maintain checksum, compare databases if checksums unequal
  - Maintain recent update lists for time *T*, exchange lists first
  - Maintain inverted index of database by timestamp; exchange information in reverse timestamp order, incrementally re-compute checksums
- **Note:**
  - These optimizations apply to the update problem for large DB
  - We will see how the same principle (anti-entropy) may be used for several other kind of applications

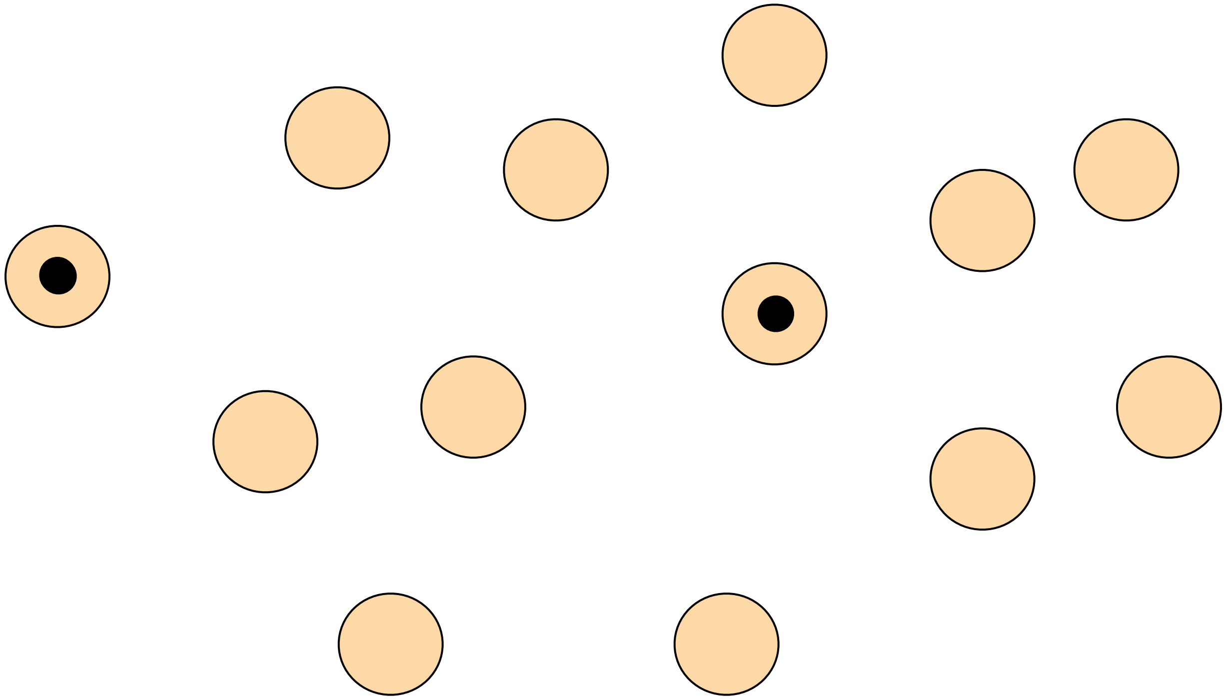
Rumor mongering - complex epidemics

- **Susceptive-infective-removed (SIR)**
  - Nodes initially *susceptive*
  - When a node receives a new update it becomes a “*hot rumor*” and the node *infective*
  - A node that has a rumor periodically chooses randomly another node to spread the rumor
  - Eventually, a node will “*lose interest*” in spreading the rumor and becomes *removed*
    - Spread too many times
    - Everybody knows it
- **Optimizations**
  - A sender can hold (and transmit) a list of infective updates rather than just one.

Rumor mongering



Rumor mongering



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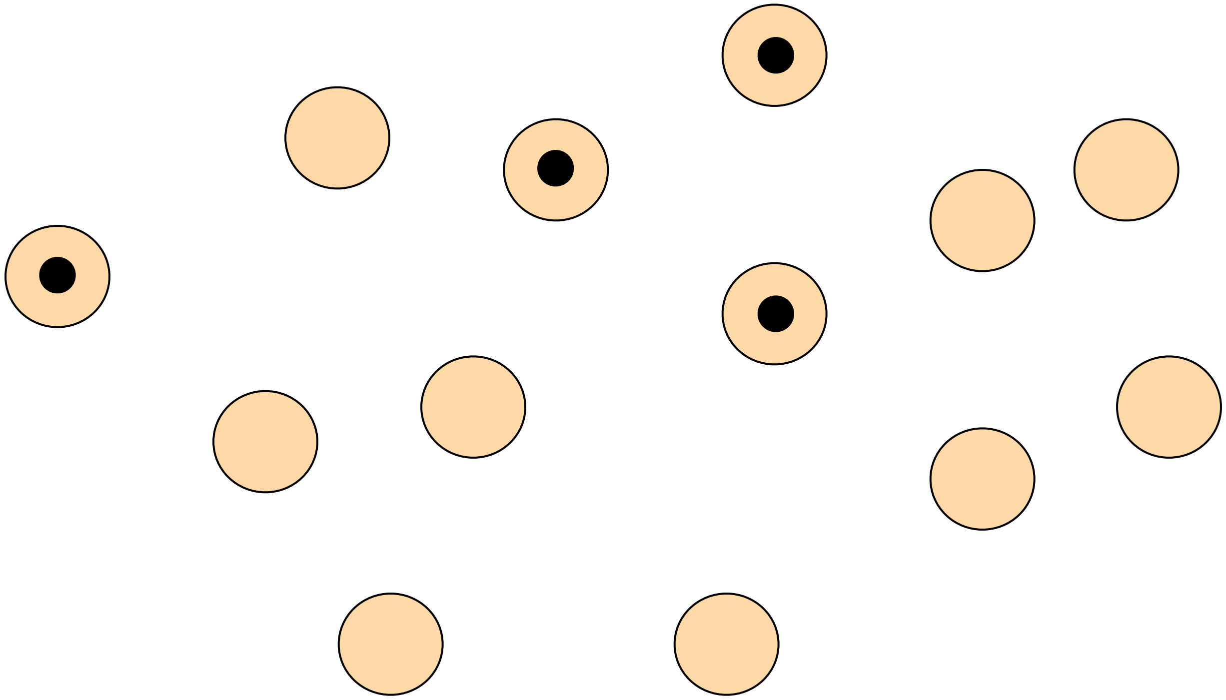
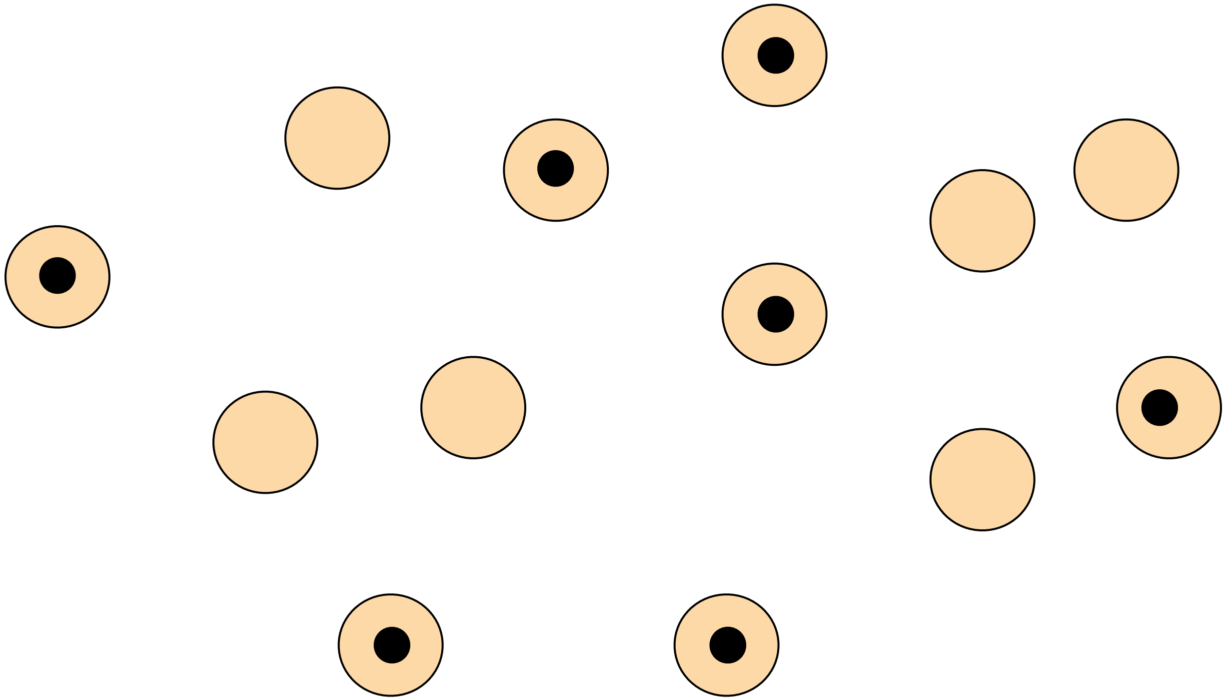


Rumor mongering



Rumor mongering: loss of interest

- **Counter vs. coin (random)**
  - *Coin* (*random*): lose interest with probability $1/k$
  - *Counter*: lose interest after k contacts

- **Feedback vs blind**
  - *Feedback*: lose interest only if the recipient knows the rumor.
  - *Blind*: lose interest regardless of the recipient.

Rumor mongering

- **How fast does the system converge to a state where all nodes are not infective? (inactive state)**
  - Eventually, everybody will lose interest
- **Once in this state, what is the fraction of nodes that know the rumor?**
  - The rumor may stop before reaching all nodes

Rumor mongering: analysis

- **Analysis from "real" epidemics theory**

- **Feedback, coin**
  - Let s, i and r denote the fraction of susceptible, infective, and removed nodes respectively. Then:

$$s + i + r = 1$$
$$\mathrm{d}s/\mathrm{d}t = -si$$
$$\mathrm{d}i/\mathrm{d}t = +si - (1/k)(1-s)i$$

  - Solving the equations:

$$s = e^{-(k+1)(1-s)}$$

  - Thus, increasing *k* we can make sure that most nodes get the rumor, exponentially better

Quality measures

- **Residue:**
  - The nodes that remain susceptible when the epidemic ends: value of s when $i = 0$
  - Residue must be as small as possible
- **Traffic:**
  - The average number of database updates sent between nodes
  - m = total update traffic / # of nodes
- **Delay - We can define two delays:**
  - t_{avg} : average time it takes for the introduction of an update to reach a node.
  - t_{last} : time it takes for the last node to get the update.

Simulation results

Using feedback and counter

Counter k	Residue s	Traffic m	Convergence	
			t_{avg}	t_{last}
1	0.176	1.74	11.0	16.8
2	0.037	3.30	12.1	16.9
3	0.011	4.53	12.5	17.4
4	0.0036	5.64	12.7	17.5
5	0.0012	6.68	12.8	17.7

Using blind and random

Counter k	Residue s	Traffic m	Convergence	
			t_{avg}	t_{last}
1	0.960	0.04	19	38
2	0.205	1.59	17	33
3	0.060	2.82	15	32
4	0.021	3.91	14.1	32
5	0.008	4.95	13.8	32

Push and pull

- **Push (what we have assumed so far)**
  - If database becomes quiescent, this scheme stops trying to introduce updates.
  - If there are many independent updates, more likely to introduce unnecessary messages.
- **Pull**
  - If many independent updates, pull is more likely to find a source with a non-empty rumor list
  - But if database quiescent, it spends time doing unnecessary update requests.

Push and pull

- **Empirically, in the database system of the authors (frequent updates)**
  - Pull has a better residue/traffic relationship than push

- **Performance of pull epidemic on 1000 nodes using feedback & counters**

Counter k	Residue s	Traffic m	Convergence t_{avg}	Convergence t_{last}
1	0.031	2.70	9.97	17.63
2	0.00058	4.49	10.07	15.39
3	0.000004	6.09	10.08	14.00

Mixing with anti-entropy

- **Rumor mongering**
  - spreads updates fast with low traffic
  - however, there is still a nonzero probability of nodes remaining susceptible after the epidemic
- **Anti-entropy**
  - can be run (infrequently) in the background to ensure all nodes eventually get the update with probability 1.
  - Since a single rumor that is already known by most nodes dies out quickly

Deletion and death certificates

- **Deletion**
  - We cannot delete an entry just by removing it from a node - the absence of the entry is not propagated.
  - If the entry has been updated recently, there may still be an update traversing the network!

- **Death certificate**
  - Solution: replace the deleted item with a *death certificate* (DC) that has a timestamp and spreads like an ordinary update

Deletion and death certificates

- **Problem:**
  - we must, at some point, delete DCs or they may consume significant space
- **Strategy 1:**
  - retain each DC until all nodes have received it
  - requires a protocol to determine which nodes have it and to handle node failures
- **Strategy 2:**
  - hold DCs for some time (e.g. 30 days) and discard them
  - pragmatic approach, still have the “resurrection” problem; increasing the time requires more space

Spatial Distribution

- **In the previous exposition**
  - The network has been considered uniform (i.e. all nodes equally reachable)
- **In reality**
  - More expensive to send updates to distant nodes
  - Especially if a critical link needs to be traversed
  - Traffic can clog these links

- **Bibliography**

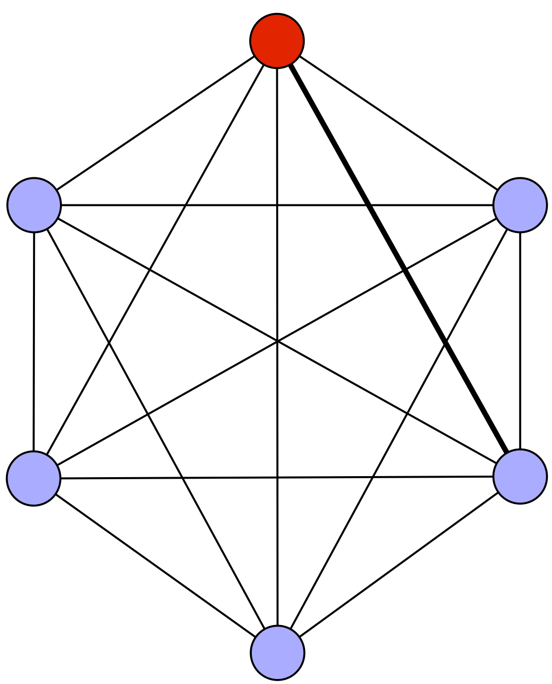
  - S. Voulgaris, D. Gavidia, and M. Van Steen. *Cyclon: Inexpensive membership management for unstructured p2p overlays*. Journal of Network and Systems Management, 13(2):197–217, 2005
  - M. Jelasity and M. van Steen. *Large-scale newscast computing on the Internet*. Technical Report IR-503 (October), Vrije Universiteit Amsterdam, Department of Computer Science, Amsterdam, The Netherlands.
  - M. Jelasity, S. Voulgaris, R. Guerraoui, A.-M. Kermarrec, and M. van Steen. *Gossip-based peer sampling*. ACM Transactions on Computer Systems, 25(3):8, August 2007
  - G. P. Jesi, A. Montresor, and M. van Steen. *Secure peer sampling*. Computer Networks, 2010. To appear.

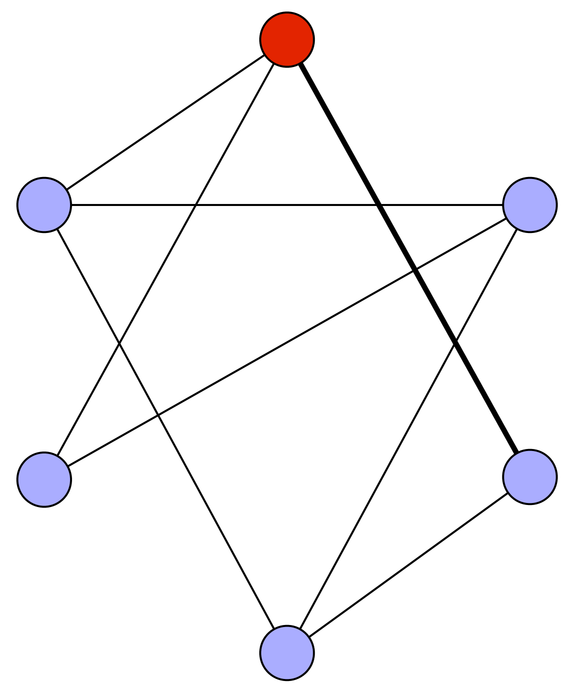
Peer sampling

- **The first problem to be solved:**
  - Where *getPeer*() get nodes from?
  - We assumed complete knwoledge of the distributed system
- **But complete knowledge is costly**
  - System is dynamic
  - Network can be extremely large
- **Solution: peer sampling**
  - Provides random samples from the participant set
  - Keeps the participants together in a connected network

Can you spot the difference?

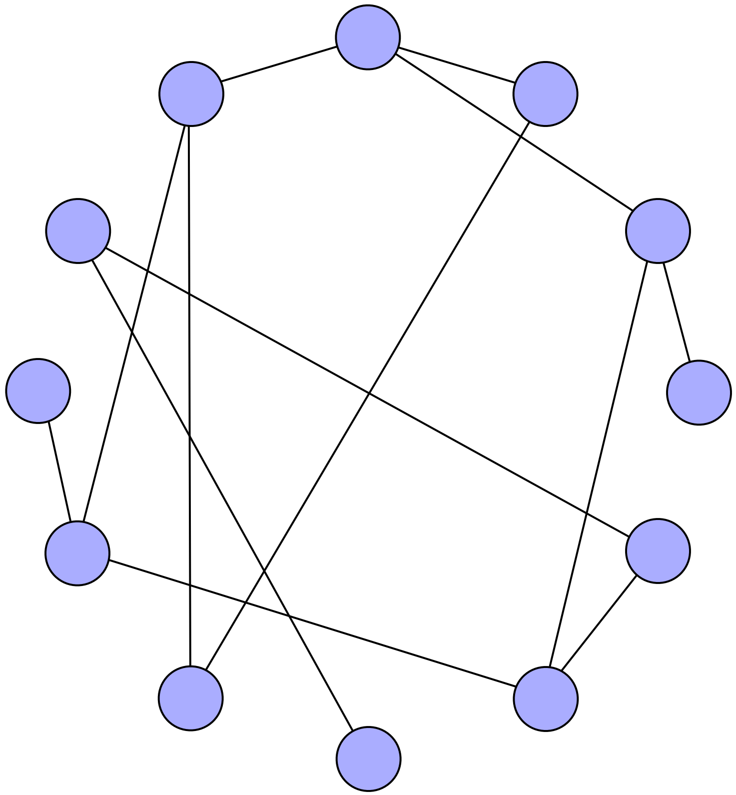
- **Traditional gossip**
  - Each node has *full* view of the network
  - Each node periodically "gossips" with a random node, out of the *whole* set
- **Peer sampling**
  - Nodes have a *partial view* of the network (a set of "neighbors")
  - Each node periodically "gossips" with a random node, out of its partial view





Overlay

- **An overlay network is a logical network <u>over</u>imposed on a physical network**
  - Nodes
  - Logical links between nodes
- **Examples**
  - Structured overlay network
    - DHTs, trees
  - Unstructured overlay network
    - Gnutella
    - Bittorrent
    - etc.



System model

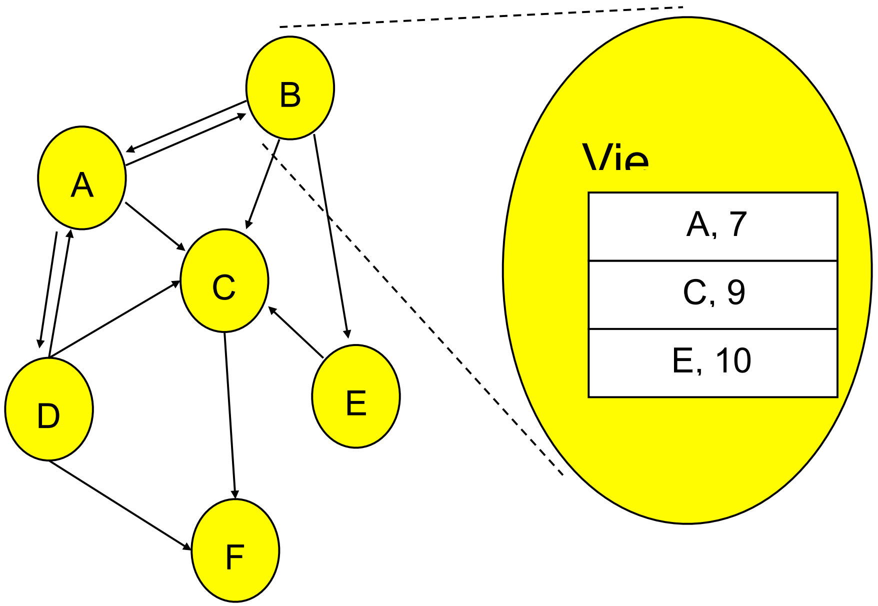
- **A dynamic collection of distributed nodes that want to participate in a common epidemic protocol**
  - Node may join / leave
  - Node may crash at any time

  $\left.\begin{array}{l}\text{Node may join / leave}\\ \text{Node may crash at any time}\end{array}\right\}$ Churn

- **Communication:**
  - To communicate with node *q*, node *p* must know its address
  - Messages can be lost – high levels of message omissions can be tolerated

Our Overlays

- **State of each node:**
  - A partial view containing *c* descriptors
  - (*c* = view size)
- **Descriptors of node *p* contains**
  - The address needed to communicate with *p*
  - Additional information that may be needed by different implementations of the *peer sampling service*
  - Additional information that may be needed by *upper layers*



A generic gossip protocol - executed by process p

Init: initialize my local *state*

Active thread

do once every δ time units

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s_p = prepareMsg(*state*, q)

send (REQ, s_p) **to** q

A "cycle" of length δ

Passive thread

do forever

receive *(t,* s_q*)* **from** *

if (t = REQ) **then**

s_p = prepareMsg(*state*, q)

send (REP, s_p) **to** q

state = update(*state*, s_q)

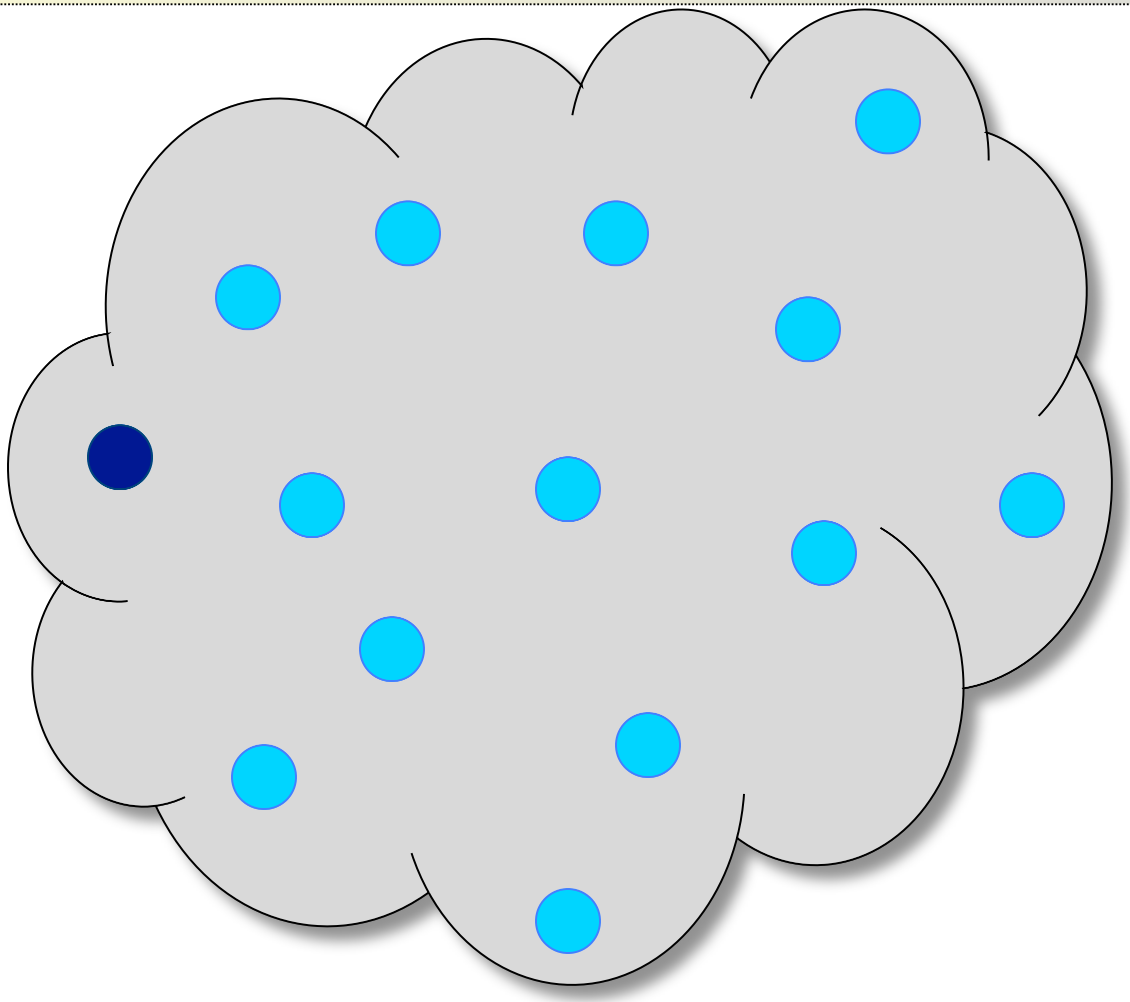
A generic algorithm

- ***getPeer*()**
  - select one of the neighbor contained in the view
- ***prepareMsg*(view, q)**
  - returns a subset of the descriptors contained in the local view
  - may add other descriptors (e.g. its own)
- ***update*(view, msgq)**
  - returns a subset of the descriptors contained in the union of the local view and the received view

Newscast

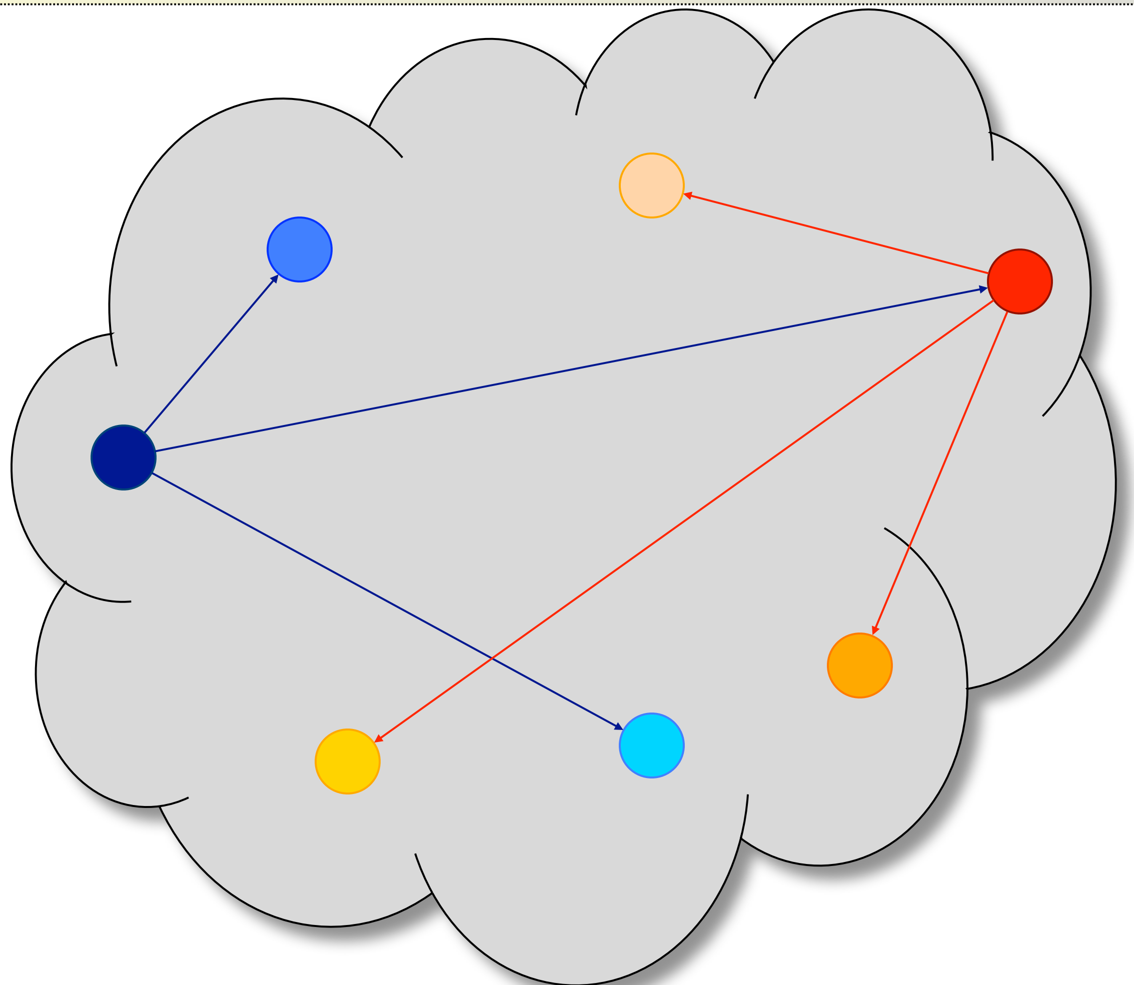
- **Descriptor: address + timestamp**
- ***getPeer*()**
  - select one node at random
- ***prepareMsg*(view, q)**
  - returns the entire view + a local descriptor with a fresh timestamp
- ***update*(view, msgq)**
  - returns the C freshest identifiers (w.r.t. timestamp) from the union of local view and message

Newscast



Newscast

ID & Address	Time stamp
	9
	12
	16



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	14

Newscast

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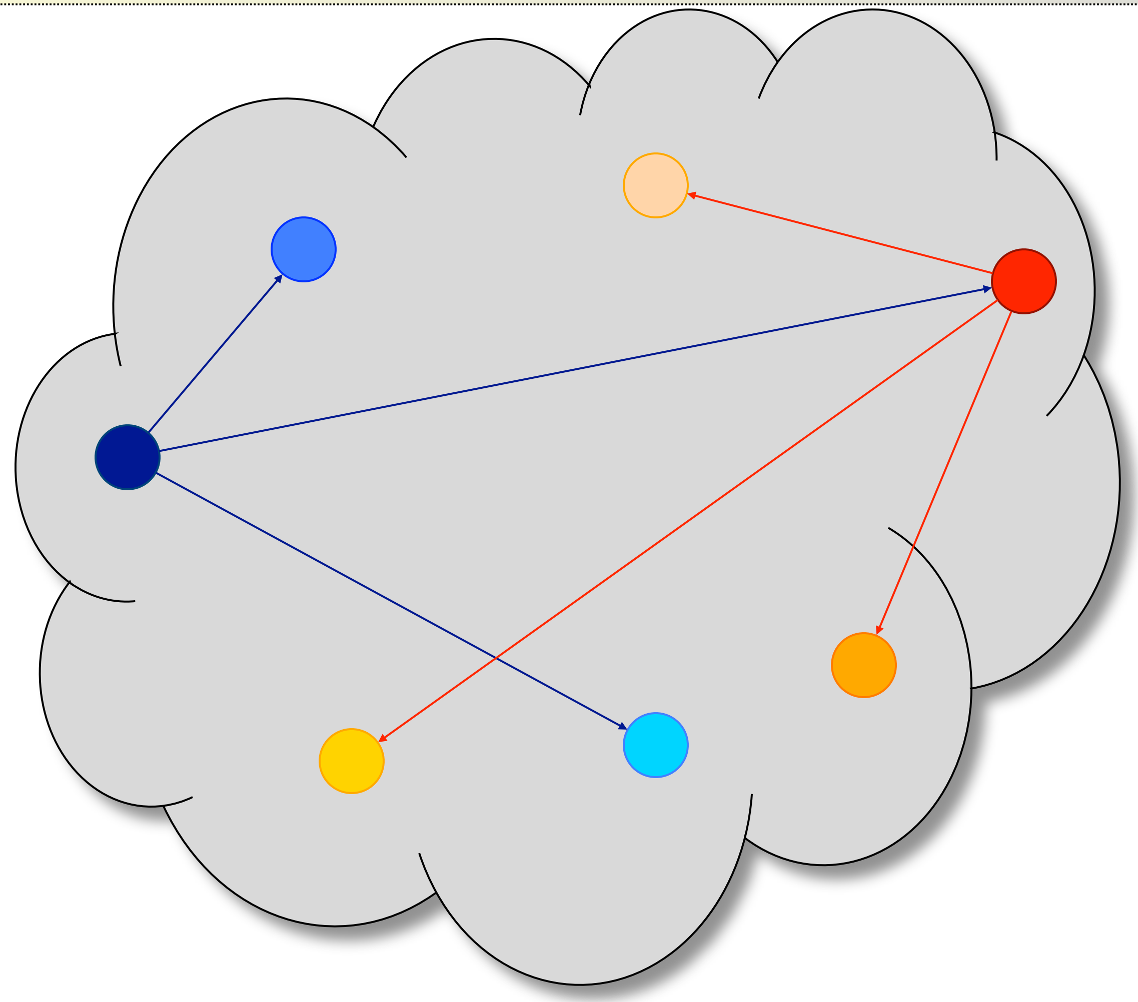

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1. Pick random peer from my view

Newscast

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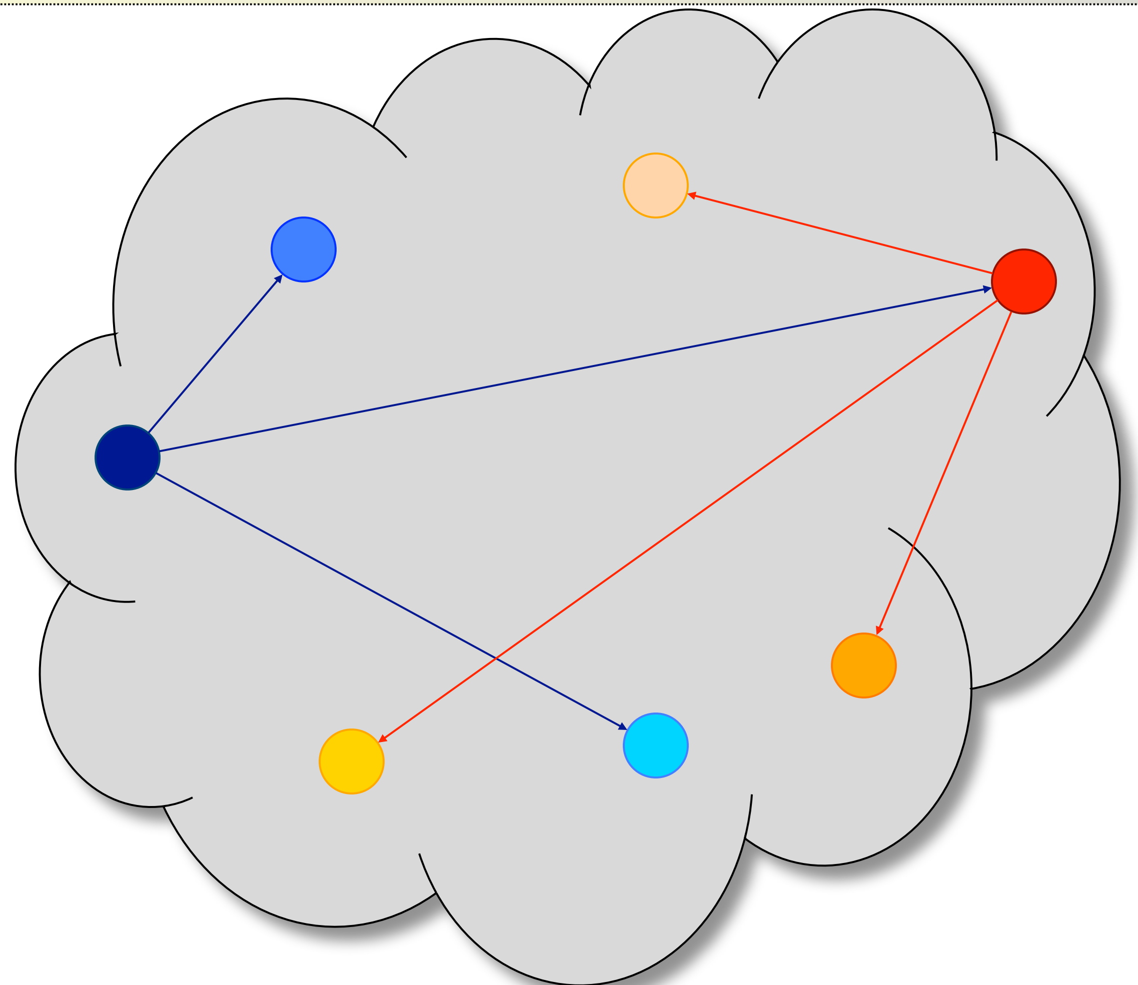

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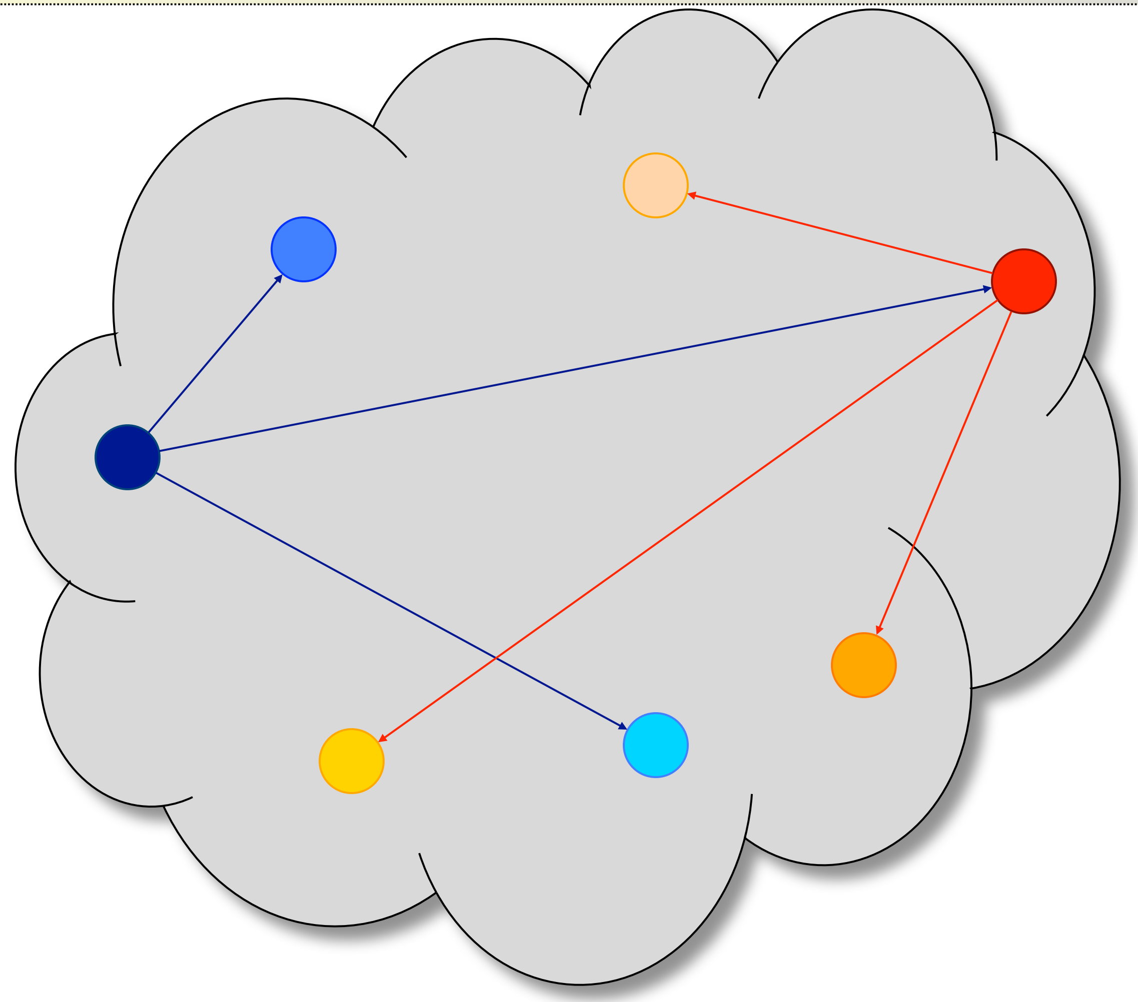
	12
	16

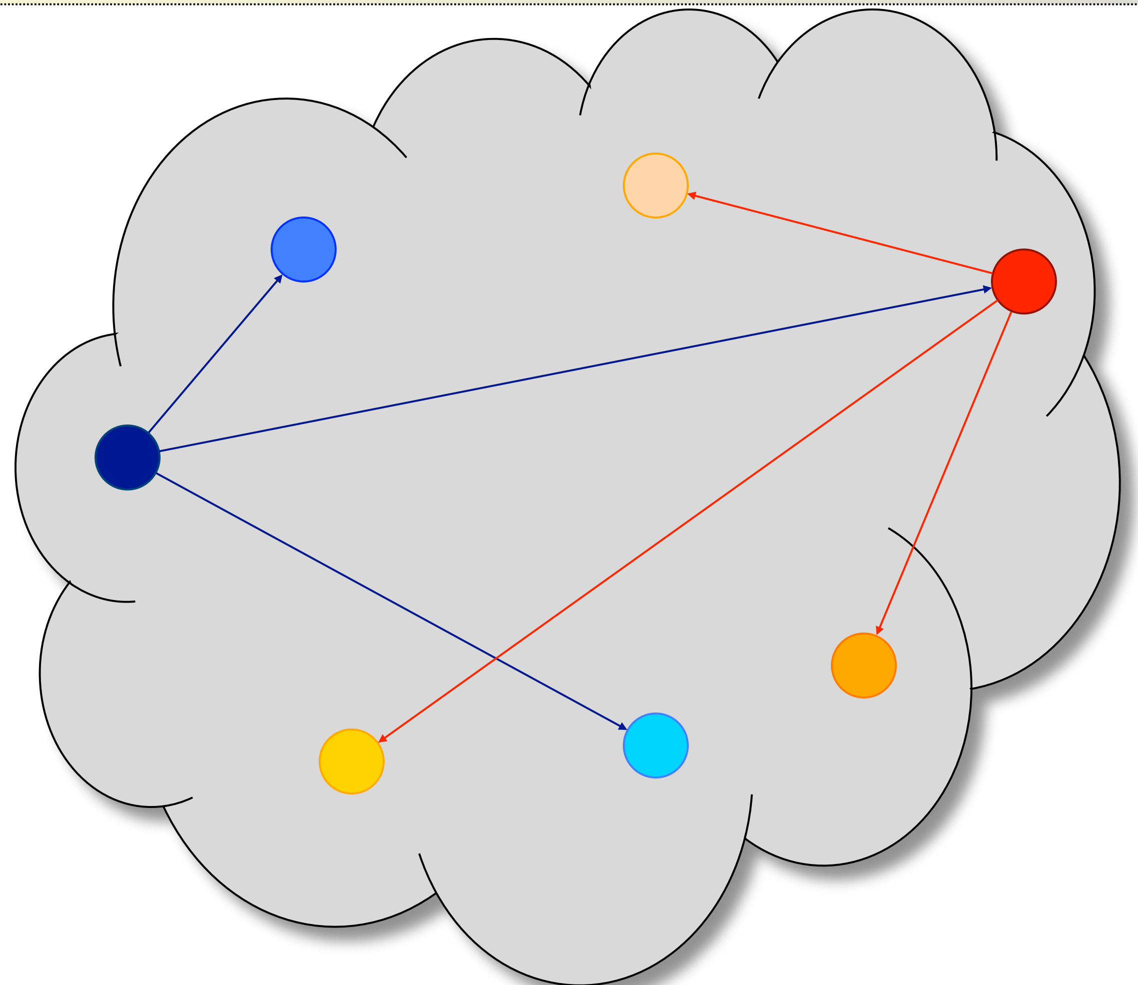


ID & Address	Time stamp
	7
	10
	14

1. Pick random peer from my view
2. Send each other view + own fresh link

Newscast

ID & Address	Time stamp
	9
	12
	16



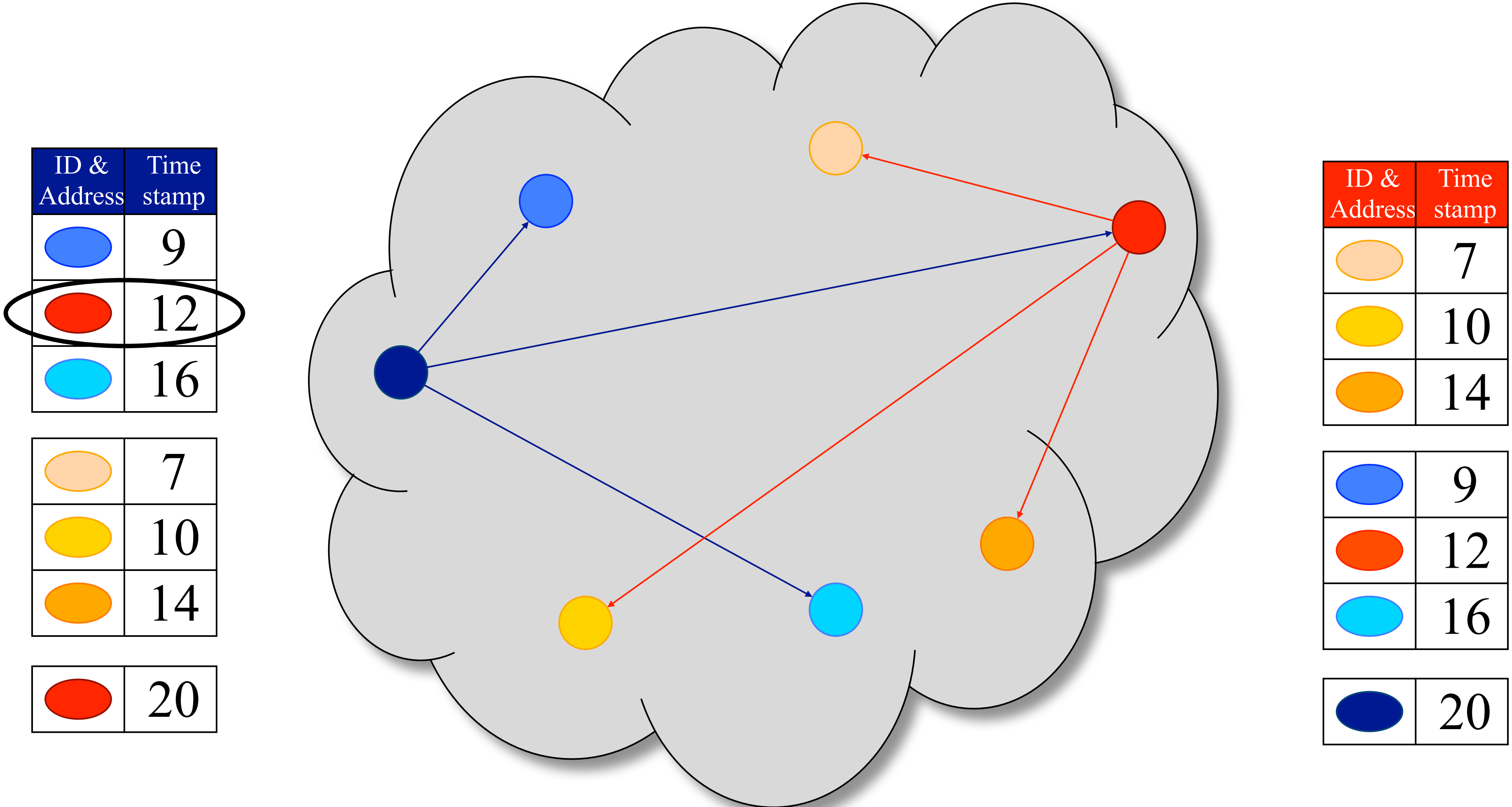
ID & Address	Time stamp
	7
	10
	14

	9
	12
	16

	20

1. Pick random peer from my view
2. Send each other view + own fresh link

Newscast



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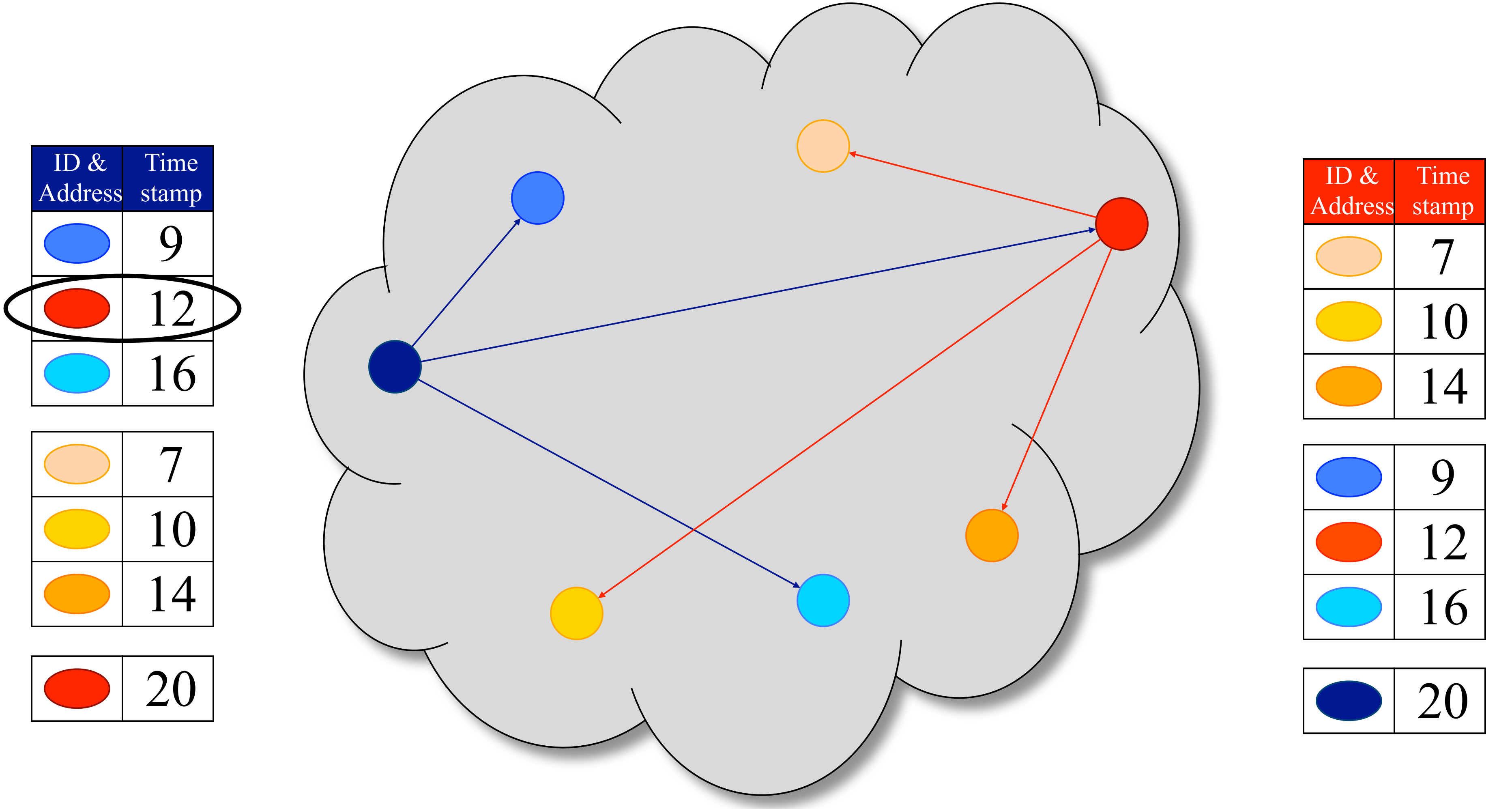
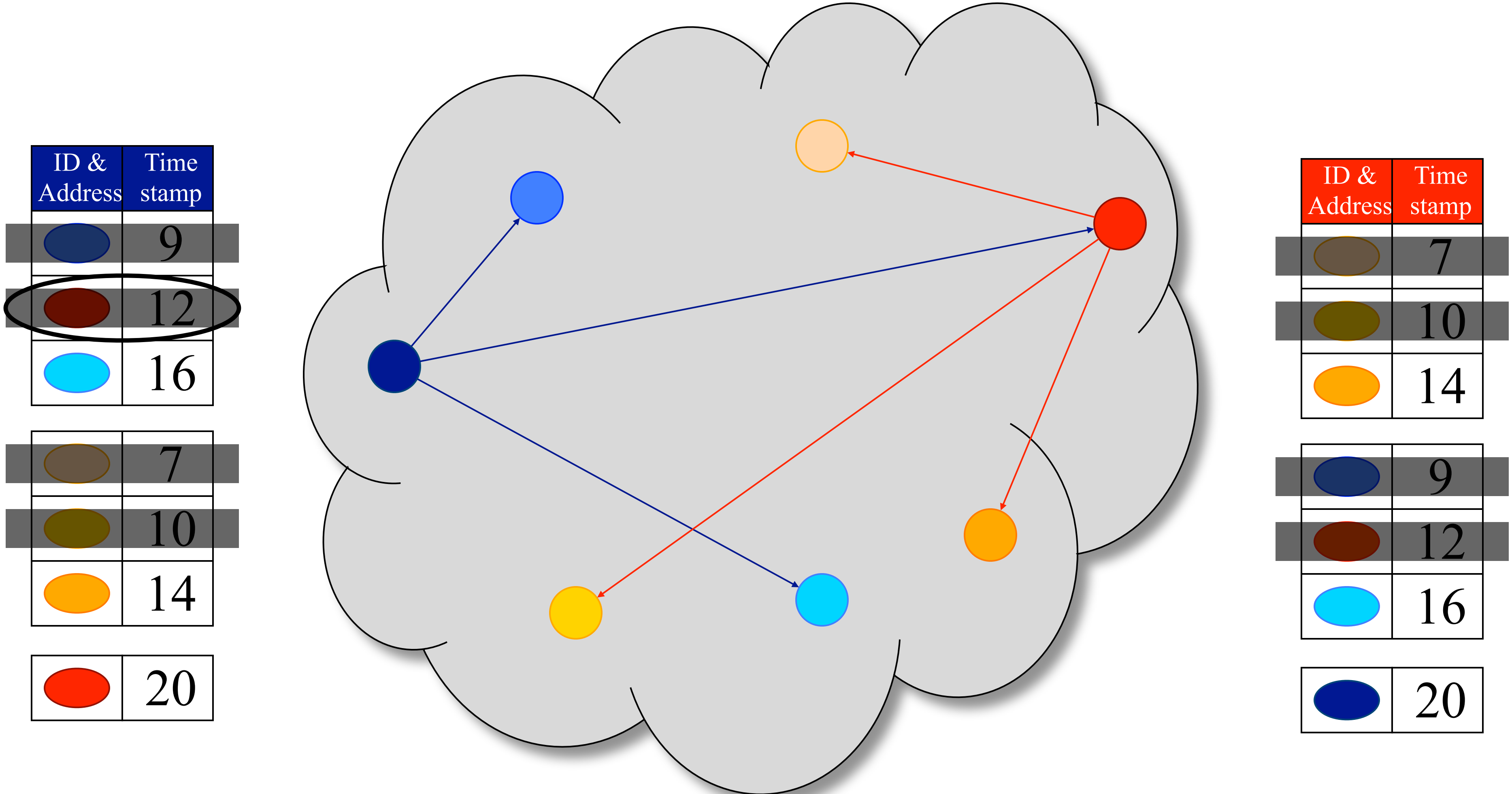
2. Send each other view + own fresh link

Newscast



1. Pick random peer from my view
2. Send each other view + own fresh link
3. Keep *c* freshest links (remove own info, duplicates)

Newscast



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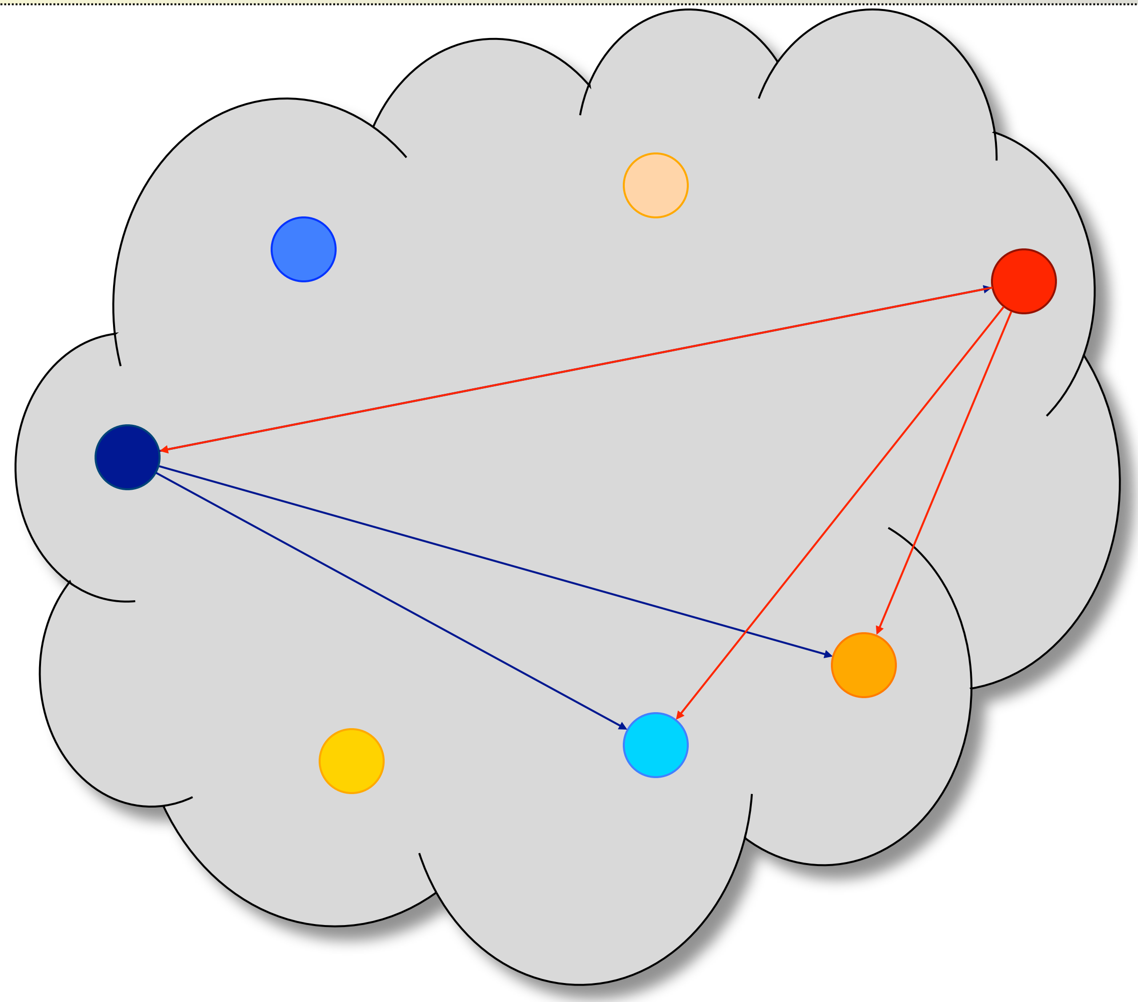
Newscast

ID & Address	Time stamp
	14
	16
	20



ID & Address	Time stamp
	14
	16
	20

1. Pick random peer from my view
2. Send each other view + own fresh link
3. Keep *c* freshest link (remove own info, duplicates)

Newscast

- **Experiments**
  - 100,000 nodes
  - C = 20 neighbors per node

Evaluation framework

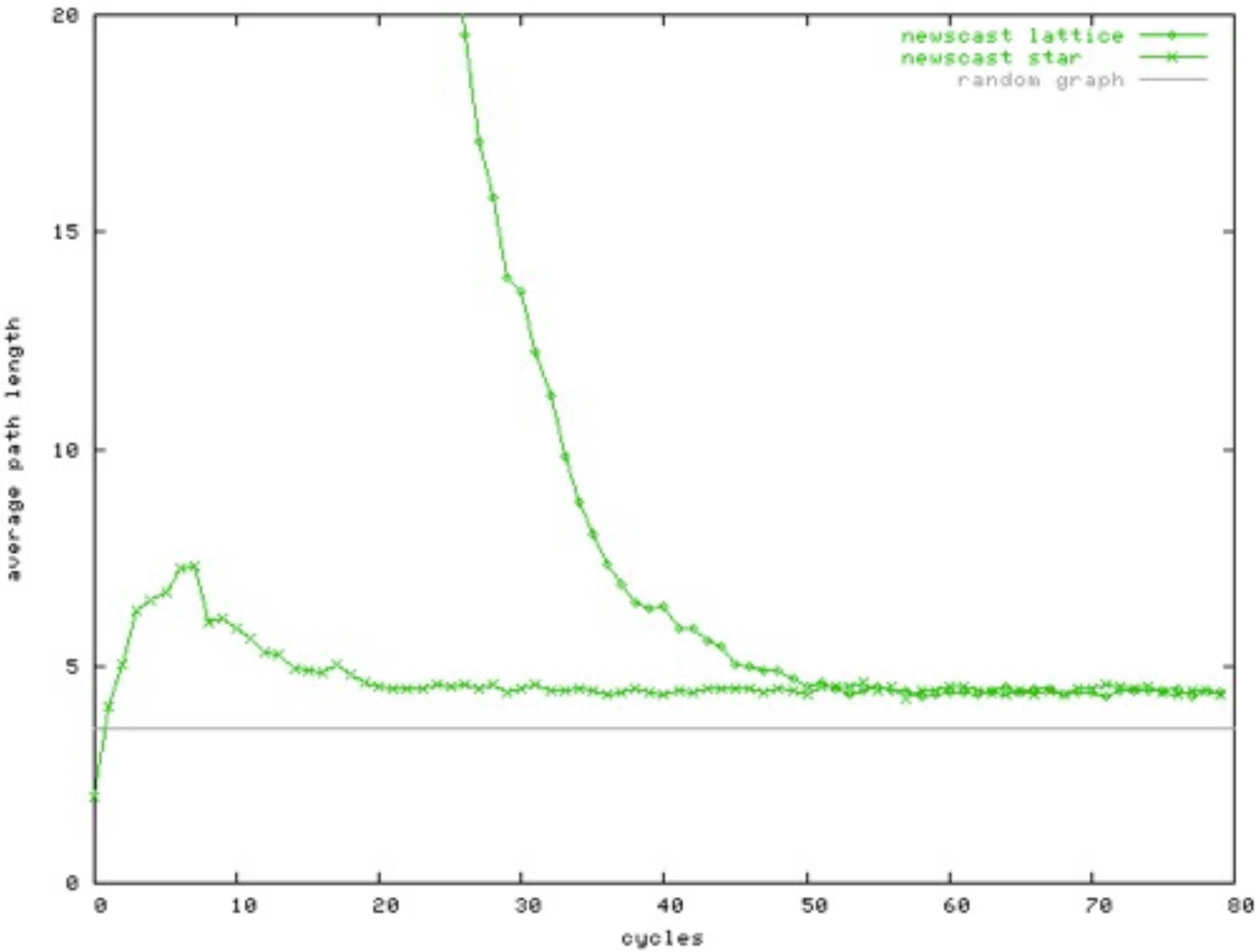
- **Average path length**
  - The average of shortest path lengths over all pairs of nodes in the graph
- **In epidemic dissemination protocols**
  - A measure of the time needed to diffuse information from a node to another

Evaluation framework

- **Clustering coefficient**
  - The clustering coefficient of a node *p* is defined as the # of edges between the neighbors of *p* divided by the # of all possible edges between those neighbors
  - Intuitively, indicates the extent to which the neighbors of *p* know each other.
  - The clustering cofficient of the graph is the average of the clustering coefficients of all nodes
  - Examples
    - for a complete graph it is 1
    - for a tree it is 0
- **In epidemic dissemination protocols**
  - High clustering coefficient means several redundant messages are sent when an epidemic protocol is used

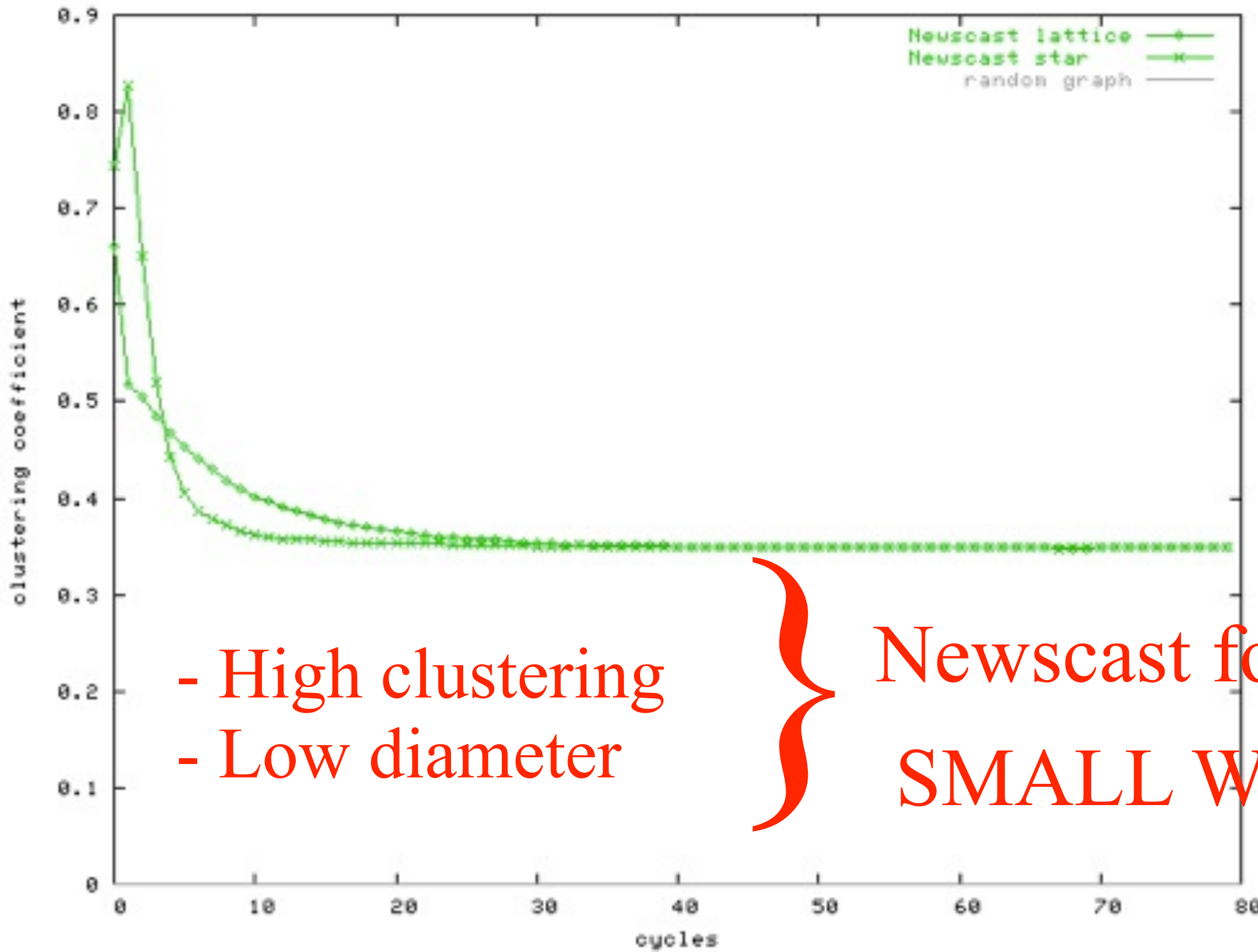
Average path length

- **Indication of the time and cost to flood the network**



Clustering coefficient

- **High clustering is bad for:**
  - Flooding: It results in many redundant messages
  - Self-healing: Strongly connected cluster → weakly connected to the rest of the network

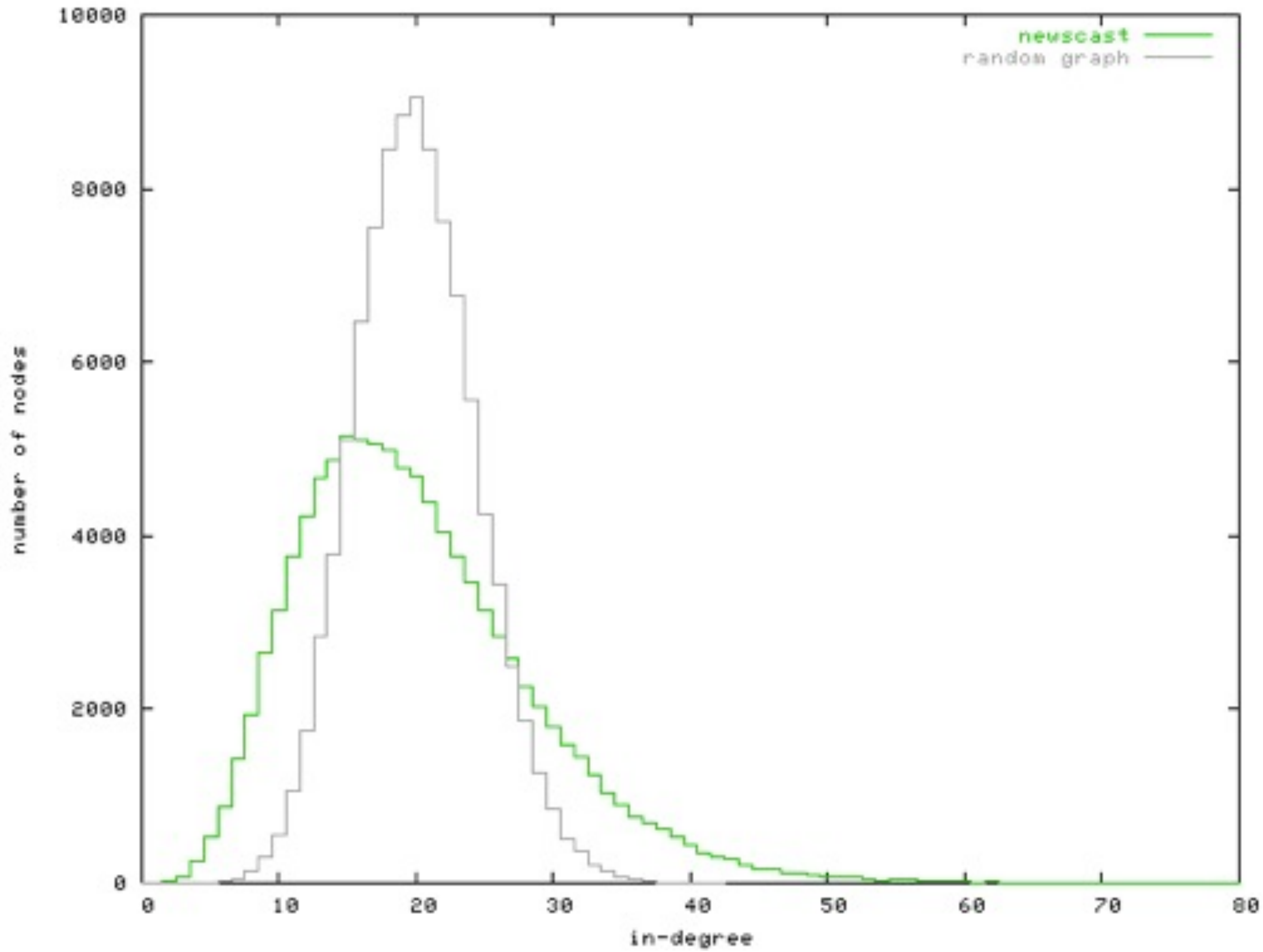


- High clustering
- Low diameter

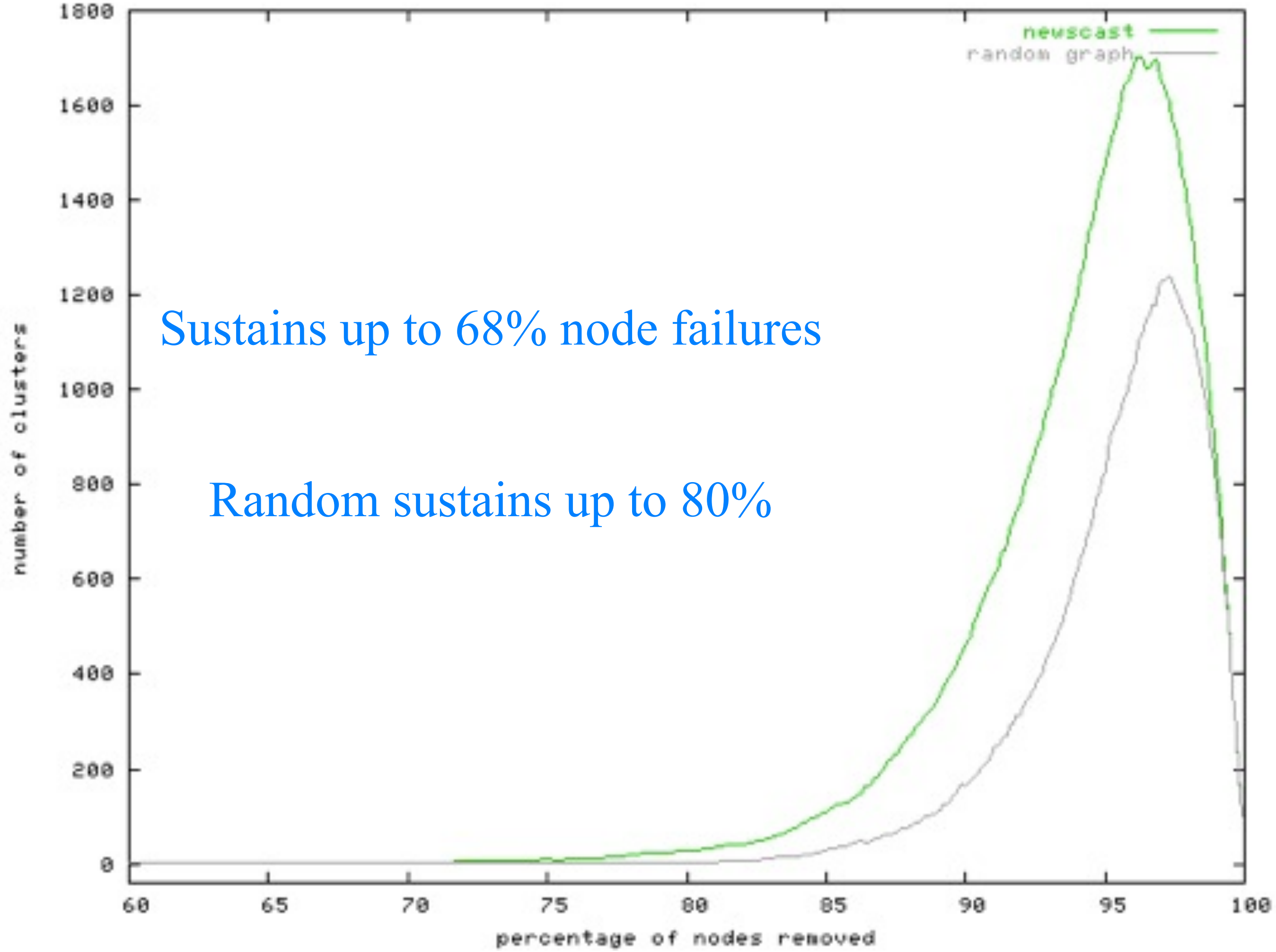
Newscast forms a SMALL WORLD

In-Degree Distribution

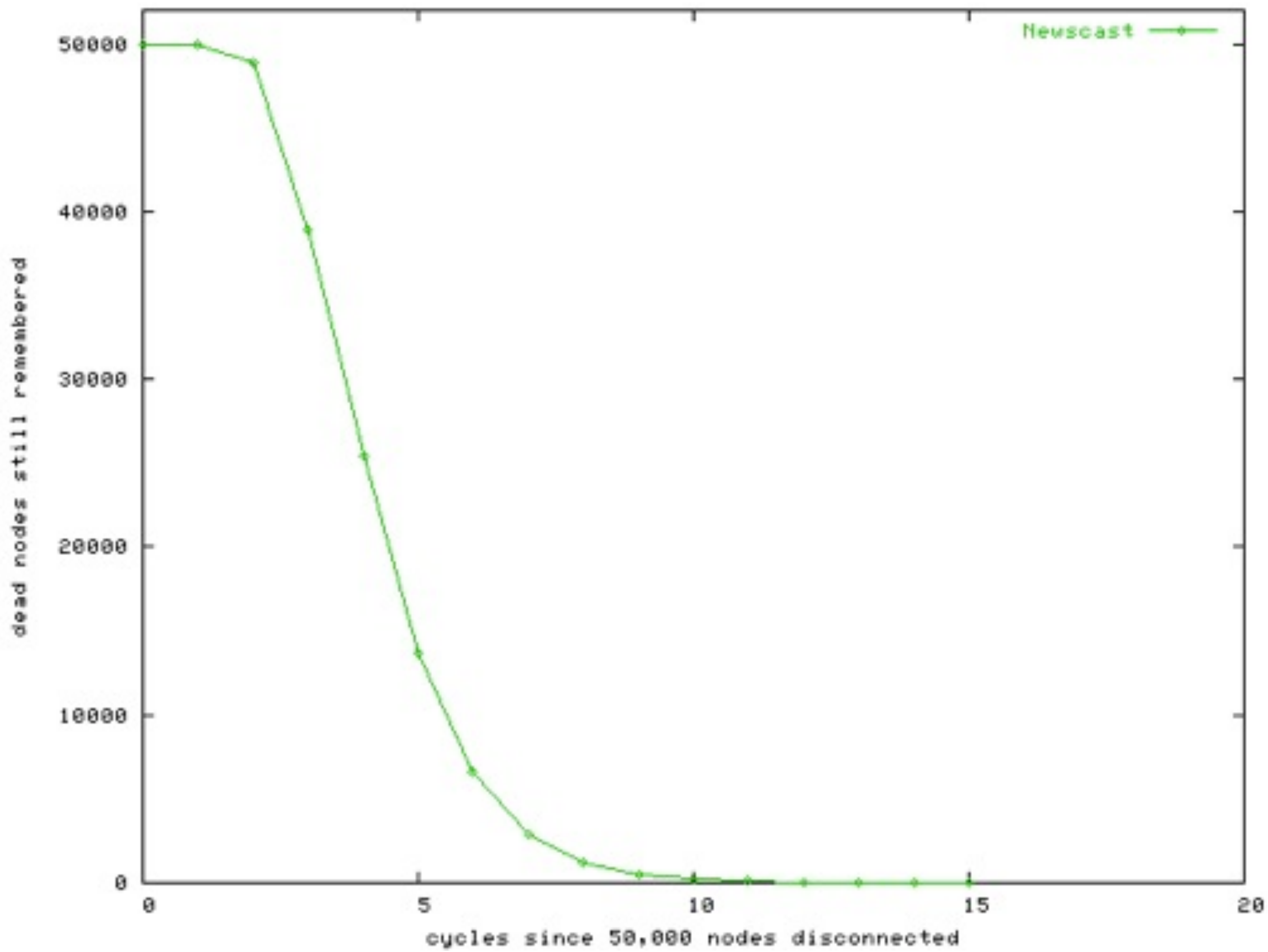
- **Affects:**
  - Robustness (shows weakly connected nodes)
  - Load balancing
  - The way epidemics spread



Robustness


newscast
random graph
number of clusters
percentage of nodes removed
Sustains up to 68% node failures
Random sustains up to 80%

Self-healing behaviour

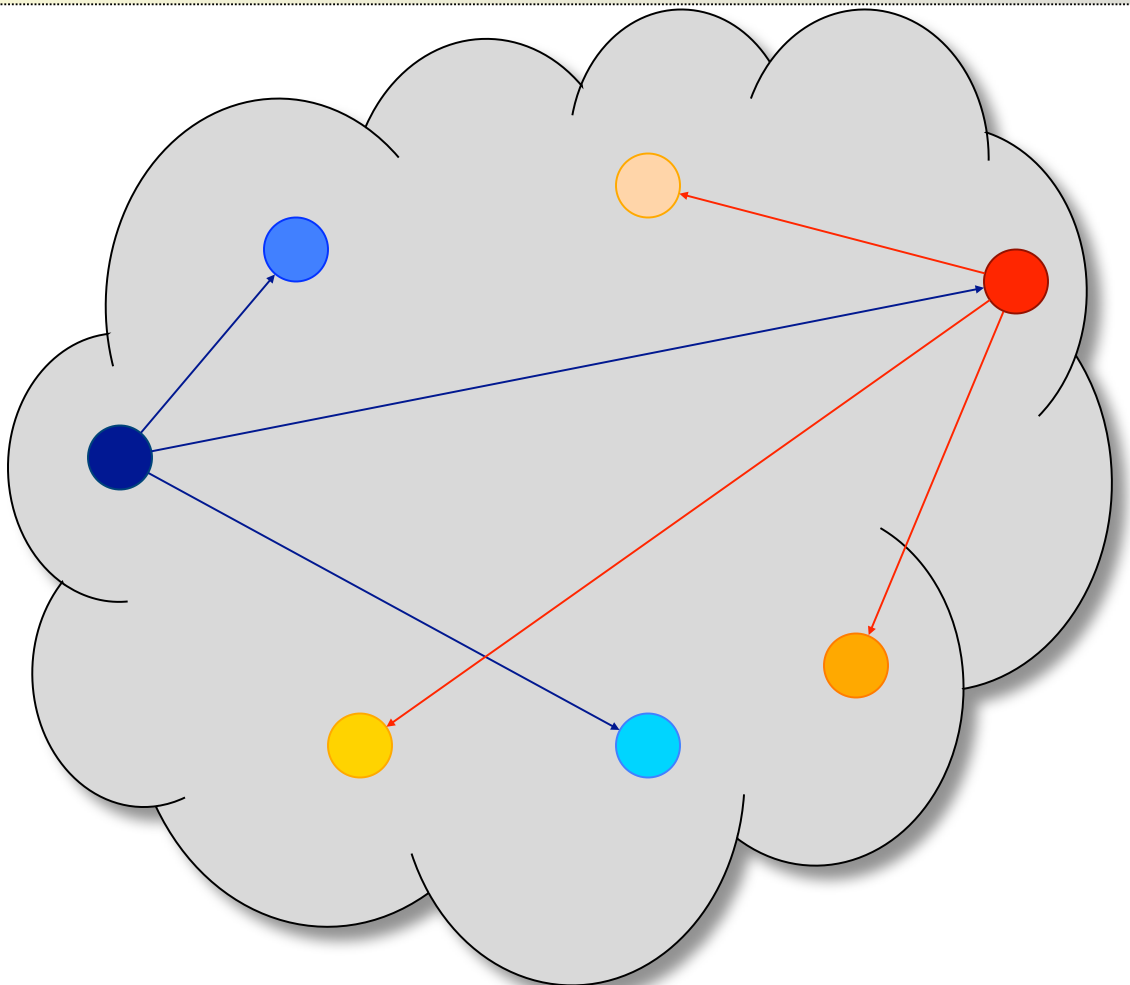


Cyclon

- **Descriptor: address + timestamp**
- ***getPeer*()**
  - select the oldest descriptor in the view
  - remove it from the view
- ***prepareMsg*(*view*, *q*)**
  - In active thread:
    - returns a subset of *t-1* random nodes, plus a fresh local identifier
  - In passive thread:
    - returns a subset of *t* random nodes
- ***update*(*view*, msg_q)**
  - discard entries in msg_q: *p*, nodes already know
  - add msg_q , removing entries sent to *q*

Cyclon

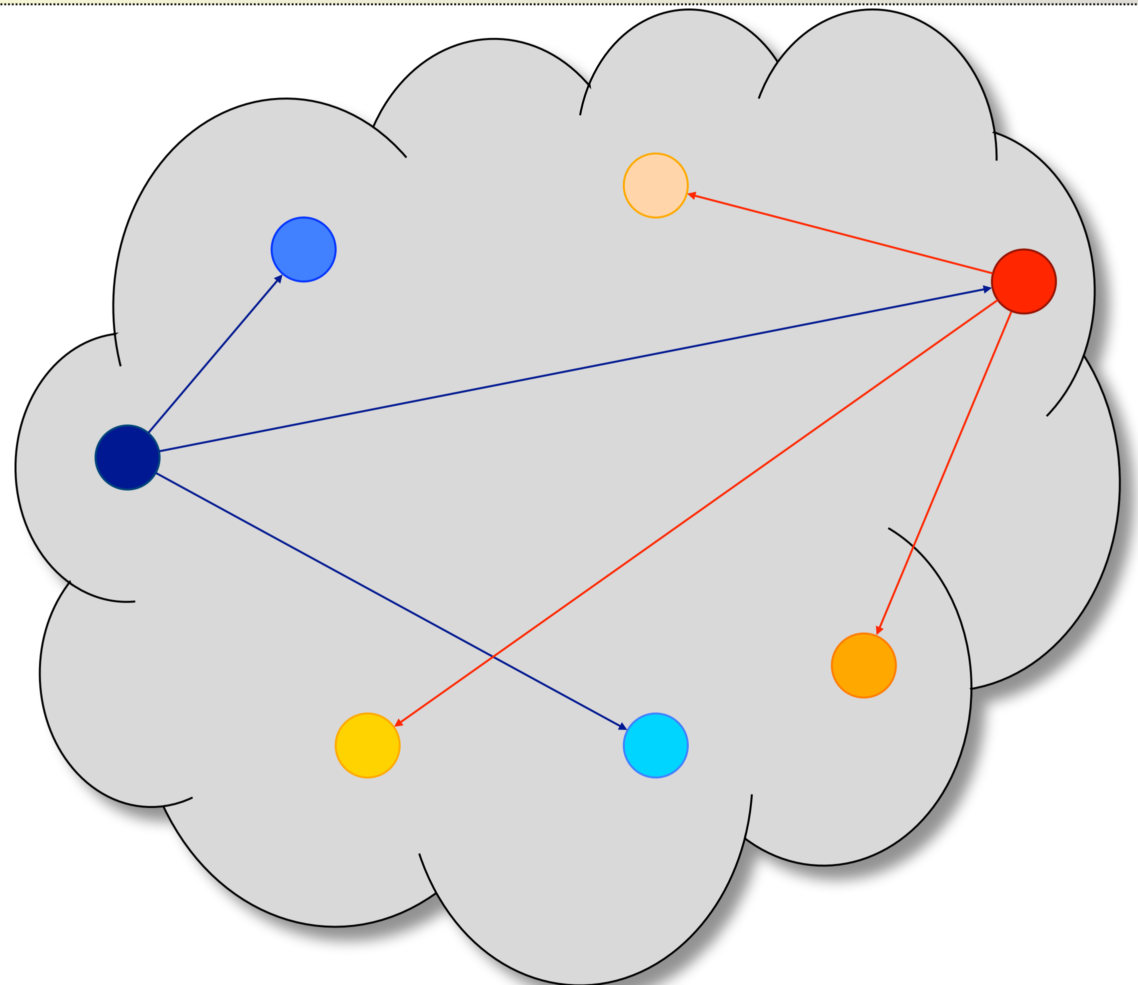
ID & Address	Time stamp
	9
	12
	4



ID & Address	Time stamp
	7
	10
	14

Cyclon

ID & Address	Time stamp
	9
	12
	4

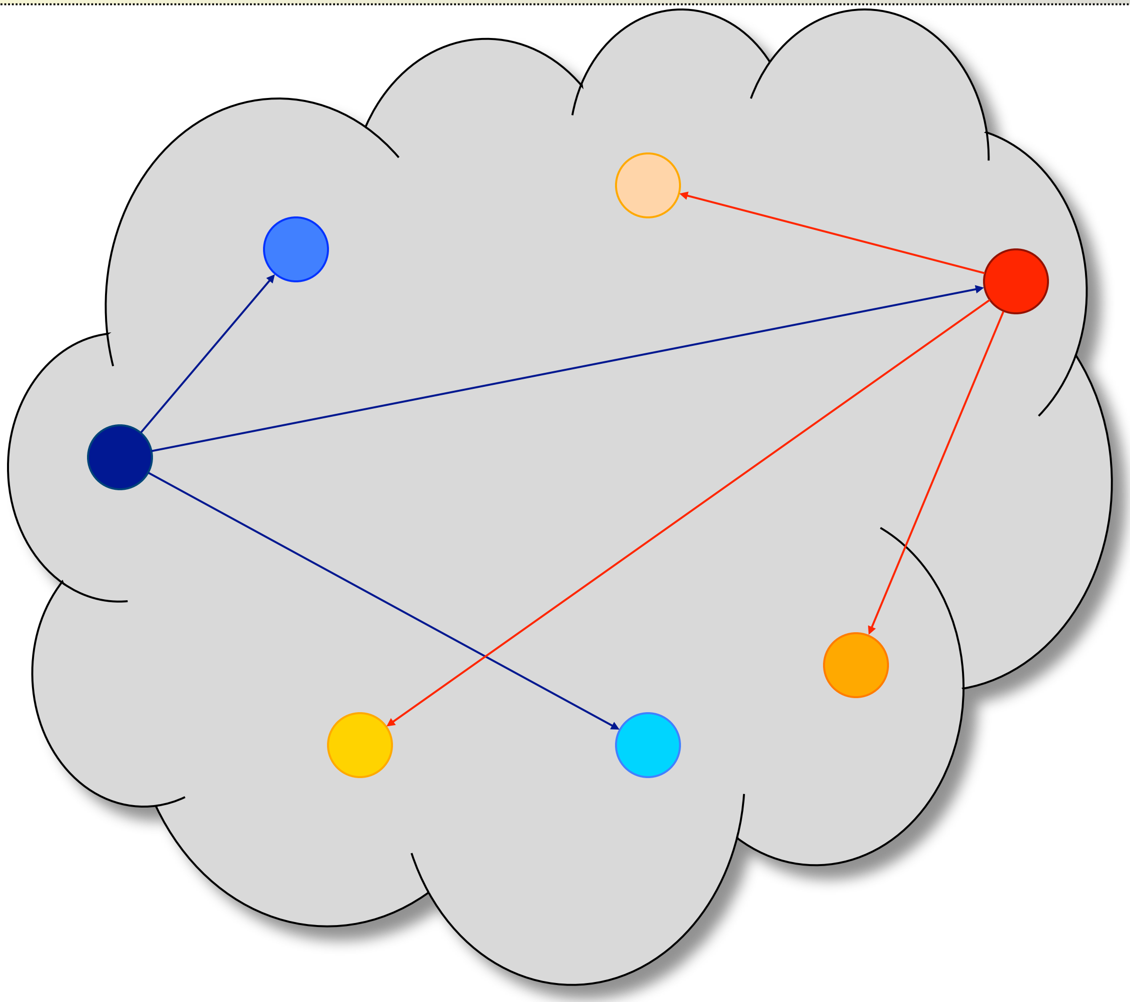


ID & Address	Time stamp
	7
	10
	14

1. Pick <u>oldest</u> peer from my view

Cyclon

ID & Address	Time stamp
	9
	12
	4



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Cyclon

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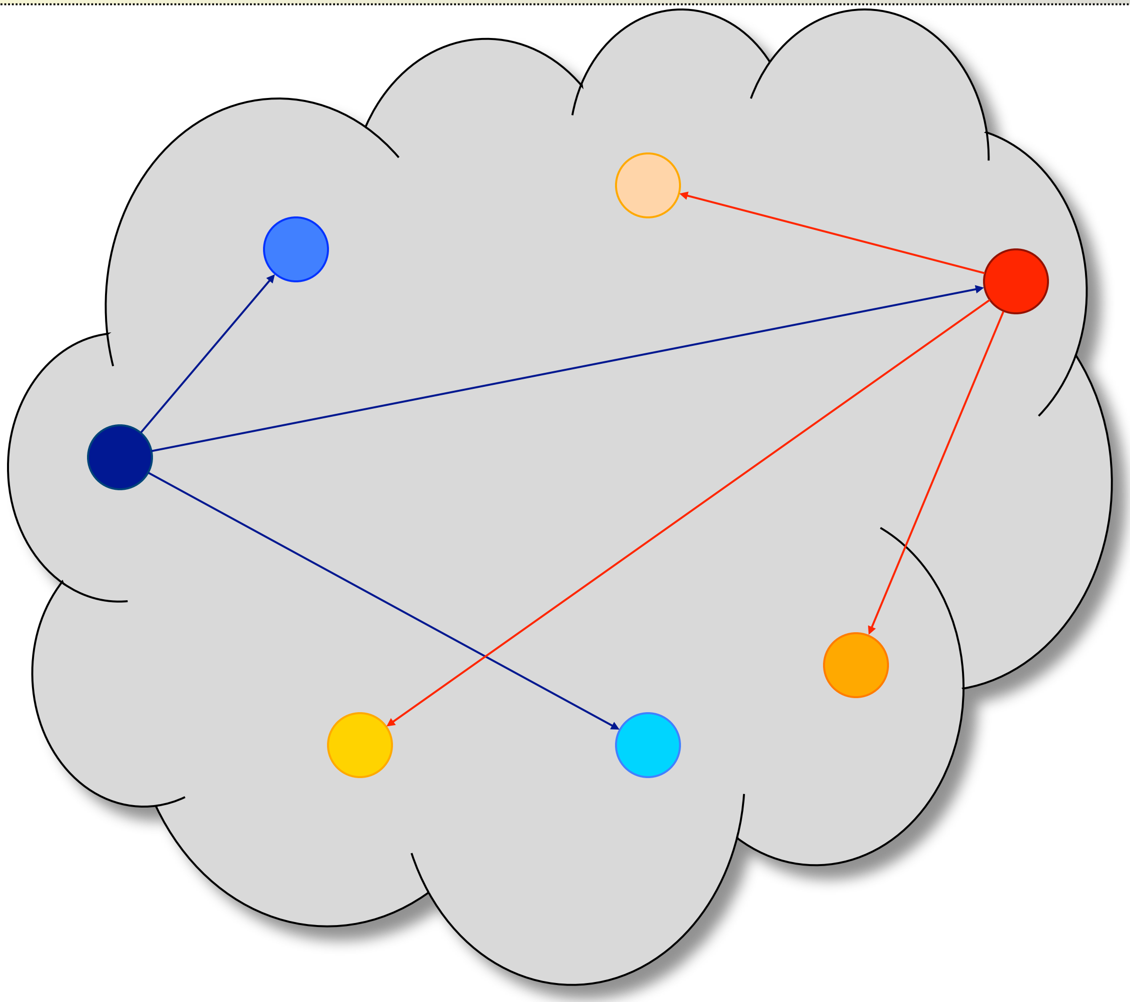

ID & Address	Time stamp
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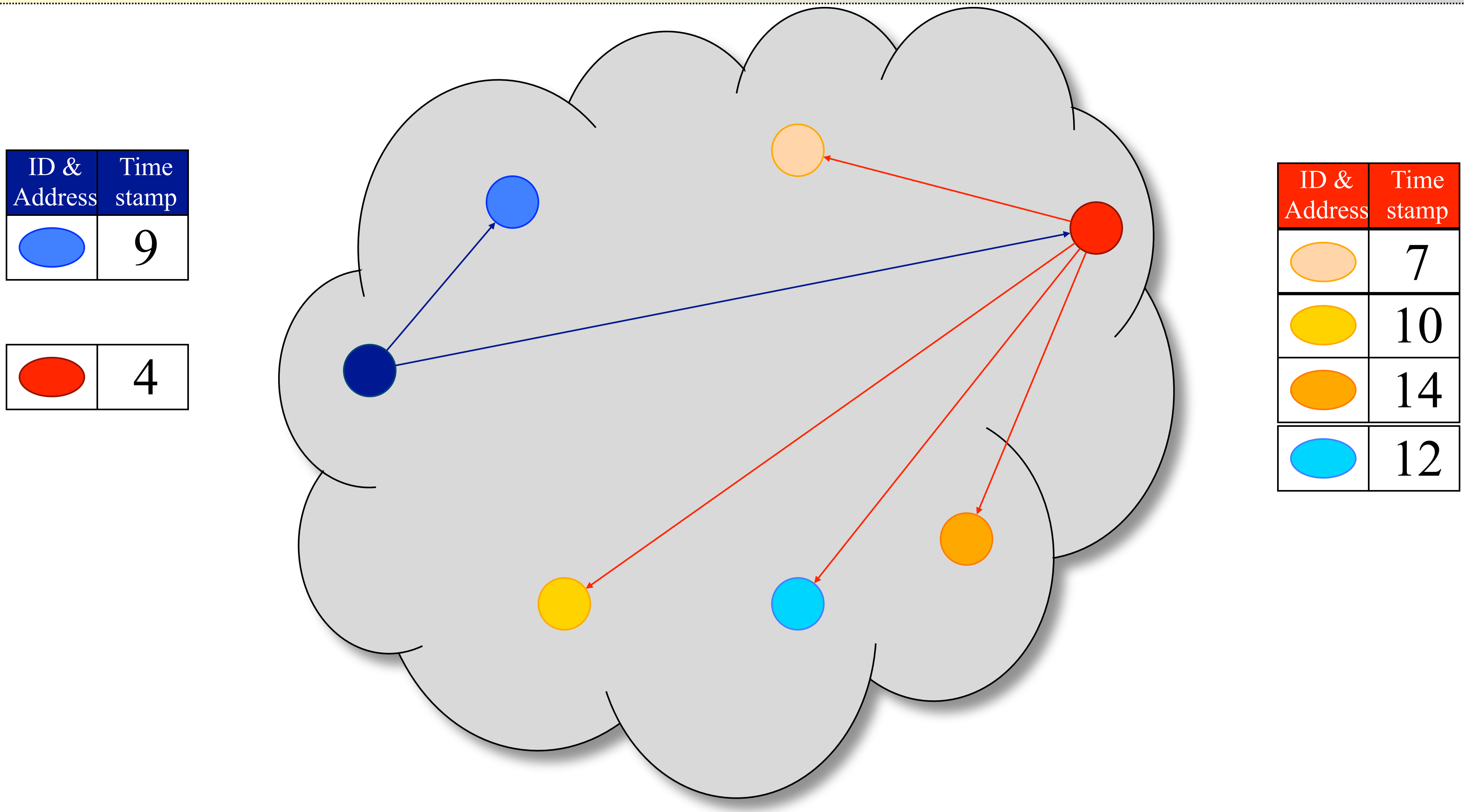
	10
	14

1. Pick <u>oldest</u> peer from my view
2. Exchange some neighbors (the pointers)

Cyclon



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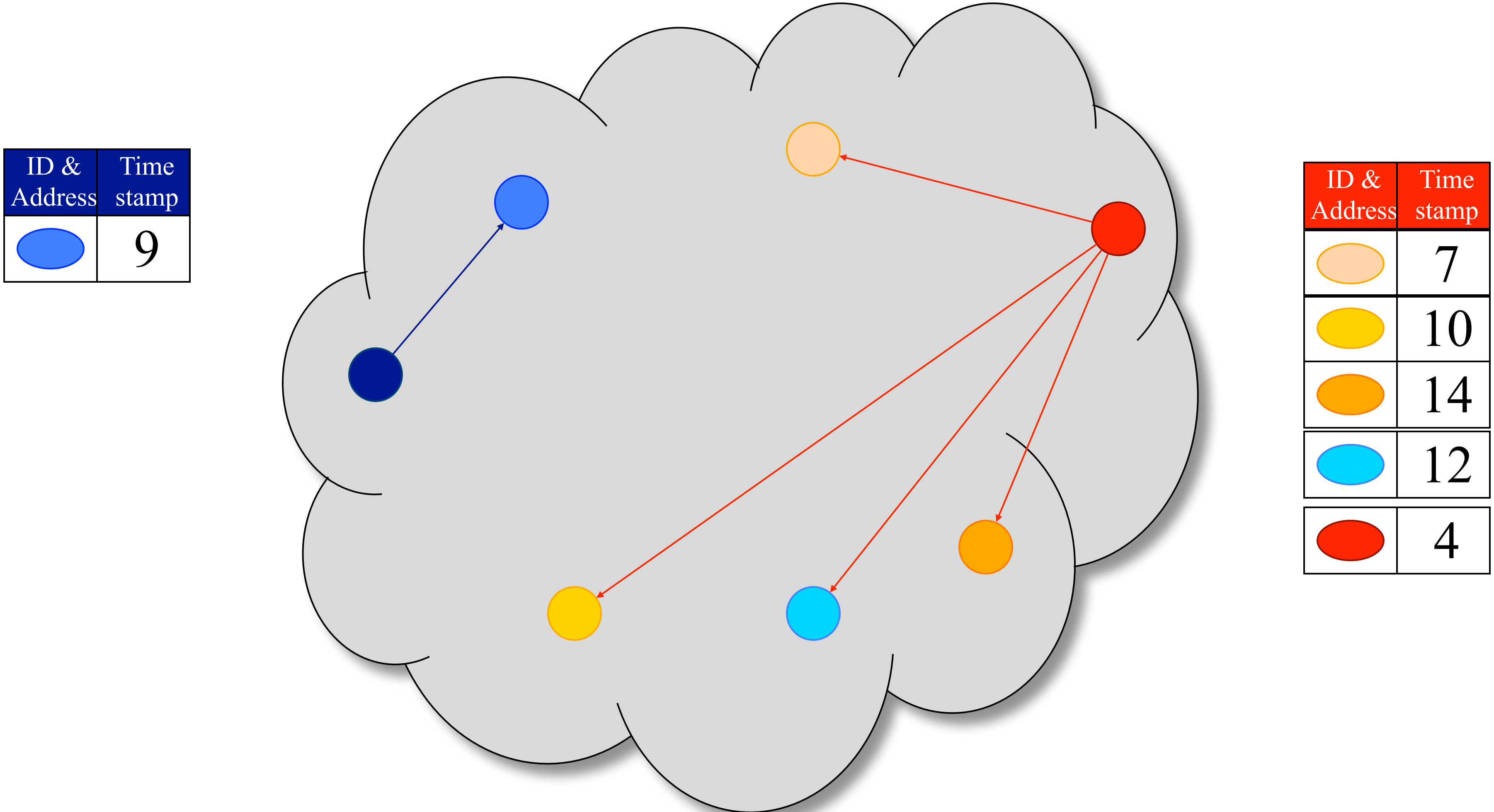
Cyclon



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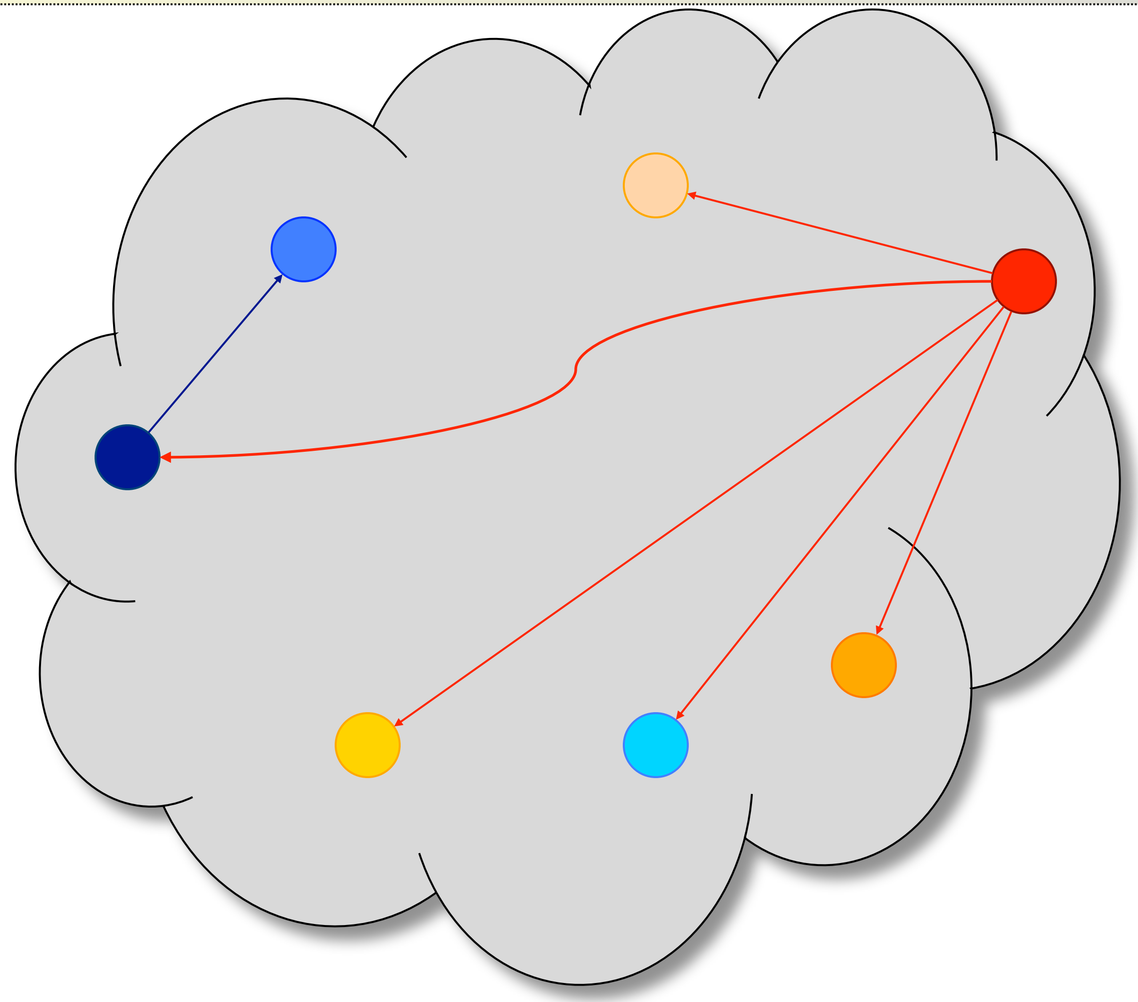
Cyclon

ID & Address	Time stamp
	9

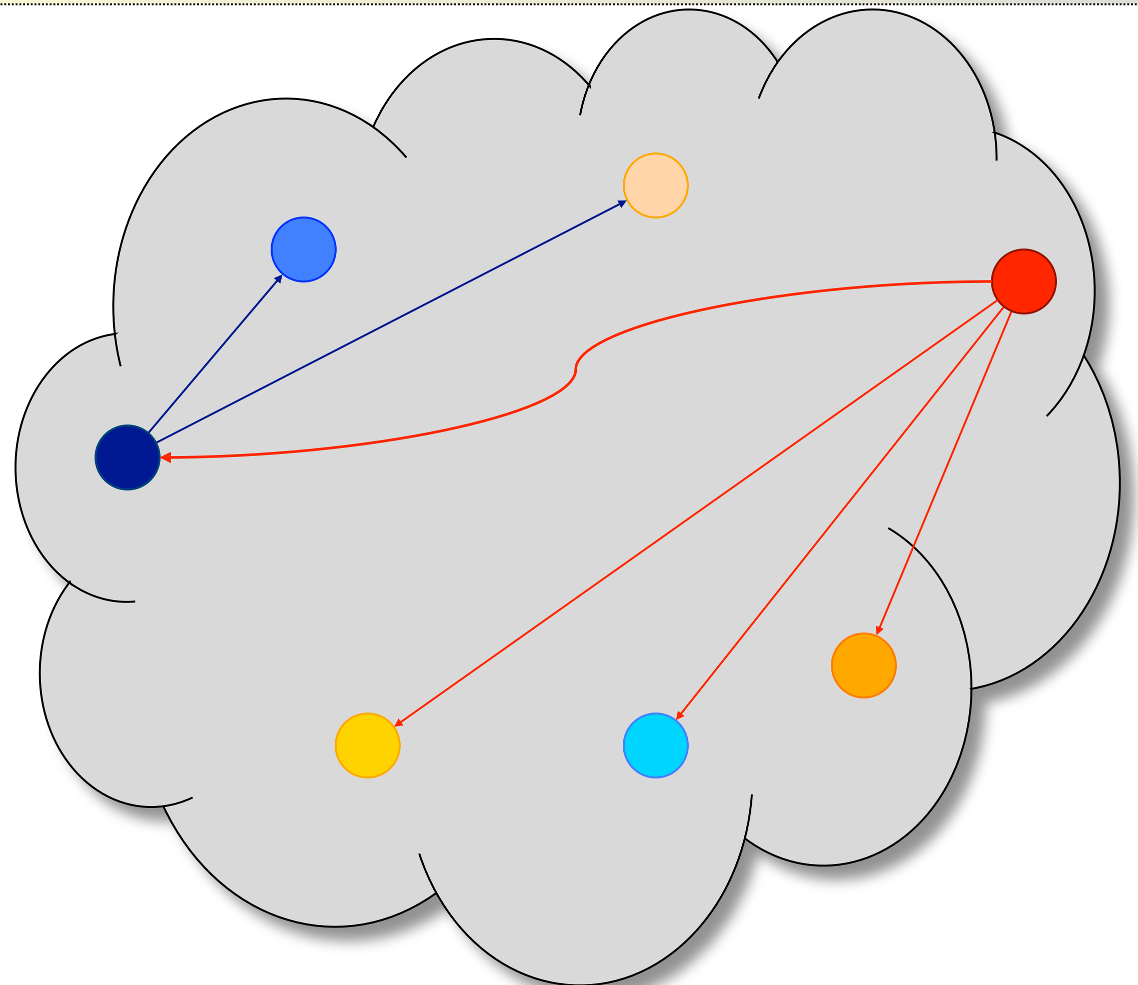


ID & Address	Time stamp
	7
	10
	14
	12
	20

1. Pick <u>oldest</u> peer from my view
2. Exchange some neighbors (the pointers)

Cyclon

ID & Address	Time stamp
	9
	7



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	20

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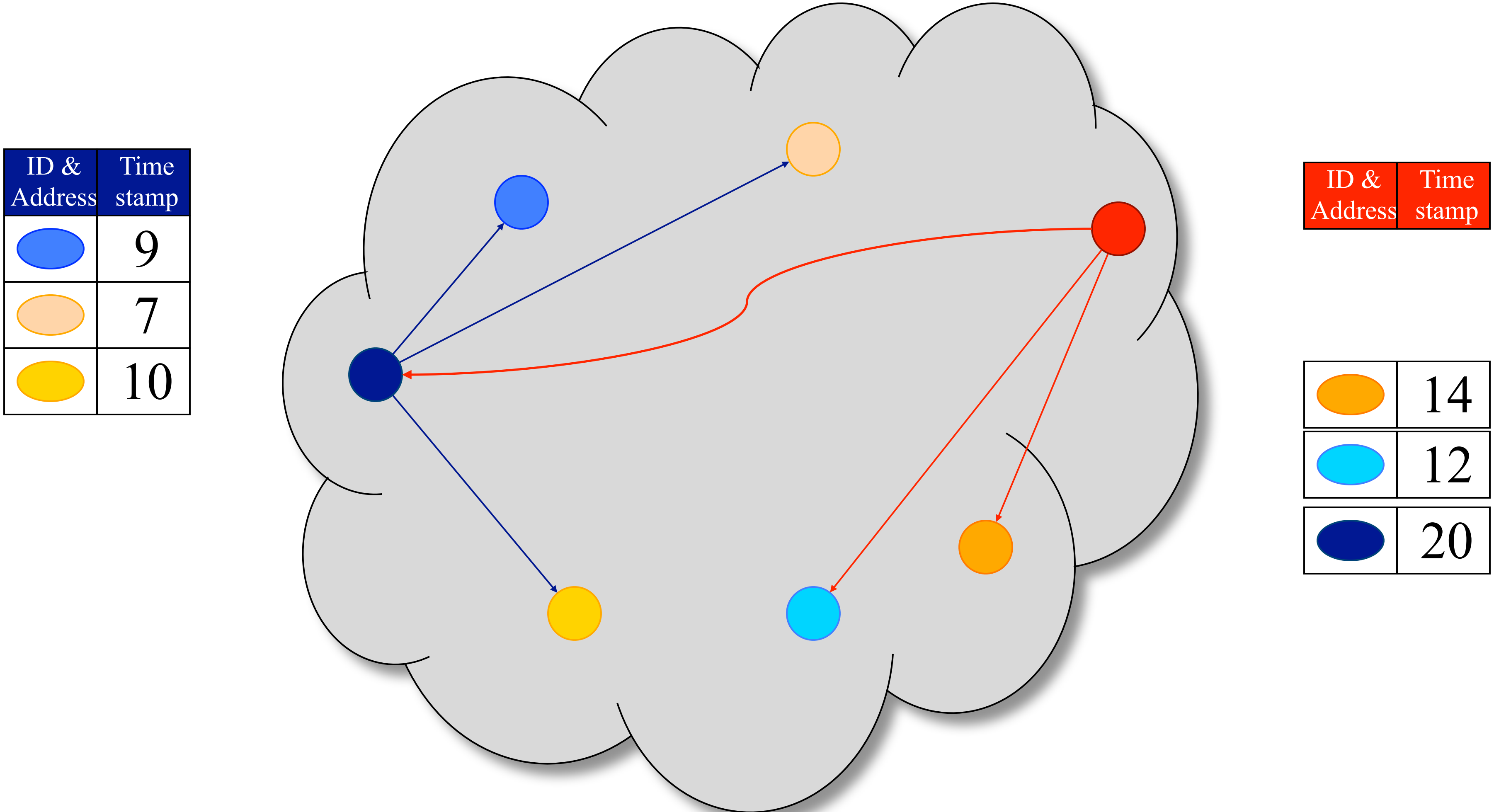
Cyclon



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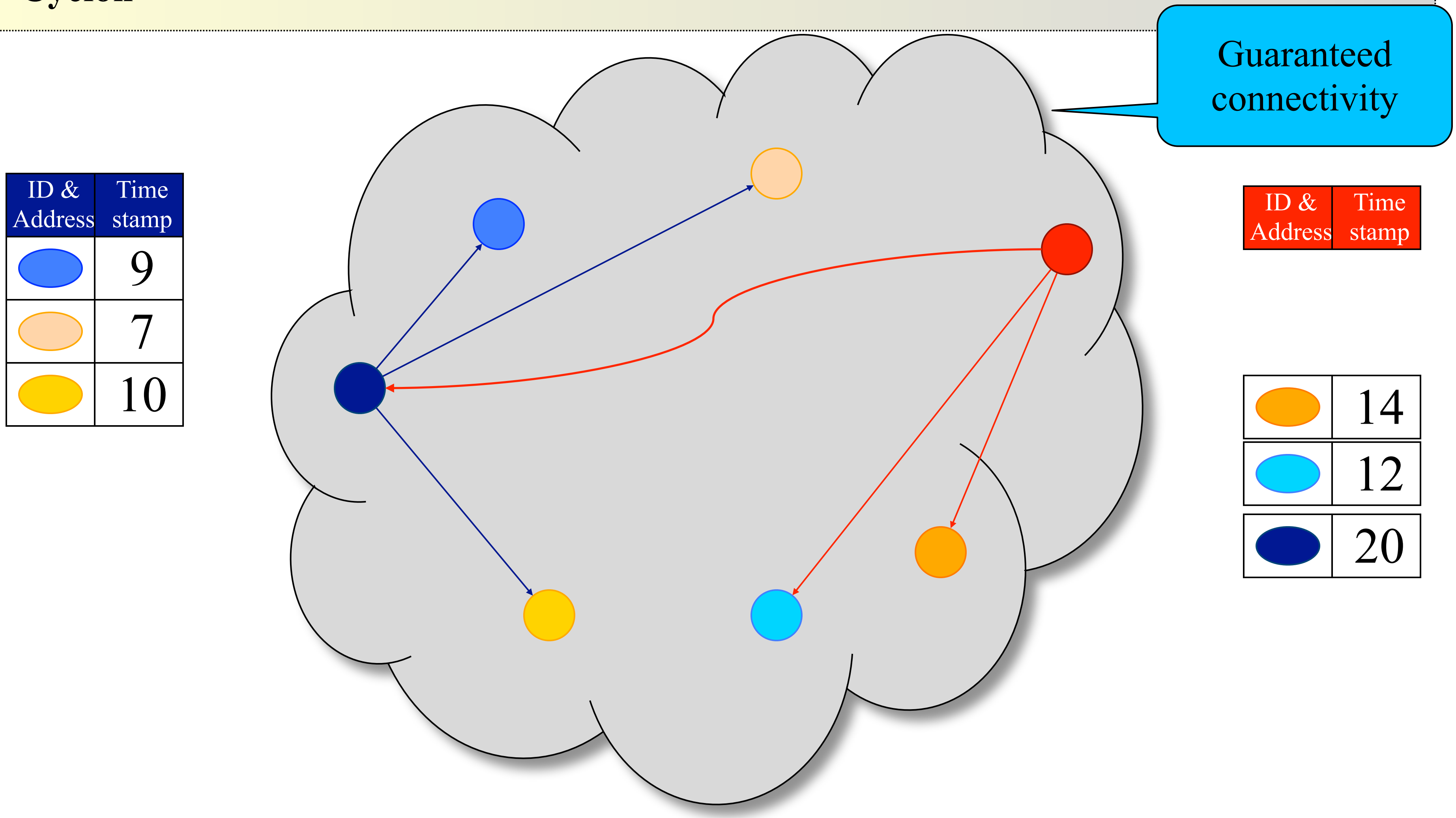
Cyclon



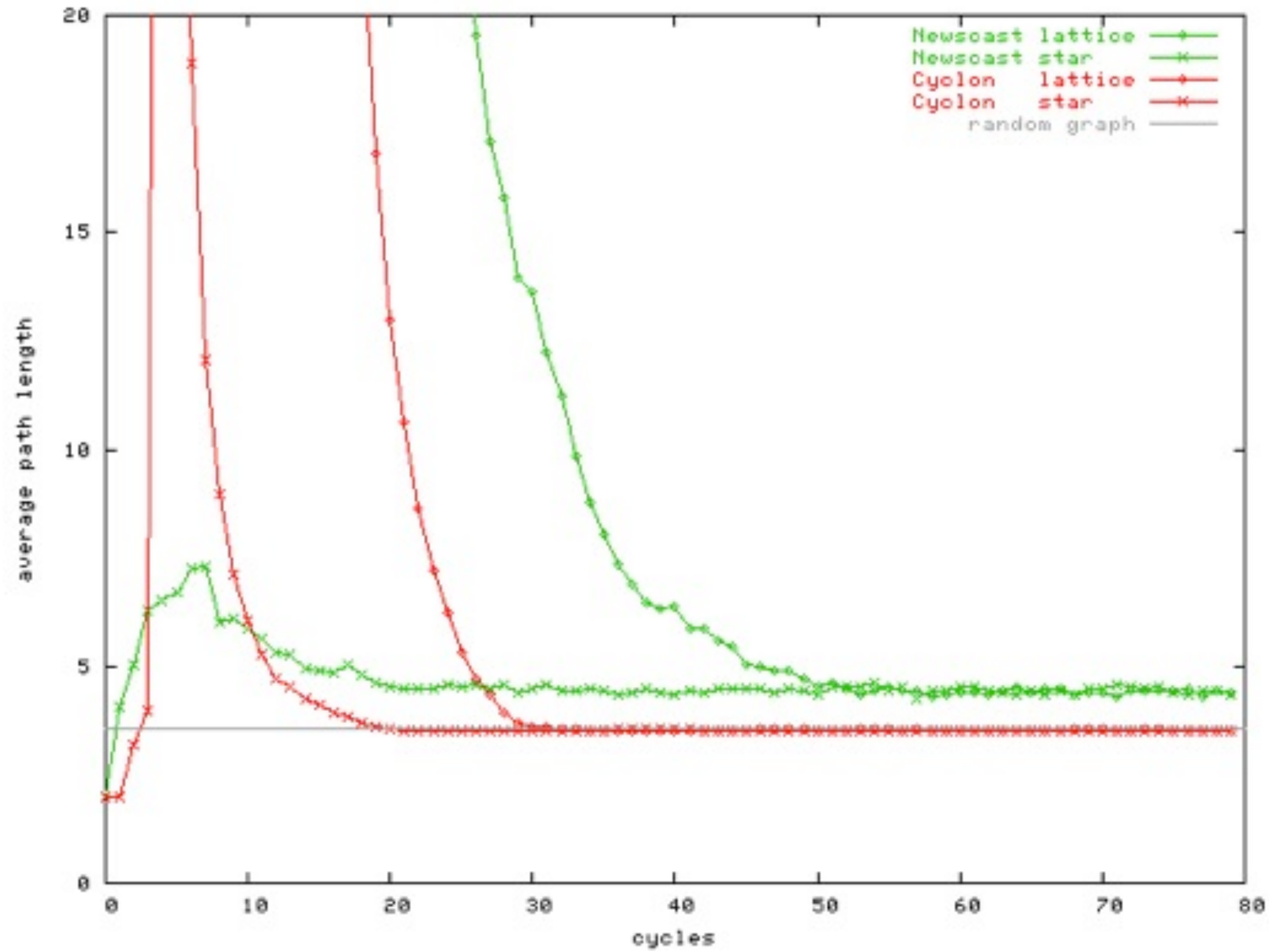
1. Pick <u>oldest</u> peer from my view
2. Exchange some neighbors (the pointers)

Obvious advantages of Cyclon

- **Connectivity is guaranteed**
- **Uses less bandwidth**
  - Only small part of the view is sent

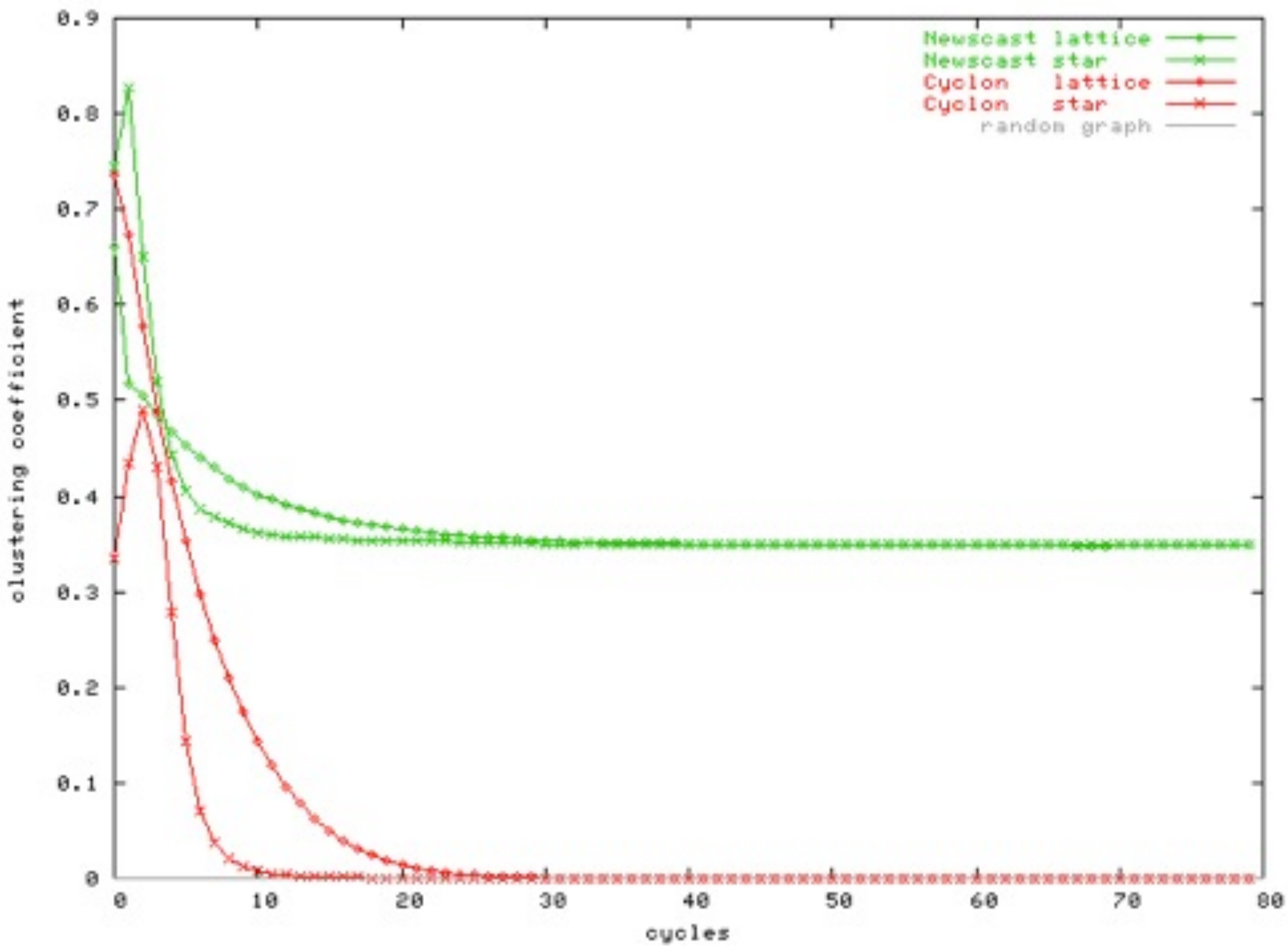
Average path length

- **Indication of the time and cost to flood the network**



Clustering coefficient

- **High clustering is bad for:**
  - Flooding: It results in many redundant messages
  - Self-healing: Strongly connected cluster → weakly connected to the rest of the network



Clustering coefficient

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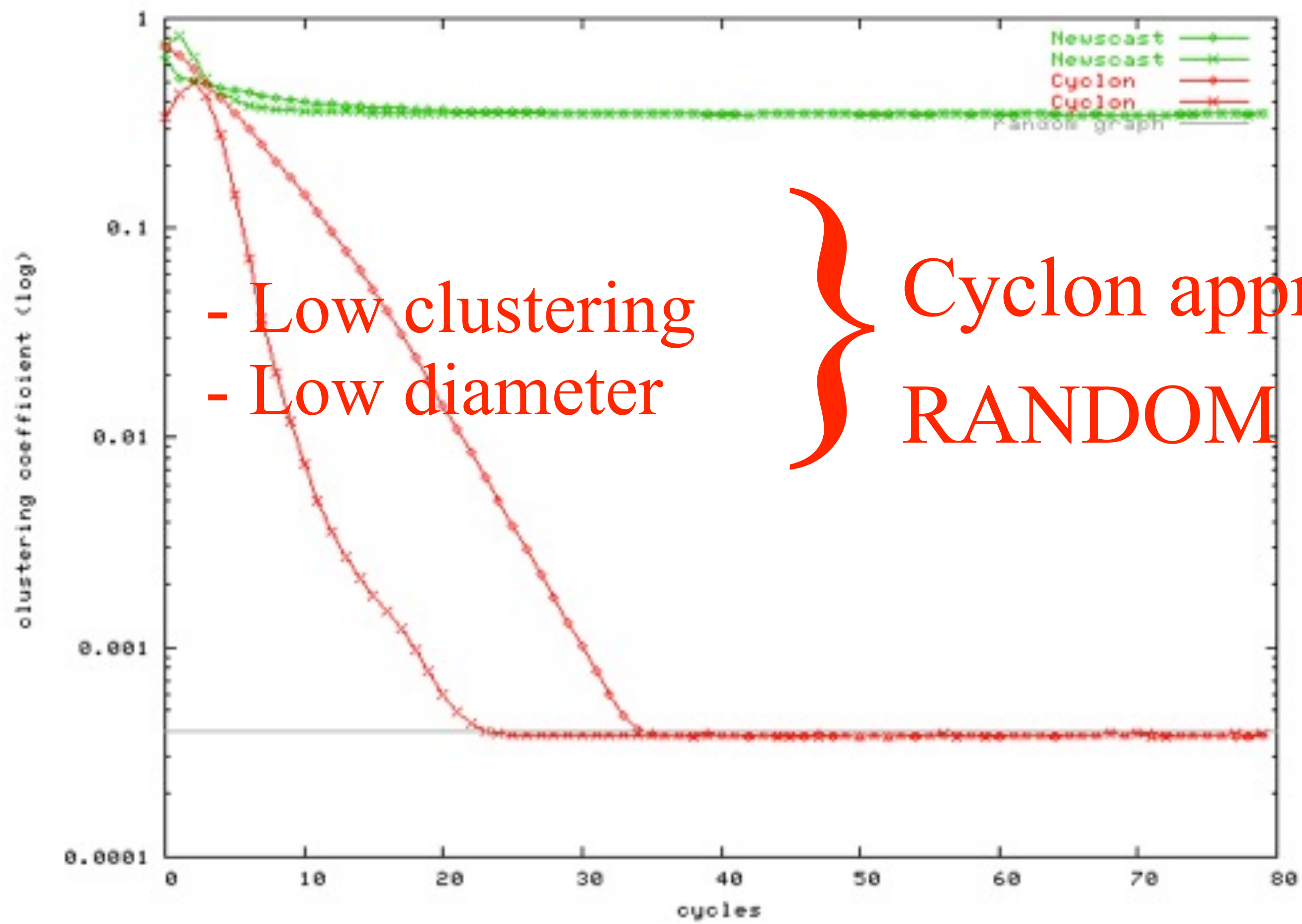
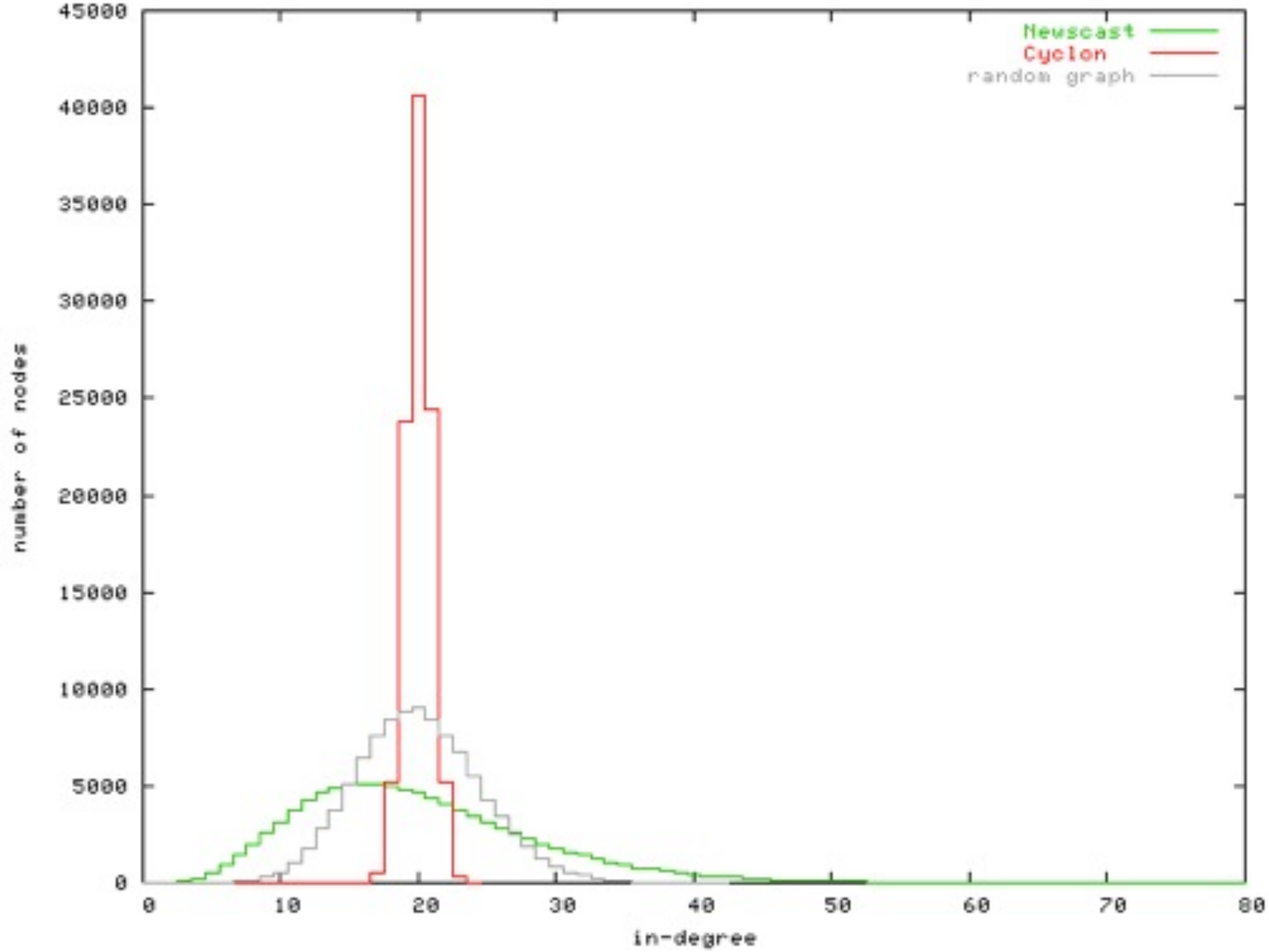


- Low clustering
- Low diameter

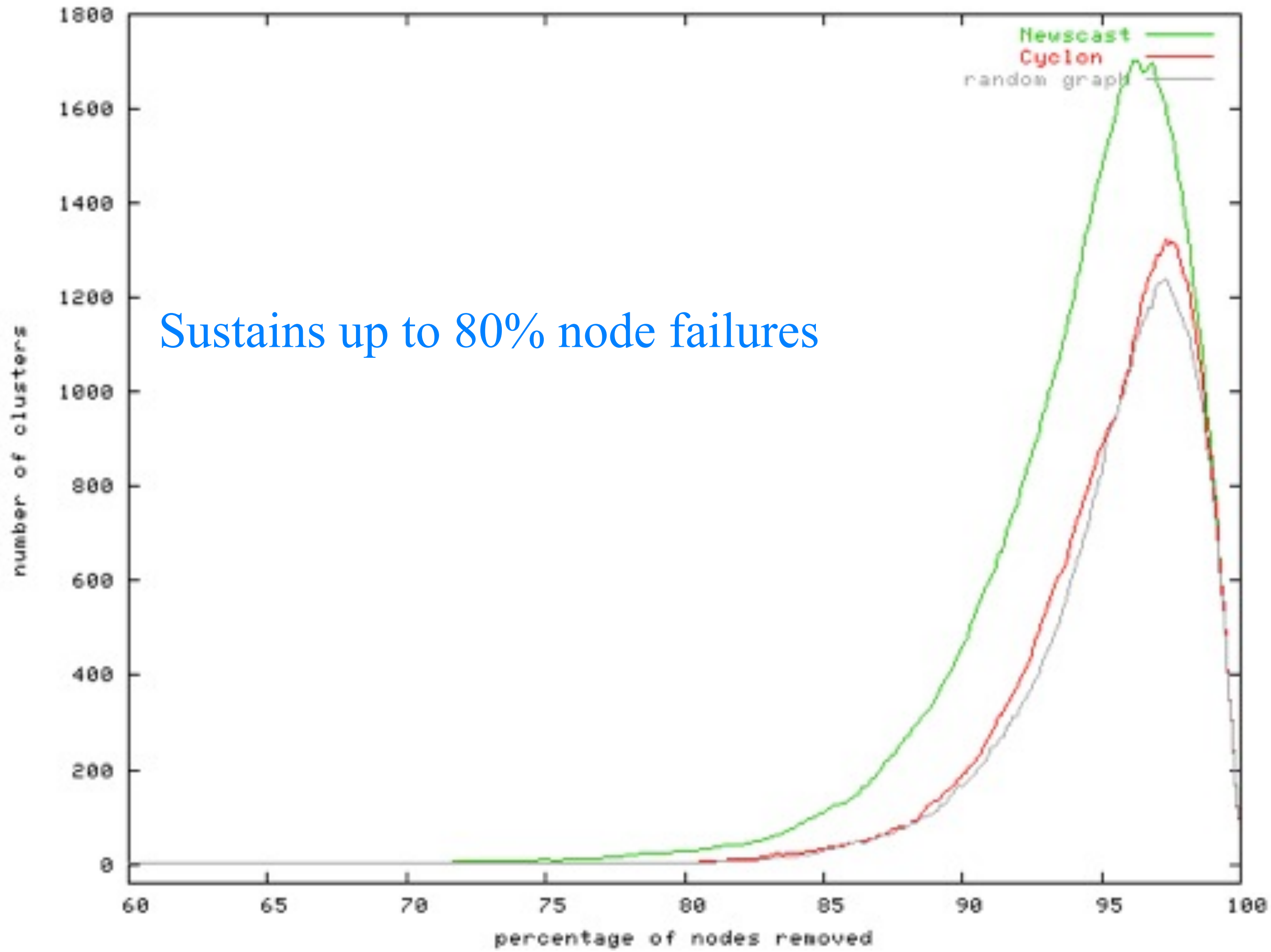
Cyclon approx. a RANDOM GRAPH

In-Degree Distribution

- **Affects:**
  - Robustness (shows weakly connected nodes)
  - Load balancing
  - The way epidemics spread

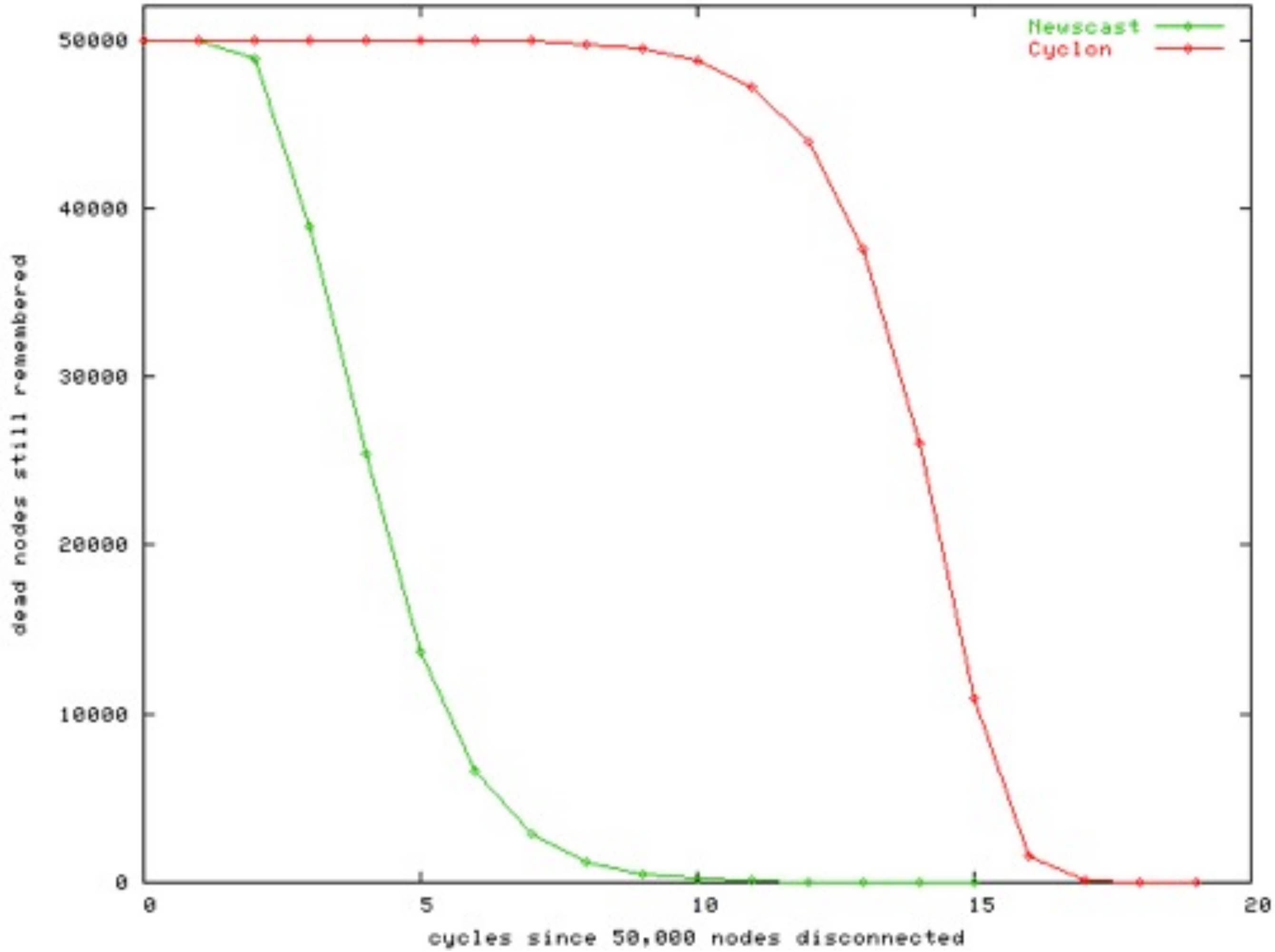


Robustness



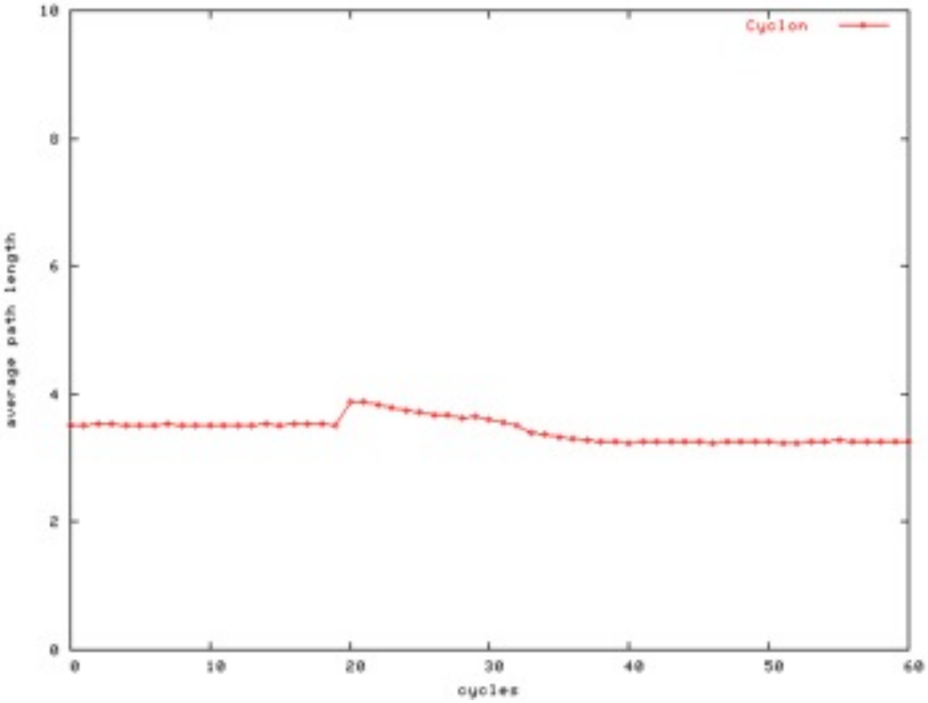
Sustains up to 80% node failures

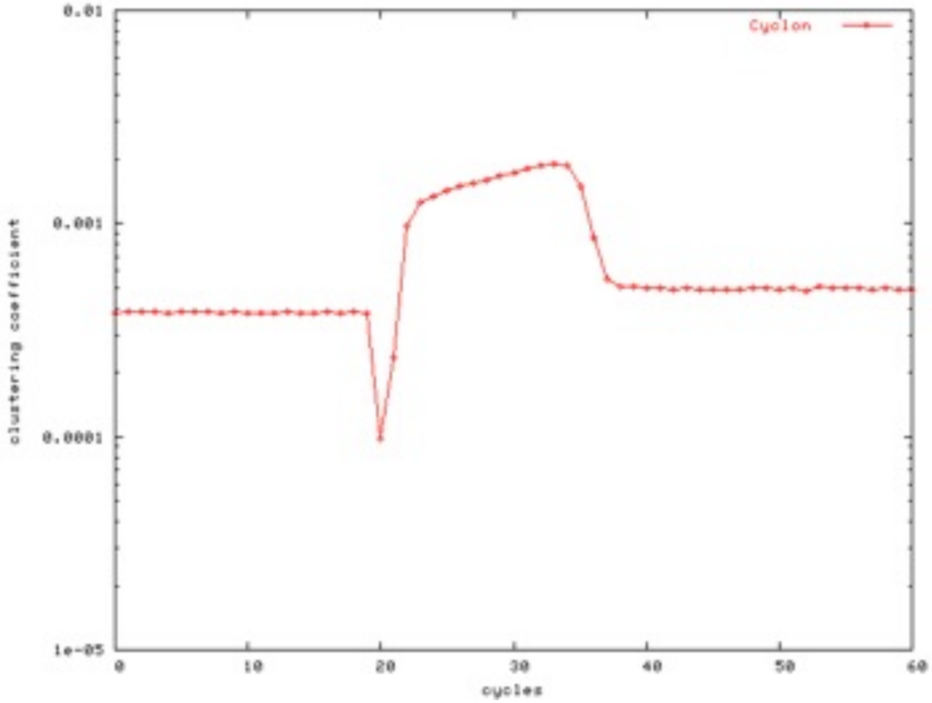
Self-healing behaviour



Self-healing behaviour

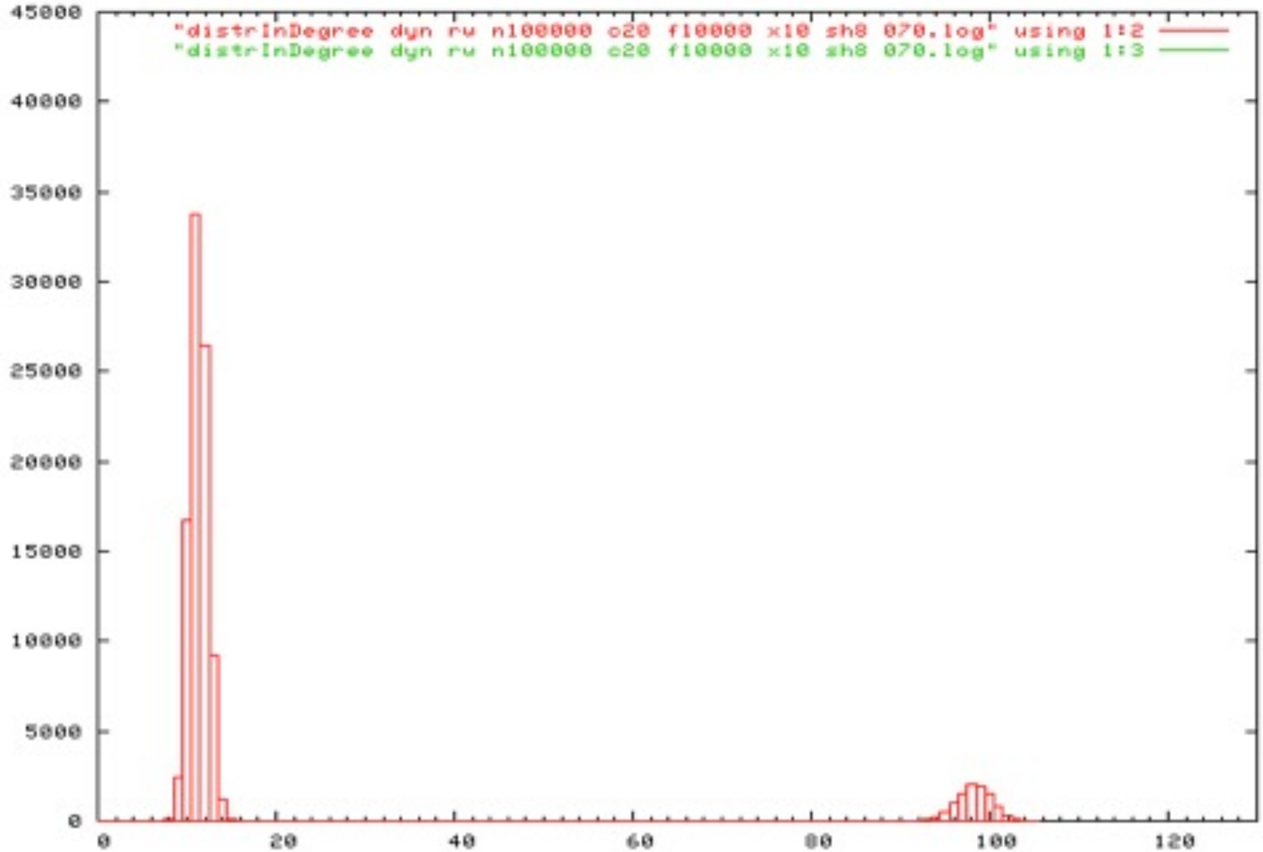
Killed 50,000 nodes at cycle 19





Non-symmetric overlays

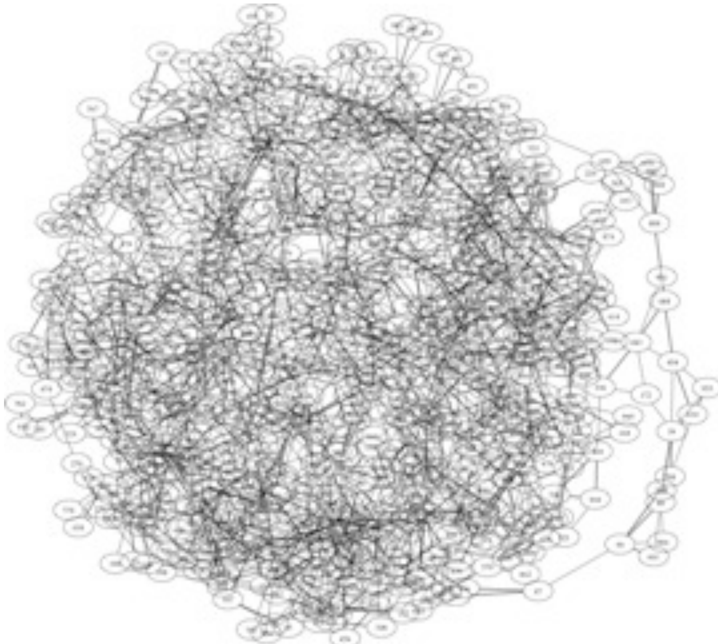
- **Non-uniform period → Non symmetric topologies**
  - A node's in-degree is proportional to its gossiping frequency
  - Can be used to create topologies with "super-nodes"

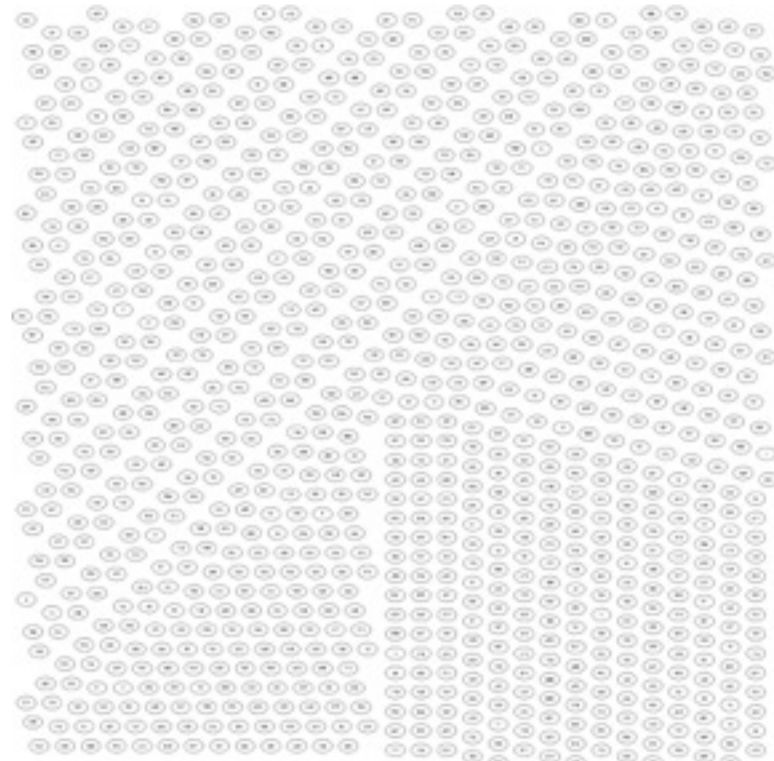


Secure peer sampling

- **This approach is vulnerable to certain kinds of malicious attacks**
- **Hub attack**
  - Hub attack involves some set of colluding nodes always gossiping their own ID's only
  - This causes a rapid spread of only those nodes to all nodes - we say their views become "polluted"
  - At this point all non-malicious nodes are cut-off from each other
  - The malicious nodes may then leave the network leaving it totally disconnected with no way to recover
  - Hence the hub attack hijacks the speed of the Gossip approach to defeat the network

Secure peer sampling

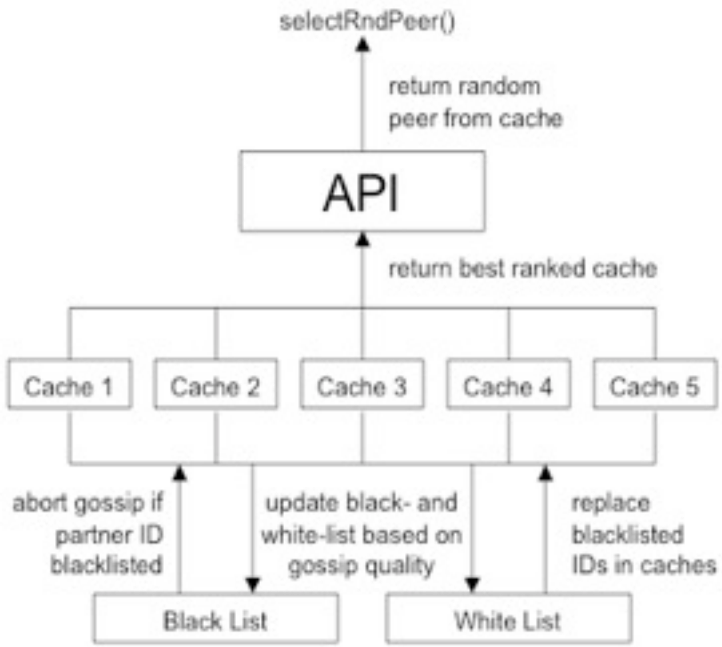


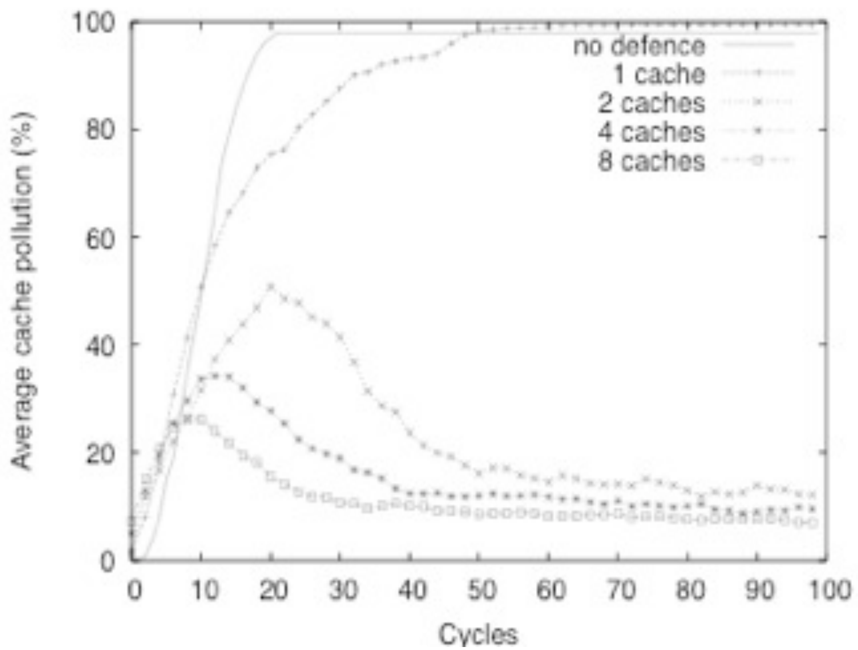


Peer sampling - solution

- **Algorithm**
  - Maintain multiple independent views in each node
  - During a gossip exchange measure similarity of exchanged views
  - With probability equal to proportion of identical nodes in two views reject the gossip and blacklist the node
  - Otherwise, whitelist the node and accept the exchange
  - Apply an aging policy to to both white and black lists
  - When supplying a random peer to API select the current “best” view

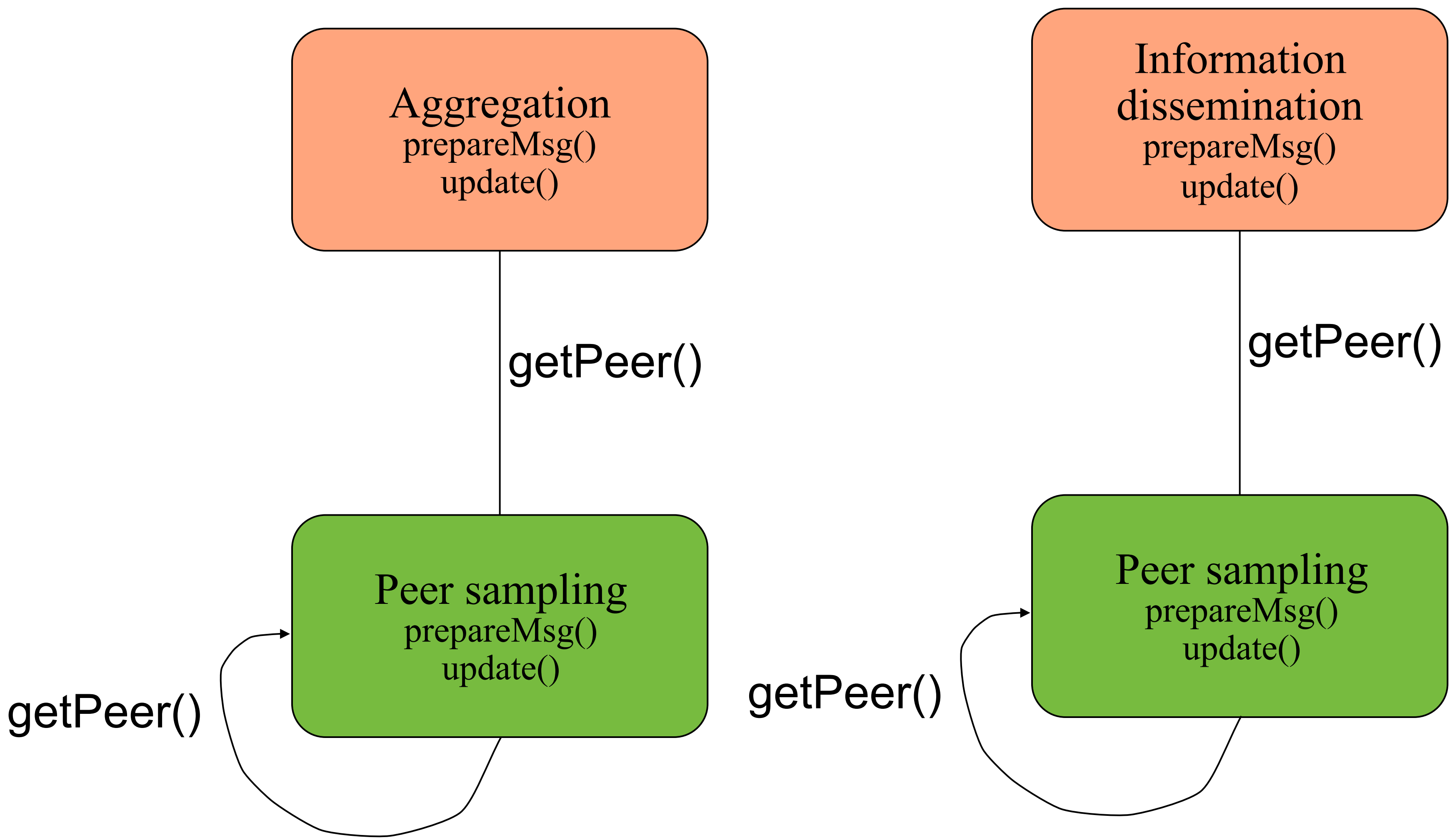
Secure peer sampling





- **1000 nodes**
- **20 malicious nodes**

How to compose peer sampling



- **Bibliography**

  - Márk Jelasity, Alberto Montresor, and Ozalp Babaoglu. *Gossip-based aggregation in large dynamic networks*. ACM Trans. Comput. Syst., 23(1):219-252, August 2005.

- **Additional bibliography**

  - Alberto Montresor, Márk Jelasity, and Ozalp Babaoglu. *Decentralized ranking in large-scale overlay networks*. In Proc. of the 1st IEEE Selfman SASO Workshop, pages 208-213, Isola di San Servolo, Venice, Italy, November 2008.

Aggregation

- **Definition**
  - *The collective name of a set of functions that provide statistical information about a system*
- **Useful in large-scale distributed systems:**
  - The *average* load of nodes in a computing grid
  - The *sum* of free space in a distributed storage
  - The *total number* of nodes in a P2P system
- **Wanted: solutions that are**
  - completely decentralized, robust

A generic gossip protocol - executed by process *p*

Init: initialize my local *state*

Active thread

do once every δ time units

q = getPeer($state$)

s_p = prepareMsg($state$, q)

send (REQ, s_p) **to** q

A "cycle" of length δ

Passive thread

do forever

receive (t, s_q) **from** *

if (t = REQ) **then**

s_p = prepareMsg($state$, q)

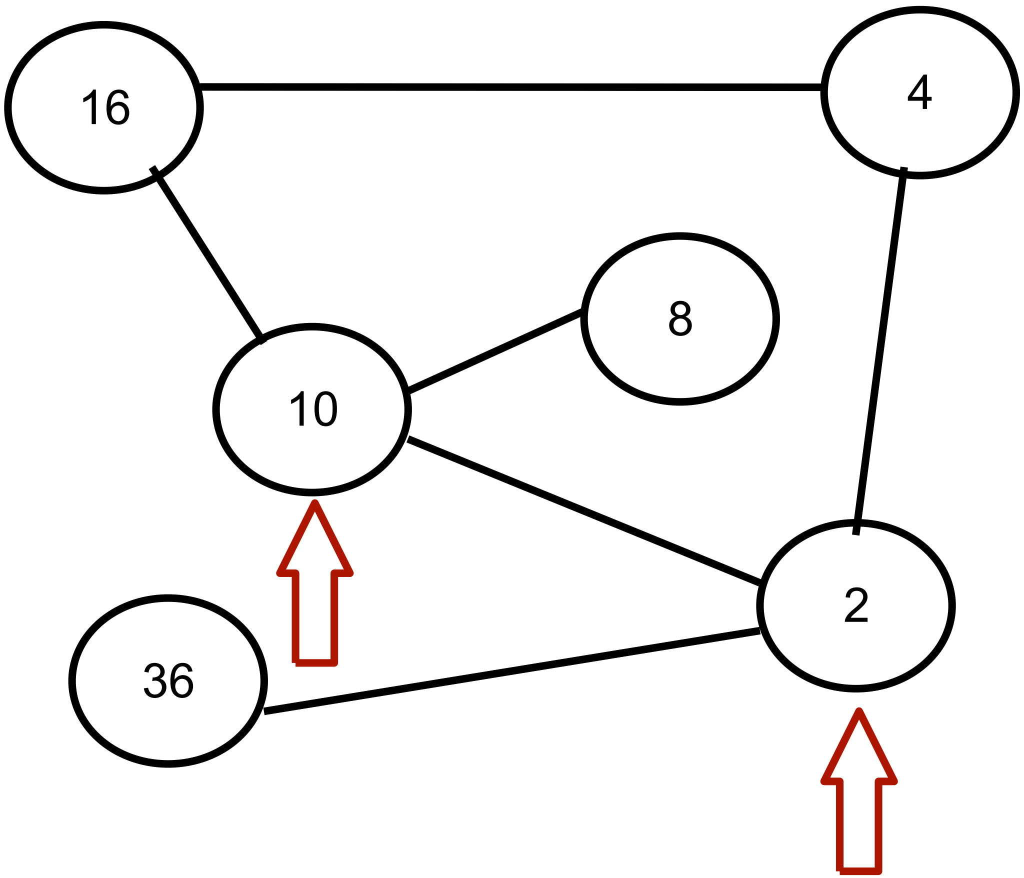
send (REP, s_p) **to** q

$state$ = update($state$, s_q)

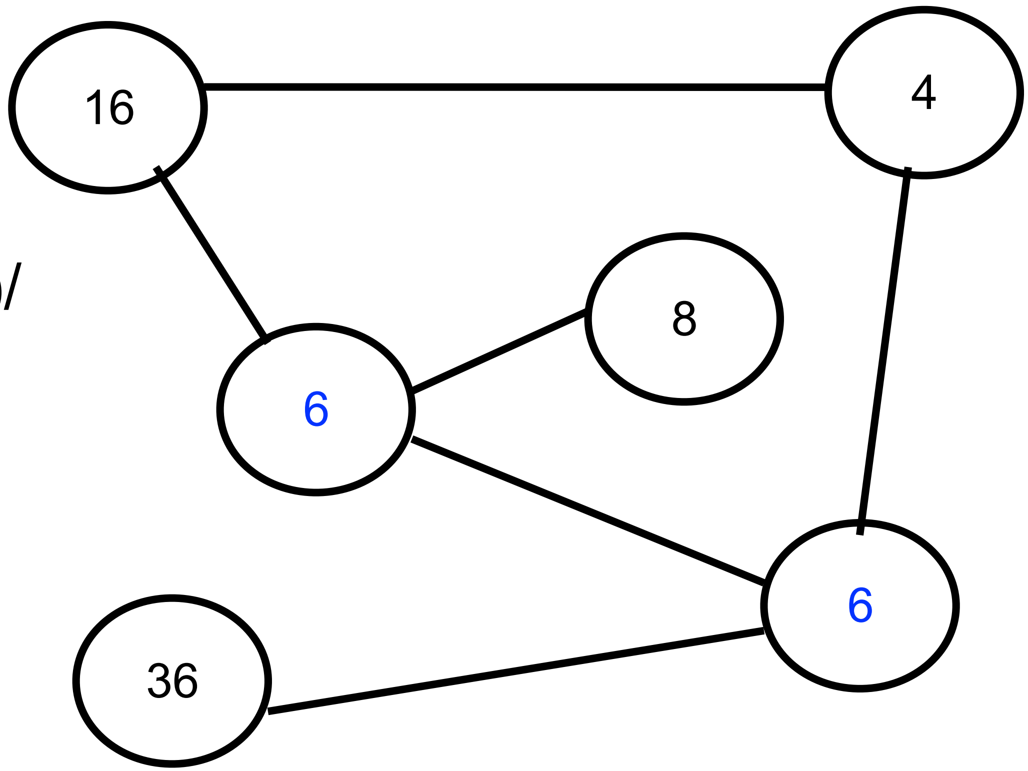
Average Aggregation

- **Using the gossip schema presented above to compute the average**
  - Local state maintained by nodes:
    - a real number representing the value to be averaged
  - Method *getPeer()*
    - invokes *getPeer()* on the underlying peer sampling layer
  - Method prepareMessage()
    - **return** $state_p$
  - Function update($state_p$, $state_q$)
    - **return** $(state_p+state_q)/2$

The idea

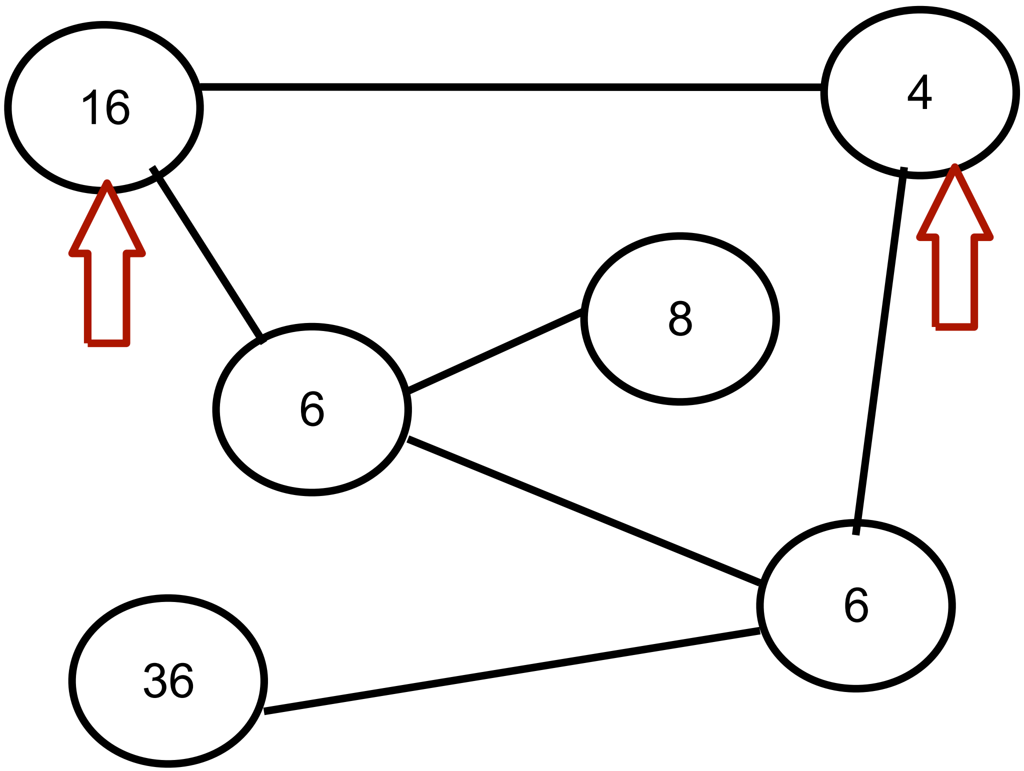


Basic operation

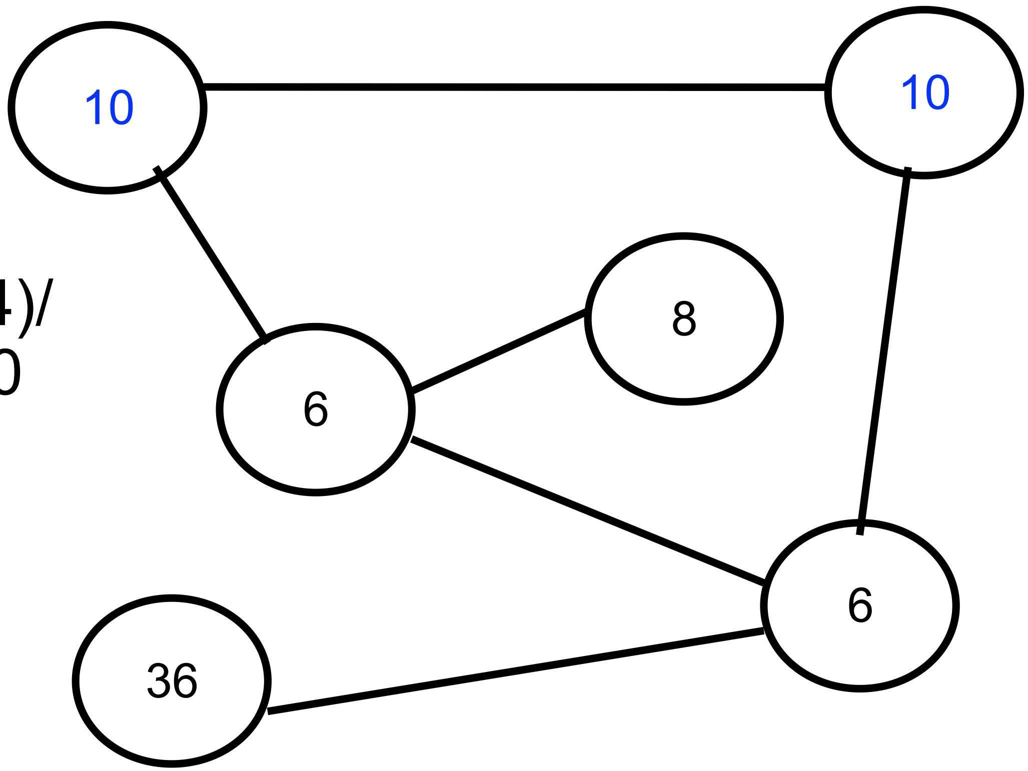


(10+2)/
2=6

Basic operation



Basic operation

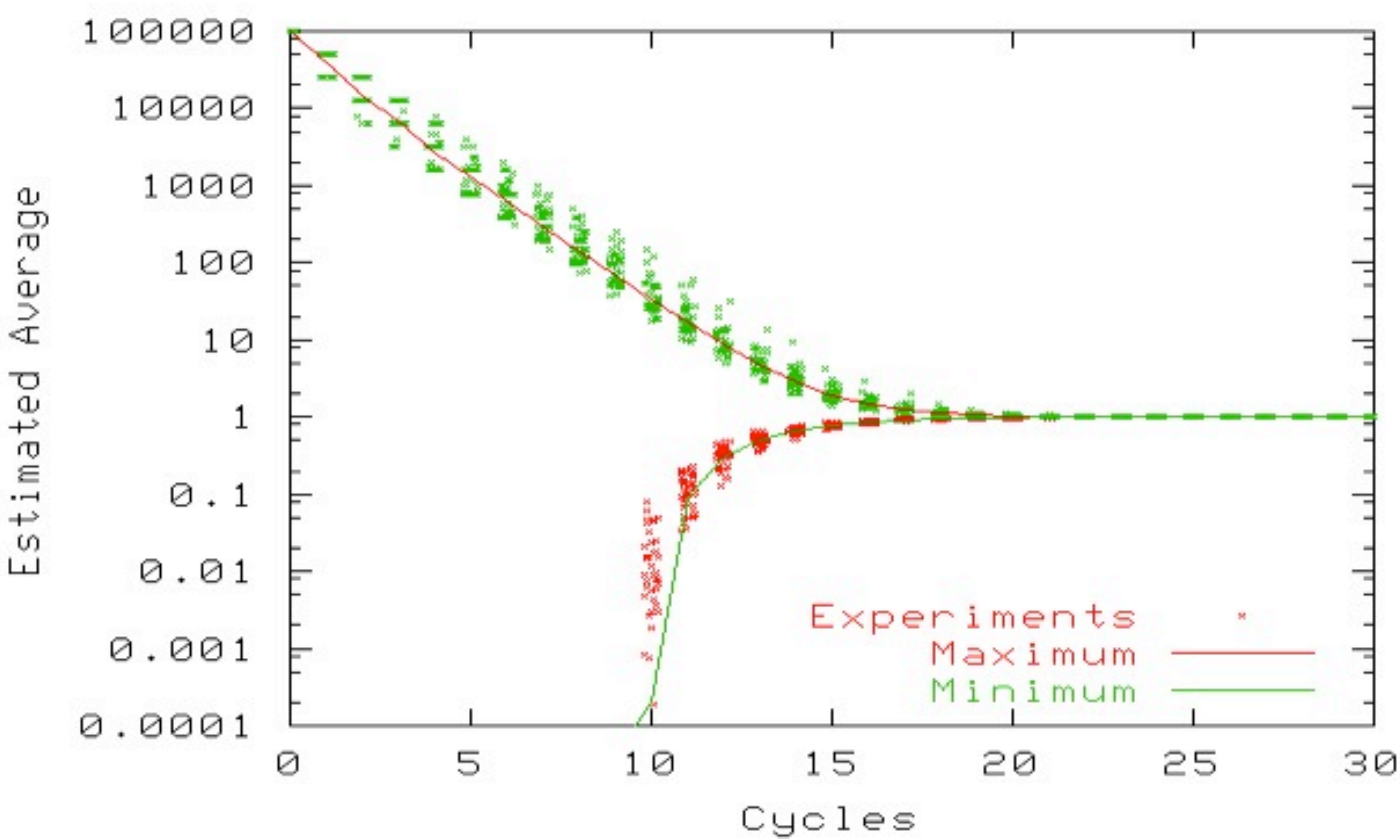


(16+4)/
2=10

Some Comments

- **If the graph is connected, each node converges to the average of the original values**
- **After each exchange:**
  - Average does not change
  - Variance is reduced
- **Different from load balancing due to lack of constraints**

A run of the protocol



Questions

- Which topology is optimal?
- How fast is convergence on different topologies?
- What are the effects of node/link failures, message omissions?

- Fully connected topol.: exponential convergence
- Random topology: practically exponential.
- Link failures: not critical
- Crashes/msg omissions can destroy convergence
- but we have a solution for that

- **From the "distributed" version to a centralized one**

do N times
  $(p, q) = getPair()$
  // perform elementary aggregation step
  $a[p] = a[q] = (a[p] + a[q])/2$

- **Notes:**
  - Vector $a[1 \ldots N]$
  - N number of nodes
  - The code corresponds to the execution of single cycle

Some definitions

- **We measure the speed of convergence of empyrical variance at cycle *i***

$$\mu_i = \frac{1}{n}\sum_{k=1}^{n} a_i[k]$$

$$\sigma_i^2 = \frac{1}{n}\sum_{k=1}^{n}(\mu_i - a_i[k])^2$$

- **Additional definitions**
  - Elementary *variance reduction step*: $\sigma_{i+1}^2 / \sigma_i^2$
  - *Variable φ_k*: the number of times that node *k* has been selected from *getPair*()

The base theorem

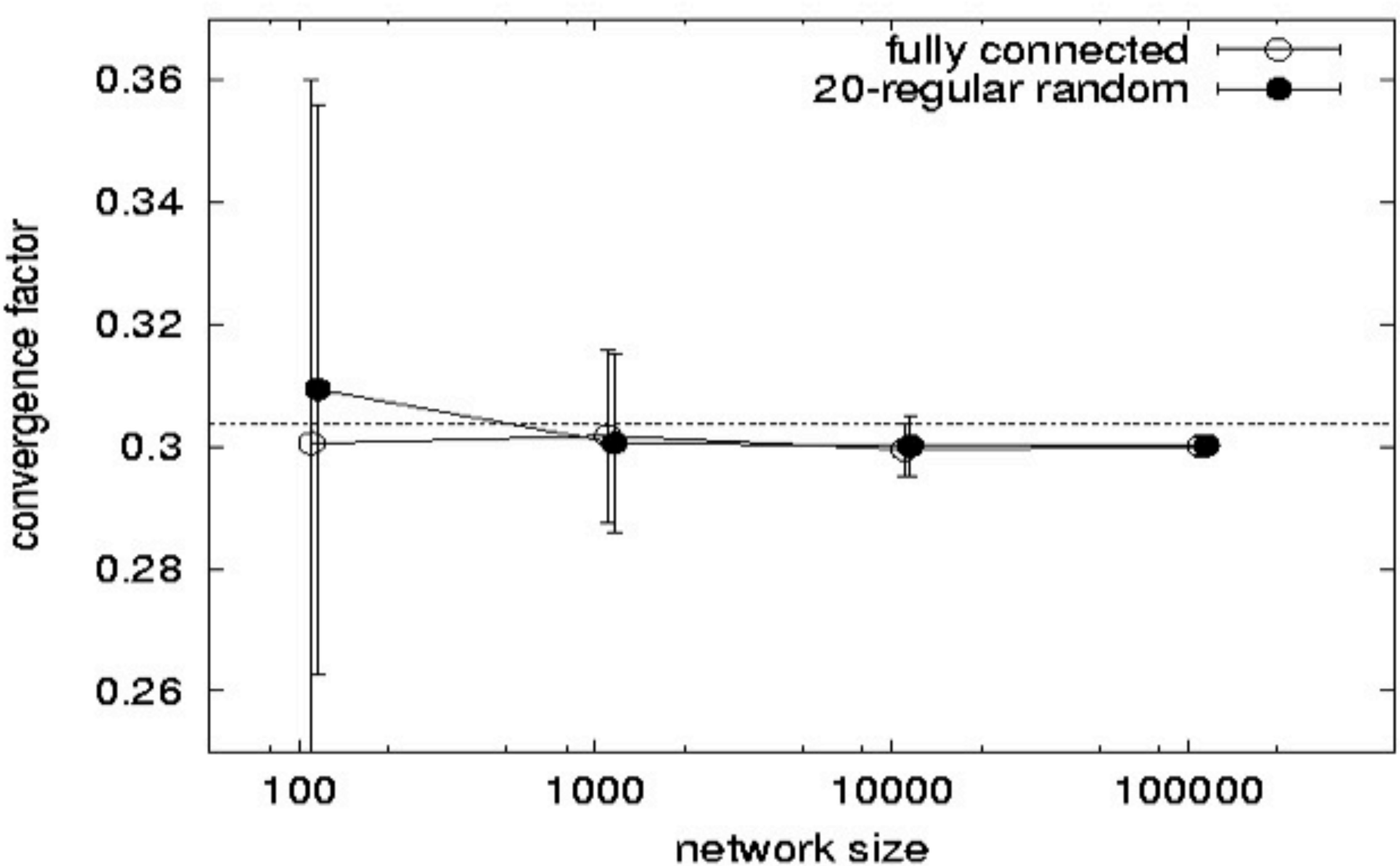
- **If**
  - Each pair of values selected by each call to *getPair*() are uncorrelated;
  - the random variables φ_k are identically distributed;
    - let φ denote a random variable with this common distribution
  - after (p, q) is returned by *getPair*() the number of times p and q will be selected by the remaining calls to *getPair*() has identical distribution
- **Then:**

$$E(\sigma_{i+1}^2) = E(2^{-\varphi})\ \sigma_i^2$$

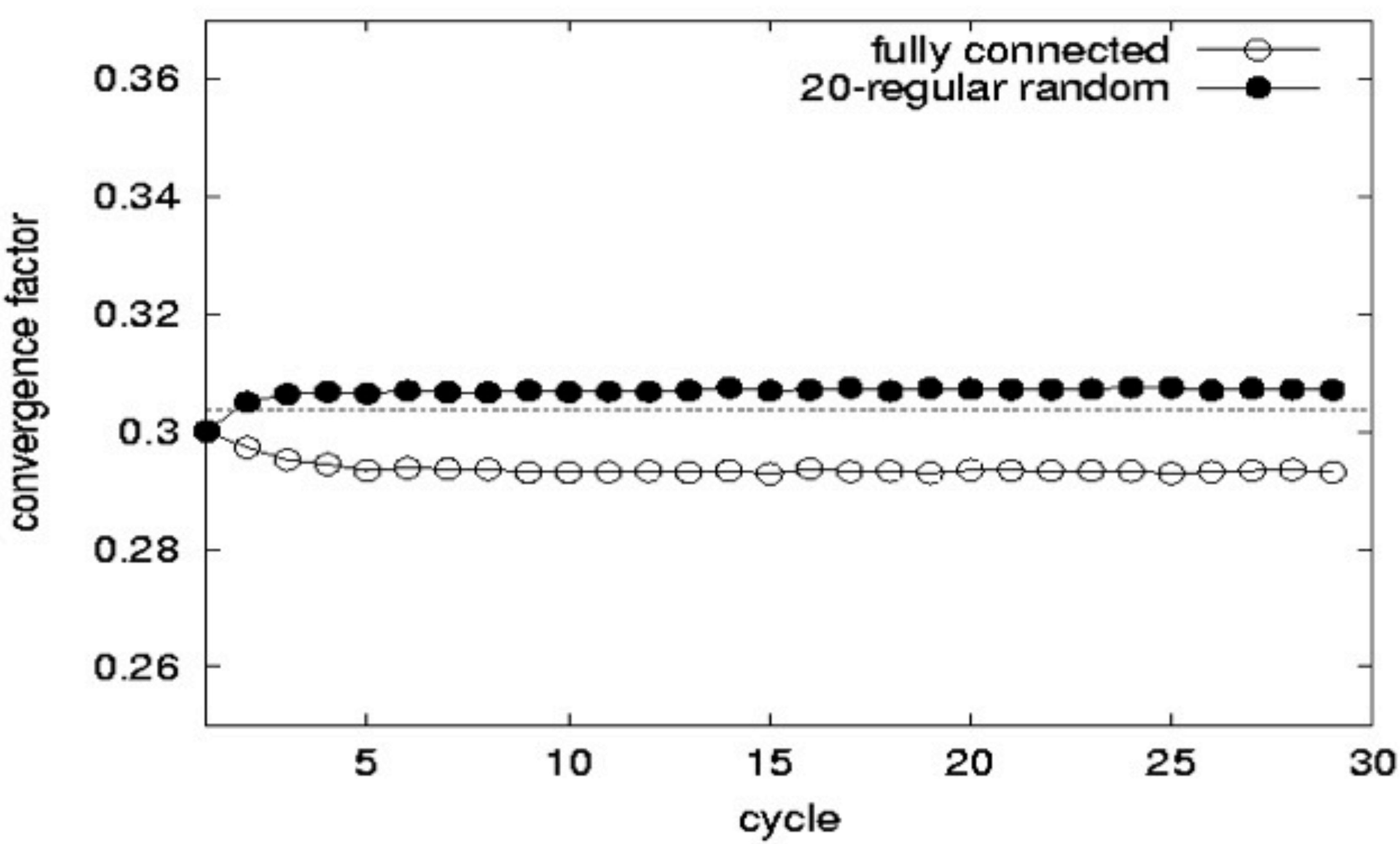
Results

- **Optimal case:** *$E(2^{-\varphi}) = E(2^{-2}) = 1/4$*
    - *getPair*() implements perfect matching
    - no corresponding local protocol
- **Random case:** $E(2^{-\varphi}) = 1/e$
    - *getPair*() implements random global sampling
    - A local corresponding protocol exists
- **Aggregation protocol:** $E(2^{-\varphi}) = 1/(2\sqrt{e})$
    - Scalability: results independent of N
    - Efficiency: convergence is very fast

Scalability



Convergence factor



Other functions

- **Average:** $update(a,b) := (a+b)/2$
- **Geometric:** $update(a,b) := (a \cdot b)^{1/2}$
- **Min/max:** $update(a,b) := min/max(a,b)$
- **Sum:** Average · Count
- **Product:** $\text{Geometric}^{\text{Count}}$
- **Variance:** compute $\overline{a^2} - a^2$

Means

How?

Obtained from means

Counting

- **The counting protocol**
  - Init: one node starts with 1, the others with 0
  - Expected average: $1/N$
- **Problem: how to select that "one node"?**
  - Concurrent instances of the counting protocol
  - Each instance is lead by a different node
  - Messages are tagged with a unique identifier
  - Nodes participate in all instances
  - Each node acts as leader with probability $p=c/NE$

Adaptivity

- **The generic protocol is not adaptive**
  - Dynamism of the network
  - Variability of values
- **Periodical restarting mechanism**
  - At each node:
    - The protocol is terminated
    - The current estimate is returned as the aggregation output
    - The current values are used to re-initialize the estimates
    - Aggregation starts again with fresh initial values

Adaptivity

- **Termination**
  - Run protocol for a predefined number of cycles λ
  - λ depends on
    - required accuracy of the output
    - the convergence factor that can be achieved
- **Restarting**
  - Divide run in consecutive epochs of length Δ
  - Start a new instance of the protocol in each epoch
  - Concurrent epochs depending on the ratio $\lambda\delta / \Delta$

Dynamic Membership

- **When a node joins the network**
  - Discovers a node *n* already in the network
  - Membership: initialization of the local neighbors
  - Receives from *n*:
    - Next epoch identifier
    - The time until the start of the next epoch
  - To guarantee convergence:
    Joining node is not allowed to participate in the current epoch

Dynamic Membership

- **Dealing with crashes, message omissions**
  - In the active thread:
    - A timeout is set to detect the failure of the contacted node
    - If the timeout expires before the message is received → the exchange step is skipped
- **What are the consequences?**
  - In general: convergence will slow down
  - In some cases: estimate may converge to the wrong value

Synchronization

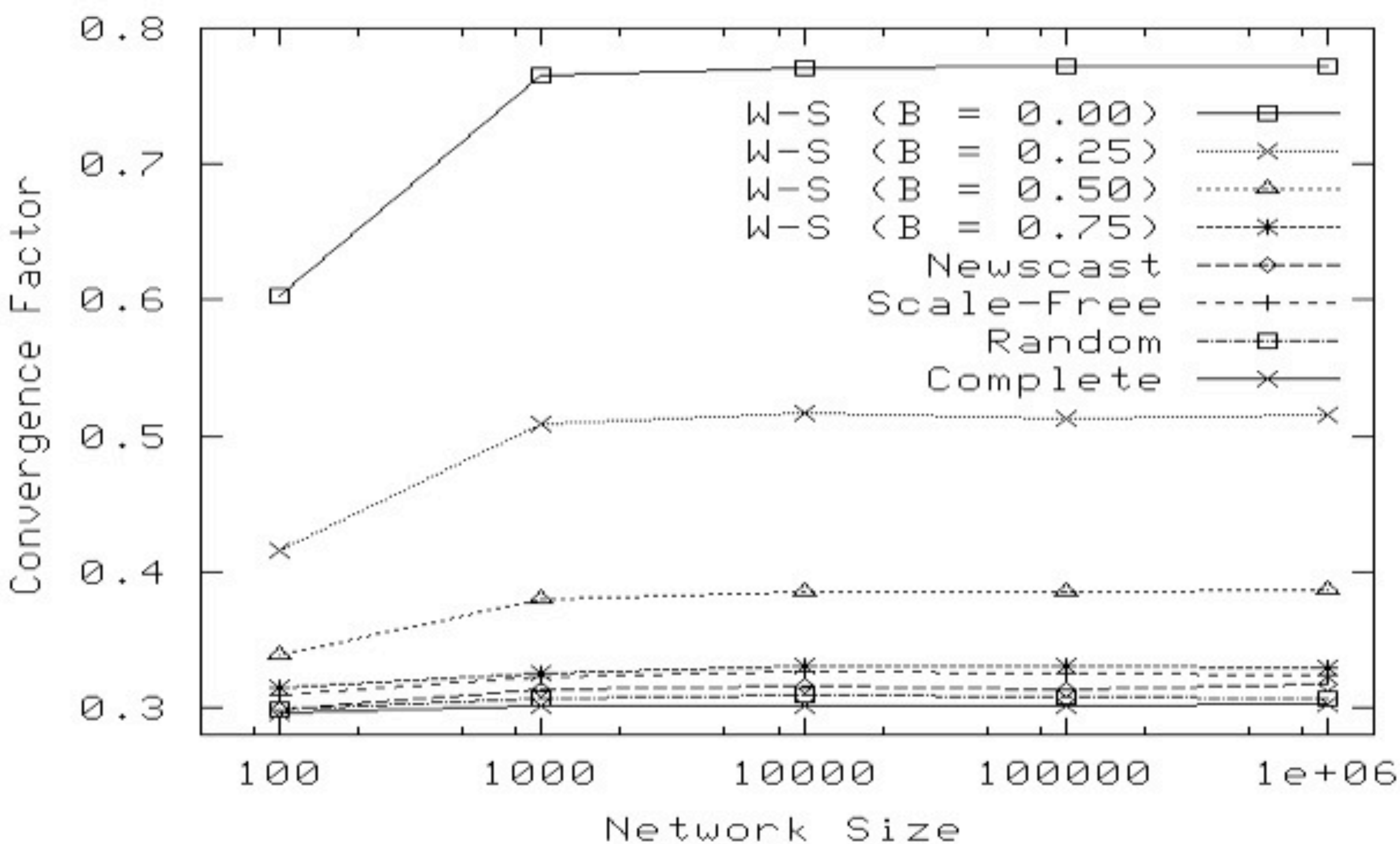
- **The protocol described so far:**
  - Assumes synchronized epochs and cycles
  - Requires synchronized clocks / communication
- **This is not realistic:**
  - Clocks may drift
  - Communication incurs unpredictable delays
- **Complete synchronization is not needed**
  - It is sufficient that the time between the first/ last node starting to participate in an epoch is bounded

Cost analysis

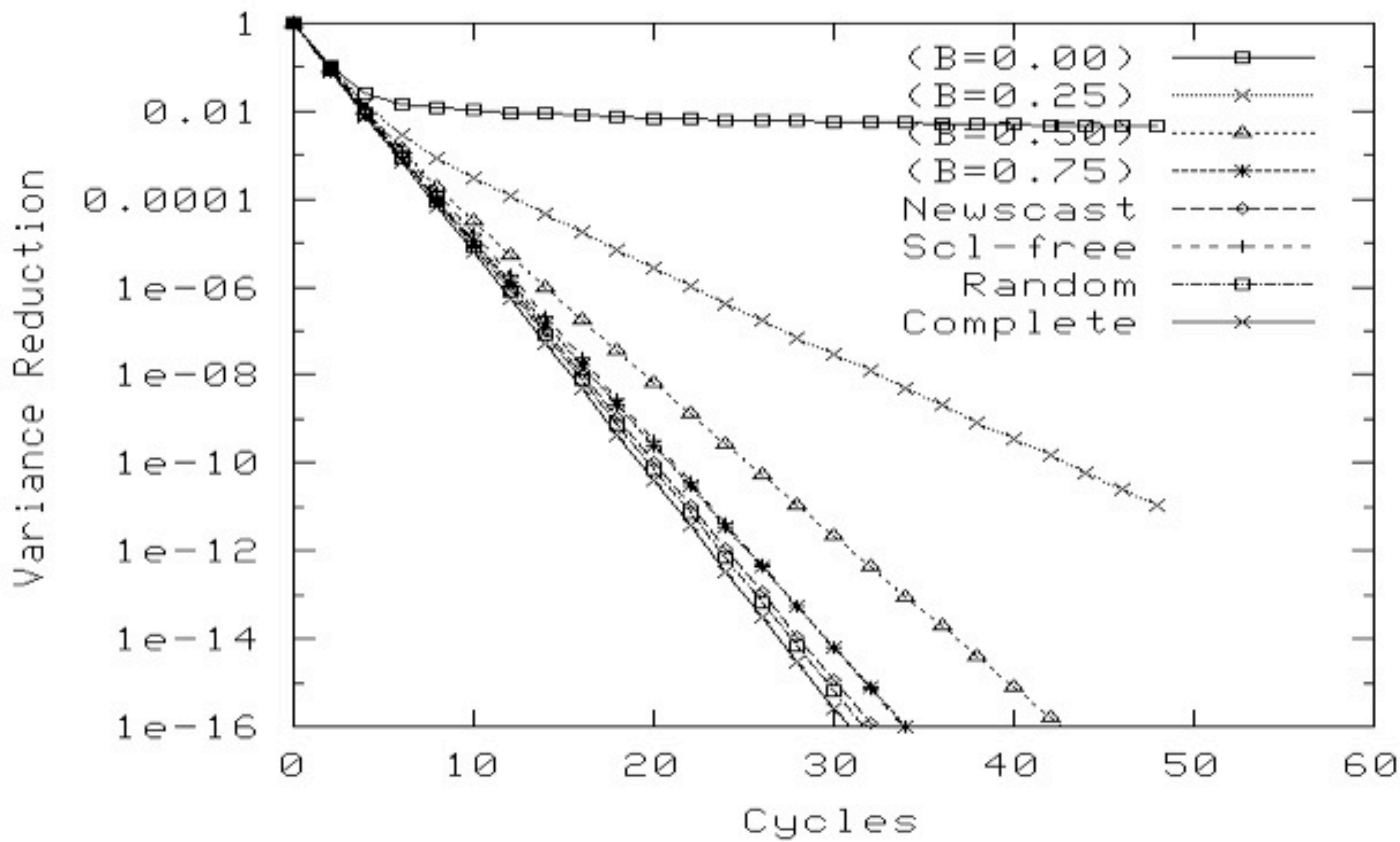
- **If the overlay is sufficiently random:**
  - exchanges = 1 + φ, where φ has Poisson distribution with average 1
- **Cycle length δ defines the time complexity of convergence:**
  - Small δ: fast convergence
  - Large δ: small cost per unit time, may be needed to complete exchanges
- **λ defines the accuracy of convergence:**
  - $E(\sigma_\lambda^2)/E(\sigma_0^2) = \rho\lambda$, ε the desired accuracy → $\lambda \geq \log_\rho \varepsilon$

Topologies

- **Theoretical results are based on the assumption that the underlying overlay is sufficiently random**
- **What about other topologies?**
  - Our aggregation scheme can be applied to generic connected topologies
  - Small-world, scale-free, newscast, random, complete
  - Convergence factor depends on randomness


W-S (B = 0.00)
W-S (B = 0.25)
W-S (B = 0.50)
W-S (B = 0.75)
Newscast
Scale-Free
Random
Complete
Convergence Factor
0.8
0.7
0.6
0.5
0.4
0.3
100
1000
10000
100000
1e+06
Network Size

Topologies



Variance Reduction
Cycles
(B=0.00)
(B=0.25)
(B=0.50)
(B=0.75)
Newscast
Scl-free
Random
Complete
1
0.01
0.0001
1e-06
1e-08
1e-10
1e-12
1e-14
1e-16
0
10
20
30
40
50
60

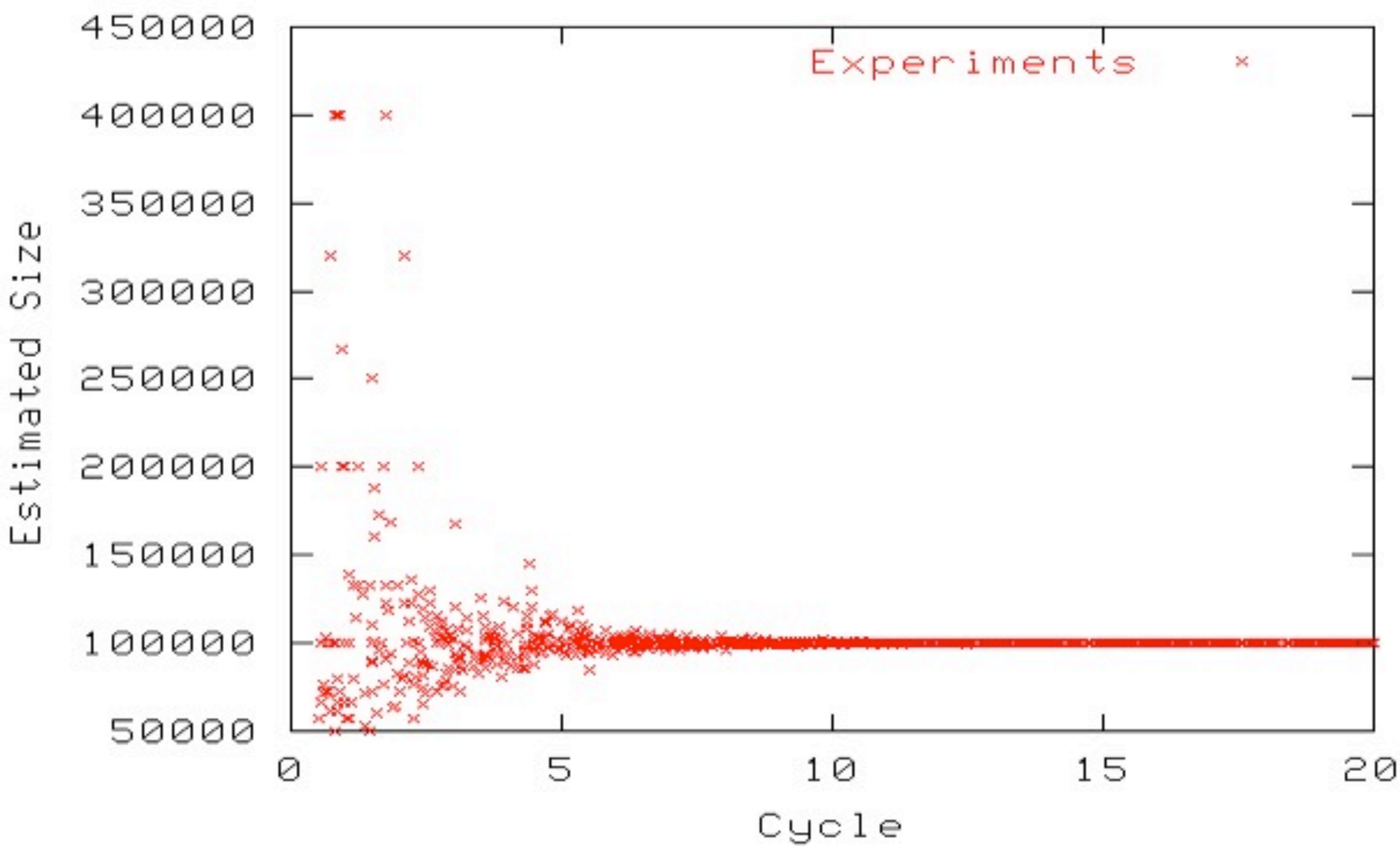
Simulation scenario

- **The underlying topology is based on Newscast**
  - Realistic, Robust
- **The count protocol is used**
  - More sensitive to failures
- **Some parameters:**
  - Network size is 100.000
  - Partial view size in Newscast is 30
  - Epoch length is 30 cycles
  - Number of experiments is 50

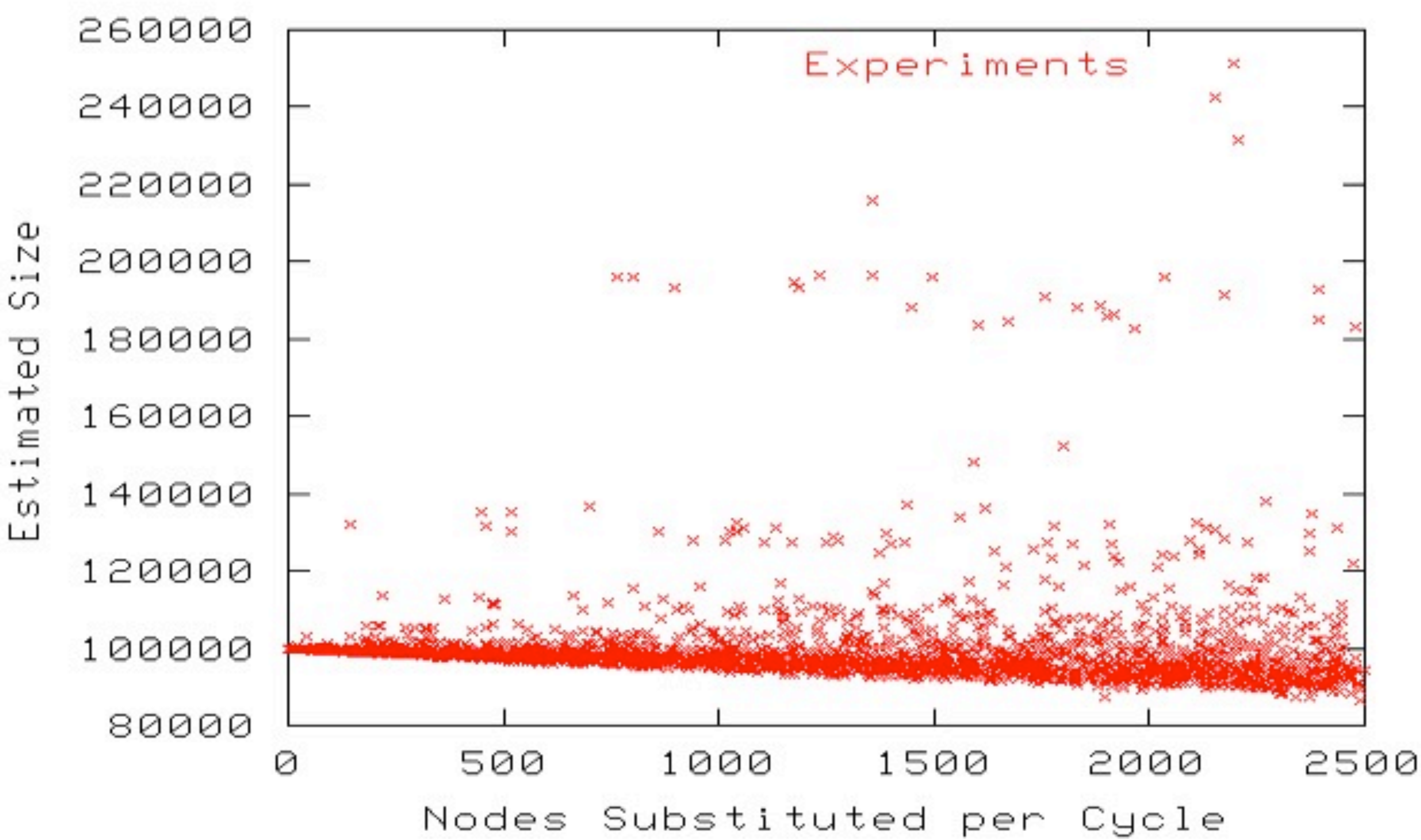
Effects of node failures

- **Effects depend on the value lost in a crash:**
  - *If lower than actual average*: estimated average will increase, estimated size will decrease
  - *If higher than actual average*: estimated average will decrease, estimated size will increase
- **The latter case is worst:**
  - In the initial cycles, some nodes hold relatively large values
- **Simulations:**
  - Sudden death / dynamic churn of nodes

Sudden death



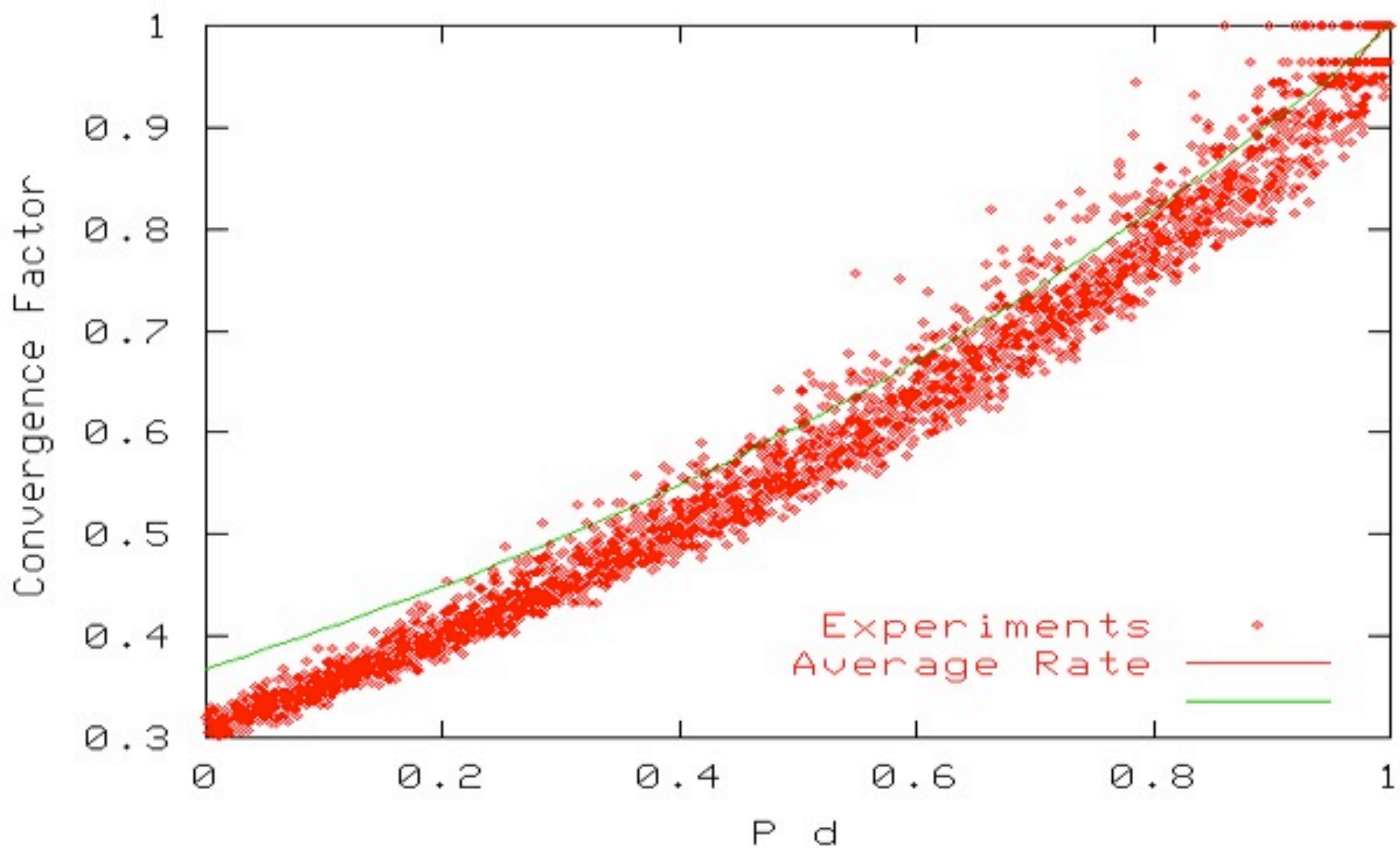
Nodes joining/crashing



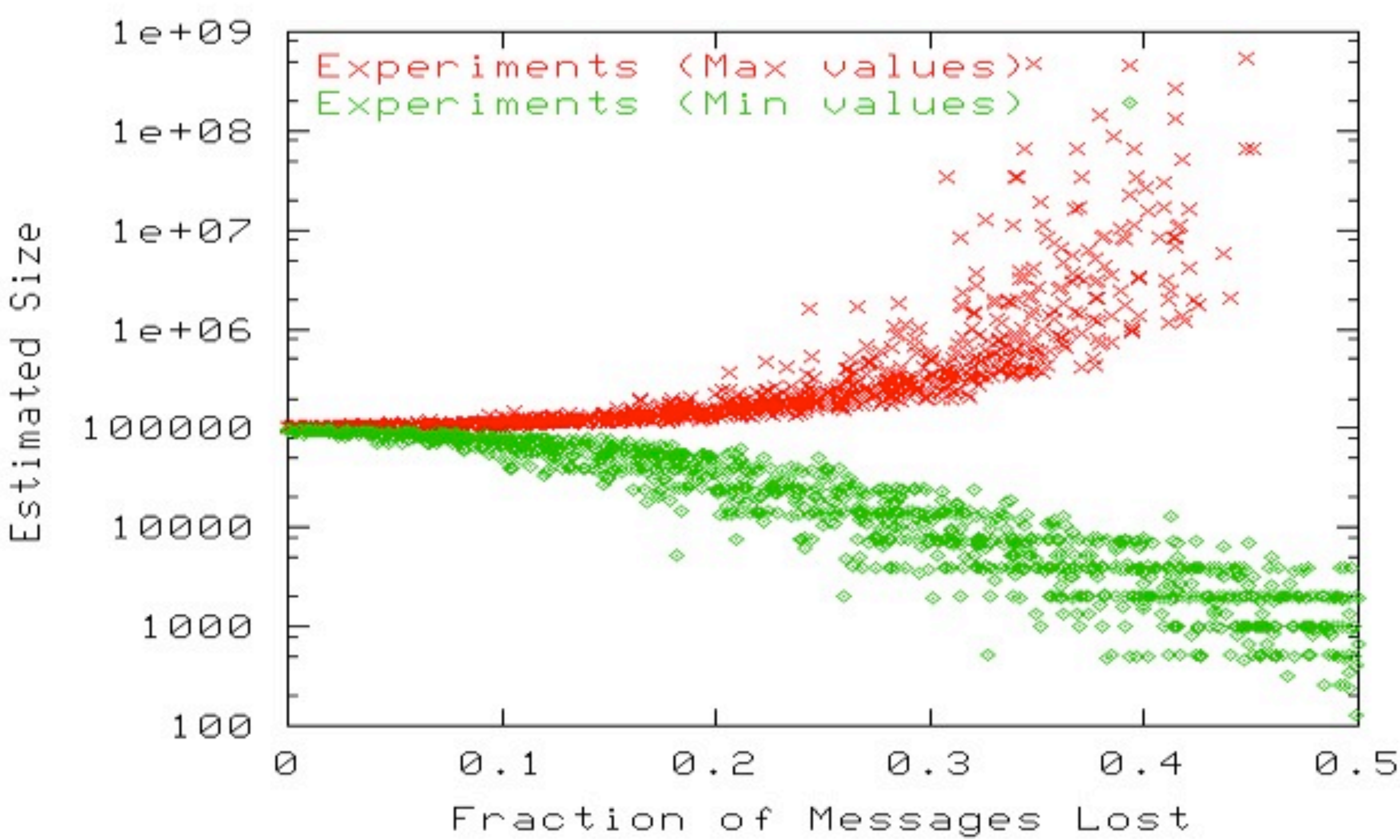
Communication failures

- **Link failures**
  - The convergence is just slowed down – some of the exchanges do not happen
- **Partitioning:**
  - If multiple concurrent protocols are started, the size of each partition will be evaluated separately
- **Message omissions:**
  - Message carry values: losing them may influence the final estimate

Link failures



Message omissions

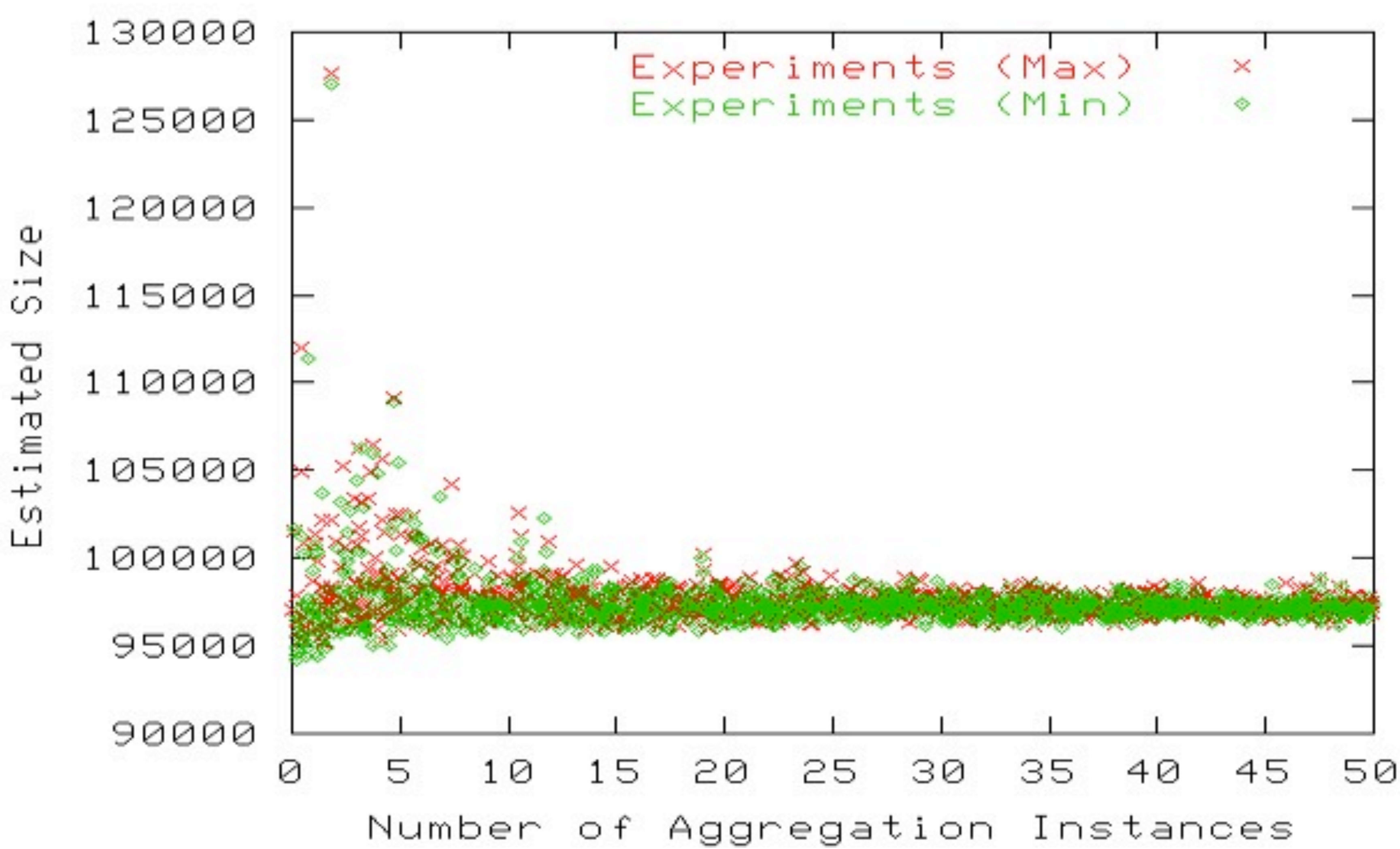


Multiple instances of aggregation

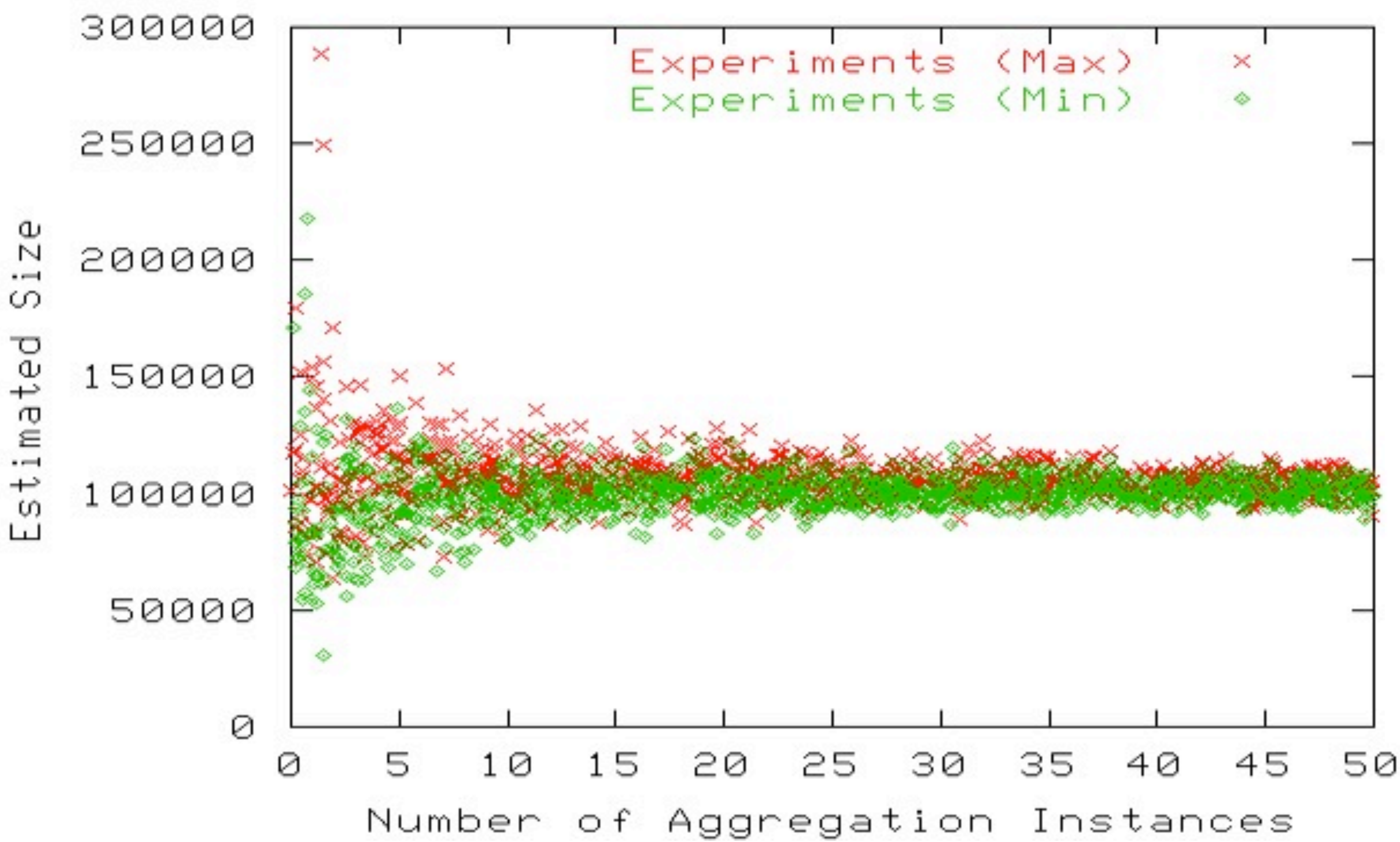
- **To improve accuracy in the case of failures:**
  - Multiple concurrent instances of the protocol may be run
  - Median value taken as result

- **Simulations**
  - Variable number of instances
  - With node failures
    - 1000 nodes substituted per cycle
  - With message omissions
    - 20% of messages lost

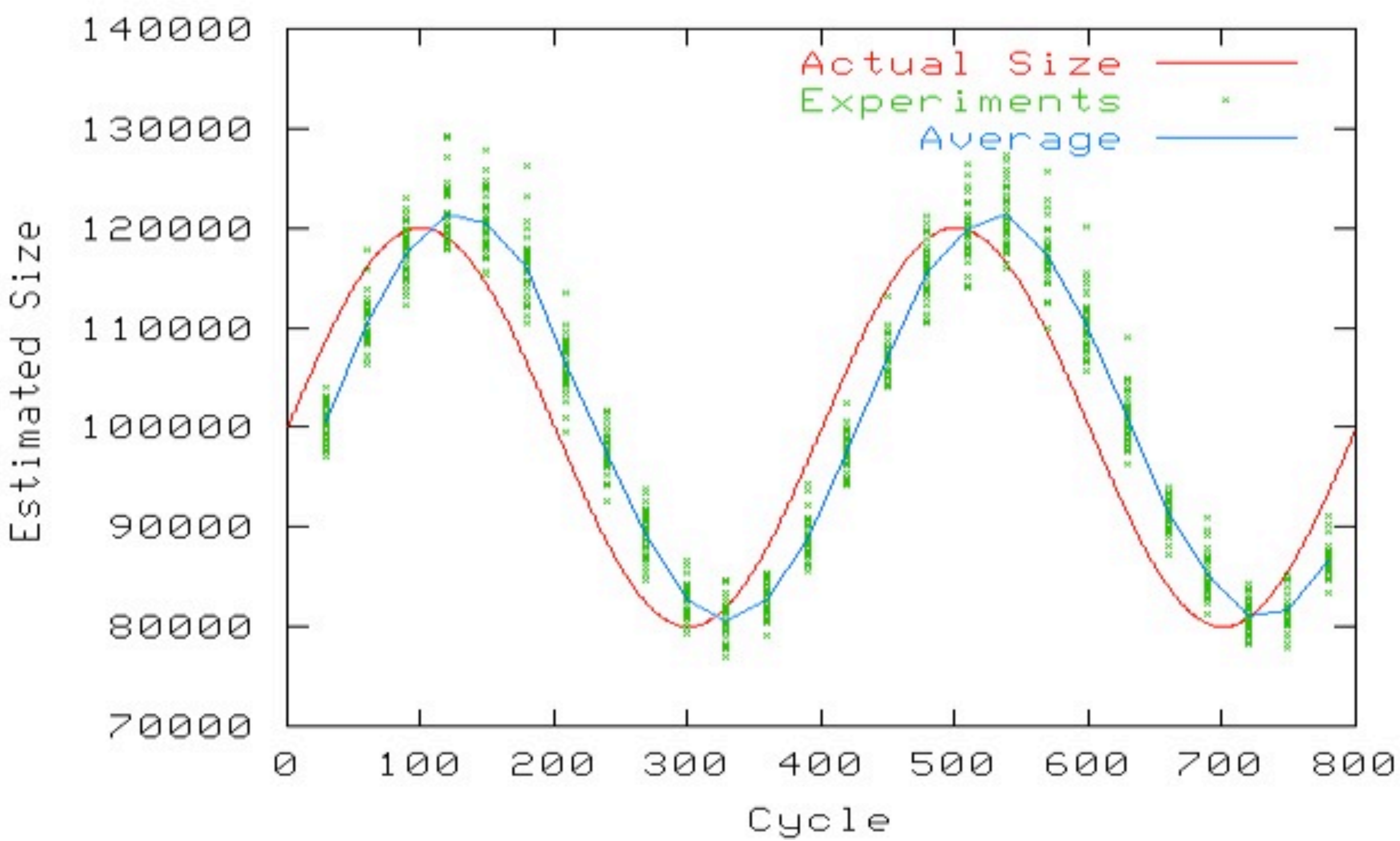
Node failures



Message omissions



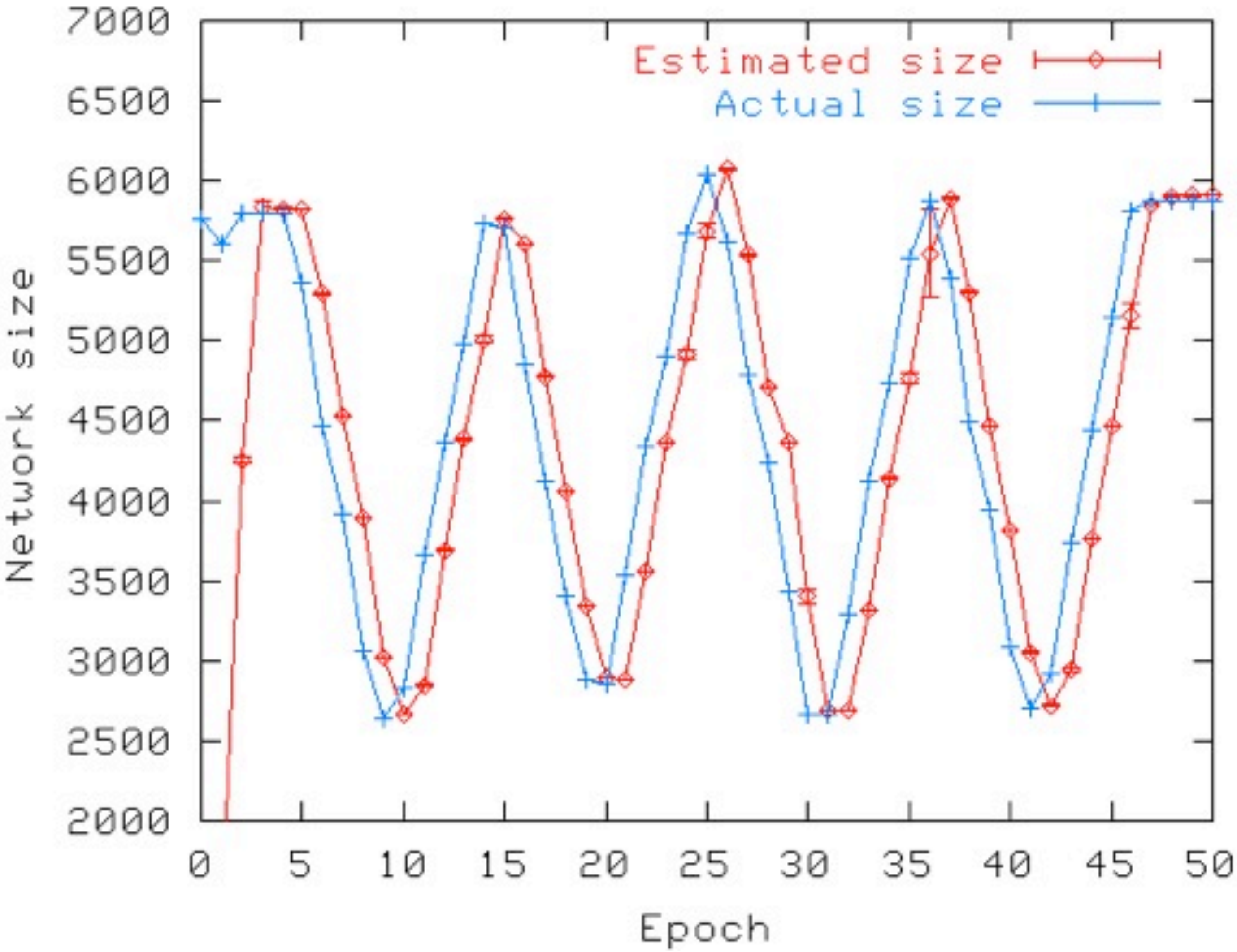
All together now!



Planet-Lab

- **Consortium**
  - >500 universities, research institutes, companies
  - >1000 nodes

600 hosts, 10 nodes per hosts



- **Bibliography**

  - M. Jelasity, A. Montresor, and O. Babaoglu. *T-Man: Gossip-based fast overlay topology construction.* Computer Networks, 53:2321-2339, 2009.
  - A. Montresor, M. Jelasity, and O. Babaoglu. Chord on demand. In Proc. of the 5th International Conference on Peer-to-Peer Computing (P2P'05), pages 87-94, Konstanz, Germany, August 2005. IEEE.

- **Additional bibliography**

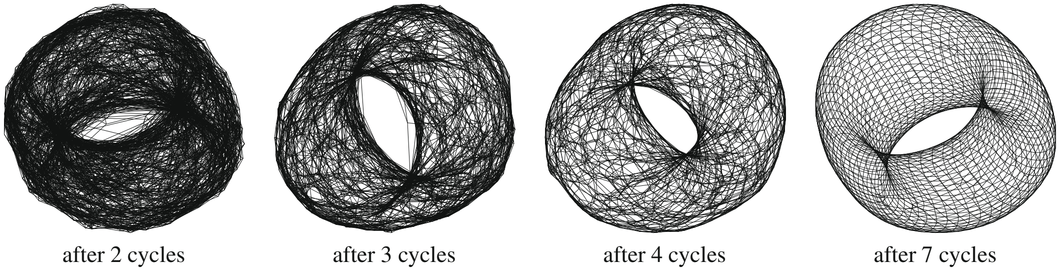
  - G.P.Jesi, A. Montresor, and O. Babaoglu. Proximity-aware superpeer overlay topologies. In Proc. of SelfMan'06, volume 3996 of Lecture Notes in Computer Science, pages 43-57, Dublin, Ireland, June 2006. Springer-Verlag.
  - A. Montresor. *A robust protocol for building superpeer overlay topologies*. In Proceedings of the 4th International Conference on Peer-to-Peer Computing, pages 202-209, Zurich, Switzerland, August 2004. IEEE

Topology bootstrap

- **Informal definition:**
  - *building a topology from the ground up as quickly and efficiently as possible*
- **Do not confuse with node bootstrap**
  - Placing a single node in the right place in the topology
  - Much more complicated: start from scratch

The T-Man Algorithm

- **T-man is a generic protocol for topology formation**
  - Topologies are expressed through ranking functions: "what are my preferred neighbors?"
- **Examples**
  - Rings, tori, trees, DHTs, etc.
  - Distributed sorting
  - Semantic proximity for file-sharing
  - Latency for proximity selection.....



Ranking function

- **Node descriptors contain attributes of the nodes**
  - A number in a sorting application
  - The id of a node in a DHT
  - A semantic description of the node
- **Example: Sorted "Virtual" Ring**
  - Let the ranking function be defined based on the distance

$$d(a,b)=min(|a-b|,\ 2^t-|a-b|)$$

assuming that attributes are included in $[0,2^t[$

Ranking function

- **Node descriptors contain attributes of the nodes**
  - A number in a sorting application
  - The id of a node in a DHT
  - A semantic description of the node
- **The ranking function may be based on a distance over a space**
  - *Space*: set of possible descriptor values
  - *Distance*: a metric $d(x,y)$ over the space
  - The ranking function of node x is defined over the distance from node x
- ***getPeer*(), *prepareMsg*() are based on a ranking function defined over node descriptors**

A generic gossip protocol - executed by process p

Init: initialize my local *state*

Active thread

do once every δ time units

q = getPeer(*state*)

s_p = prepareMsg(*state*, q)

send (REQ, s_p) **to** q

A "cycle" of length δ

Passive thread

do forever

receive (t, s_q) **from** *

if (t = REQ) **then**

s_p = prepareMsg(*state*, q)

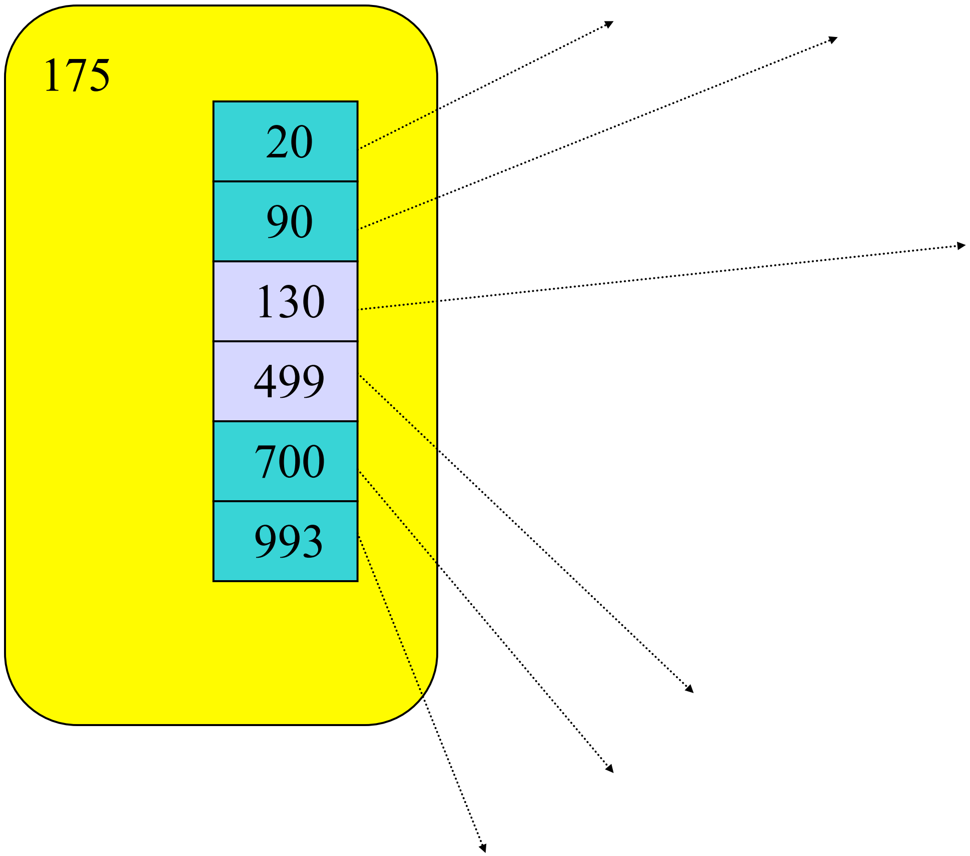
send (REP, s_p) **to** q

state = update(*state*, s_q)

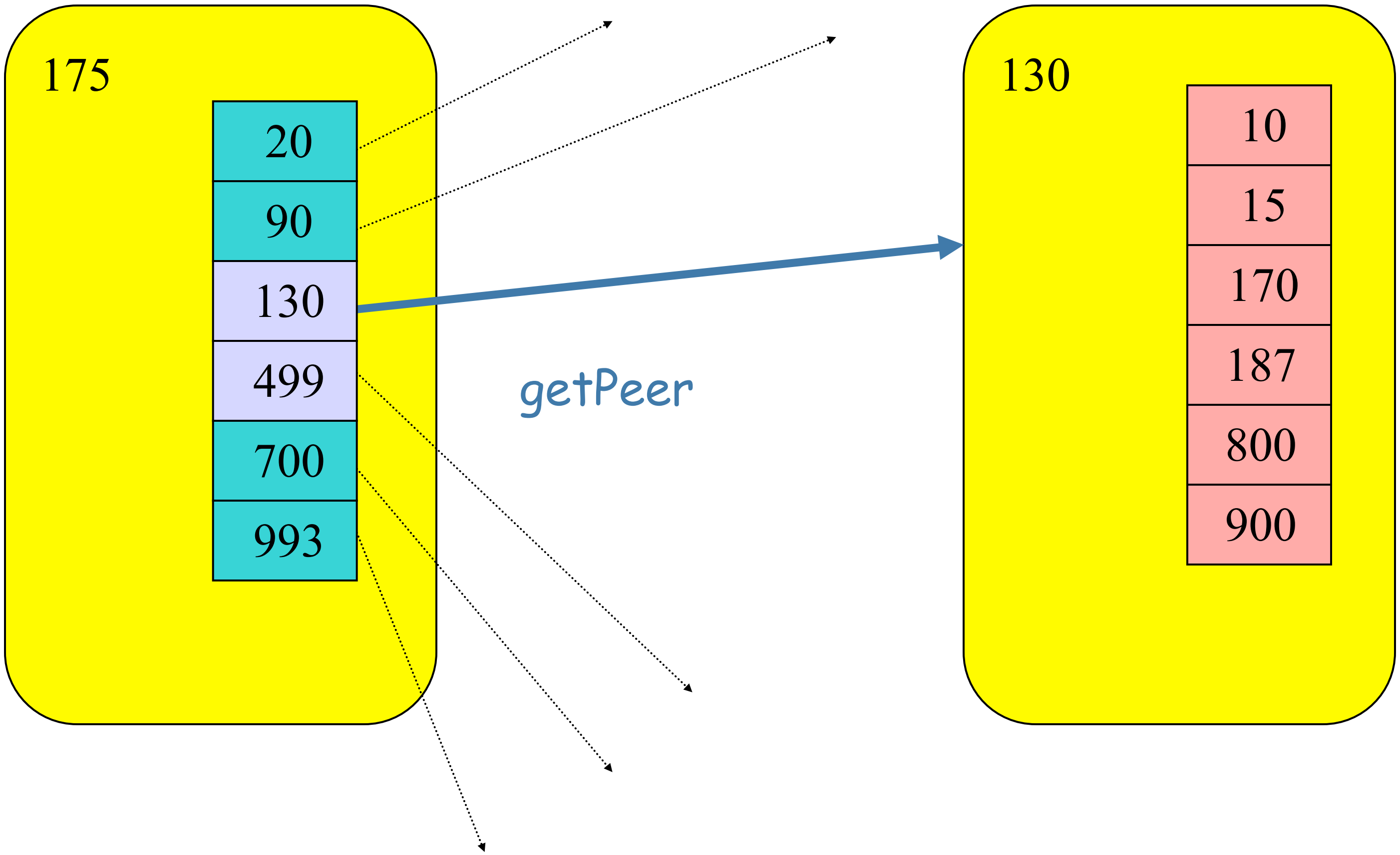
Gossip customization for topology construction

- **local state**
  - partial view, initialized randomly based on Newscast
  - the view grows whenever a message is received
- ***getPeer*():**
  - randomly select a peer q from the r nodes in my view that are closest to p in terms of distance
- ***prepareMsg*():**
  - send to q the r nodes in local view that are closest to q
  - q responds with the r nodes in its view that are closest to p
- ***update*():**
  - both p and q merge the received nodes to their view

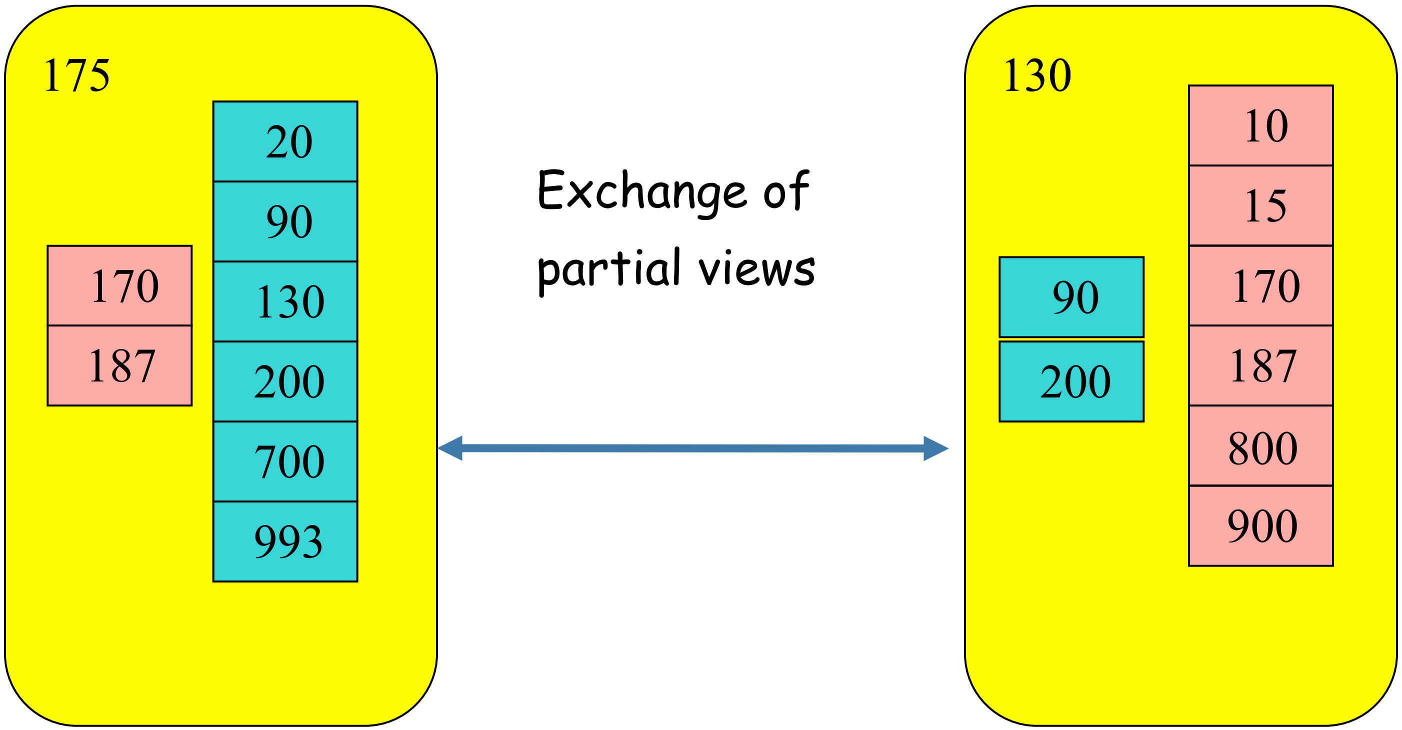
T-man: Topology Management



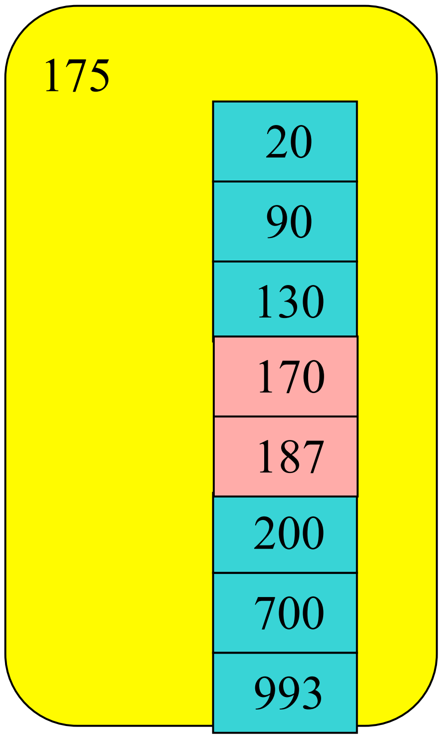
T-man: Topology Management



T-man: Topology Management

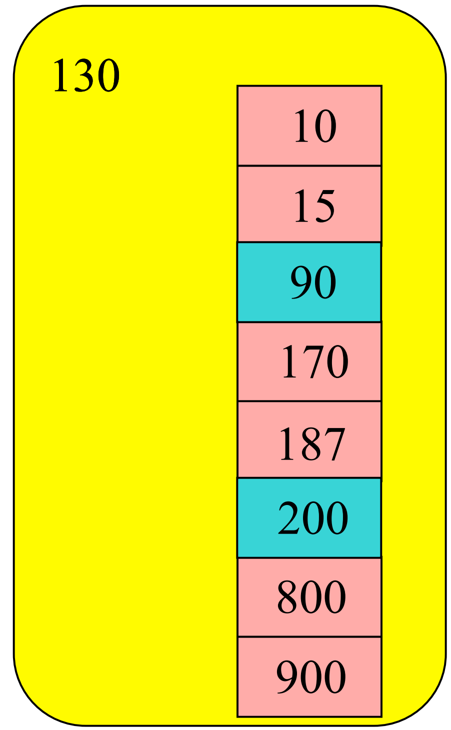


T-man: Topology Management



Both sides apply update

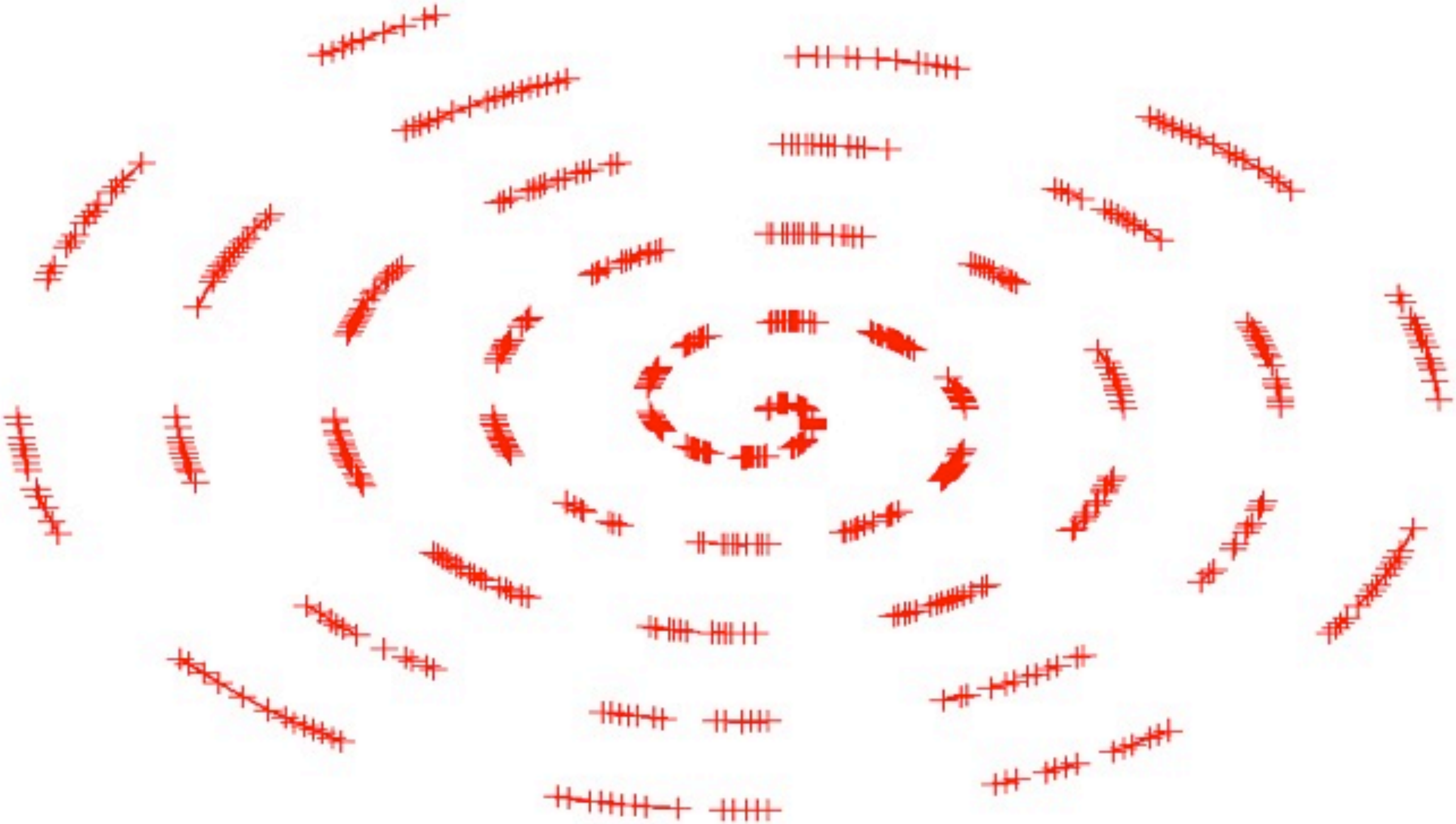
thereby redefining topology



Distance functions

- **Example: Line or ring**
  - Space: [0, 1[
  - Distance over the line: $d(a,b) = | a\text{-}b |$
  - Distance over thr ring: $d(a,b) = min \{ | a\text{-}b | , 1\text{-}|a\text{-}b| \}$
- **Example: Grid or torus (Manhattan Distance)**
  - Space: [0, 1[· [0, 1[
  - Distance: $d(a,b) = | a_x – b_x | + | a_y – b_y |$

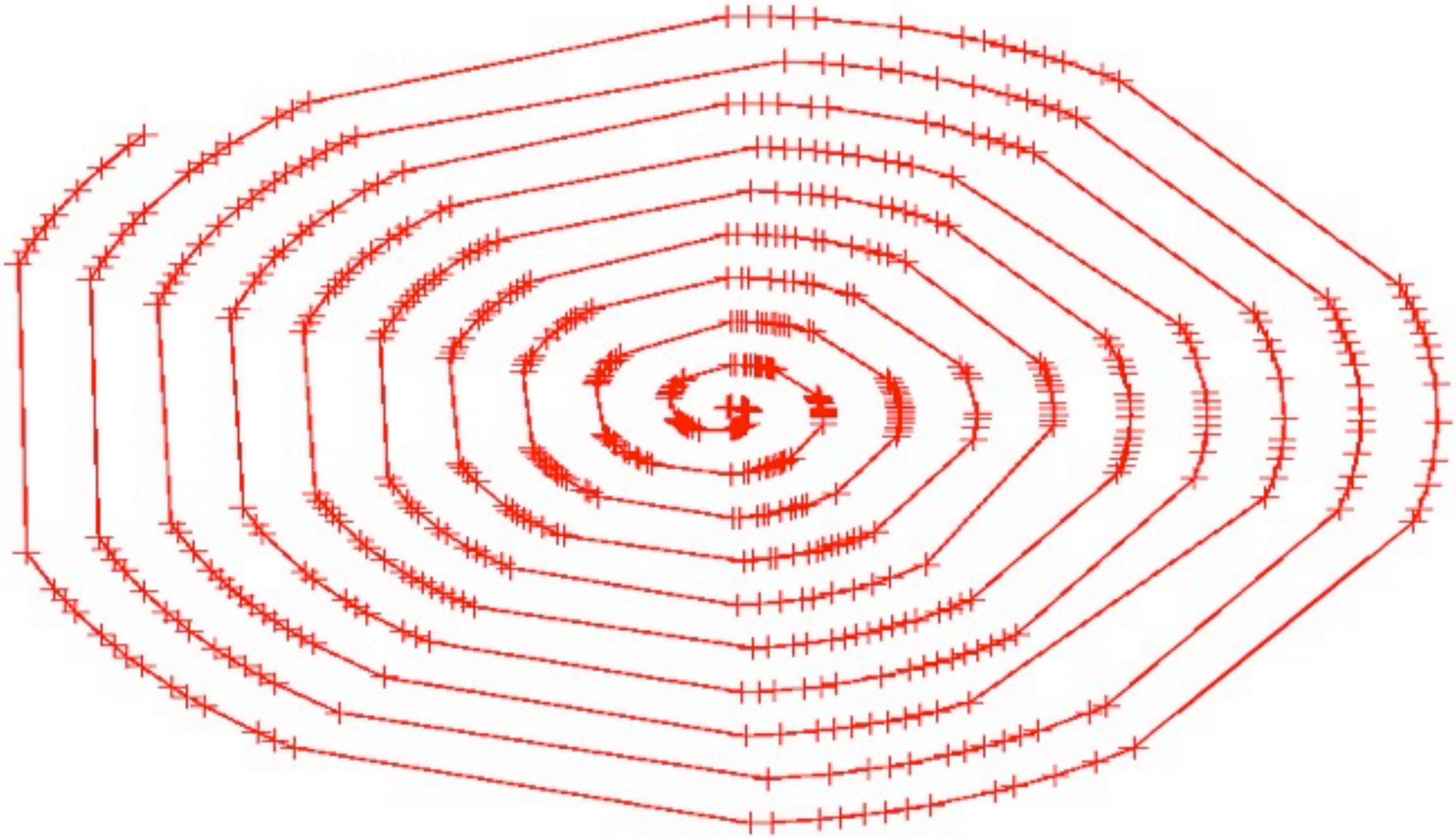
Example: Line



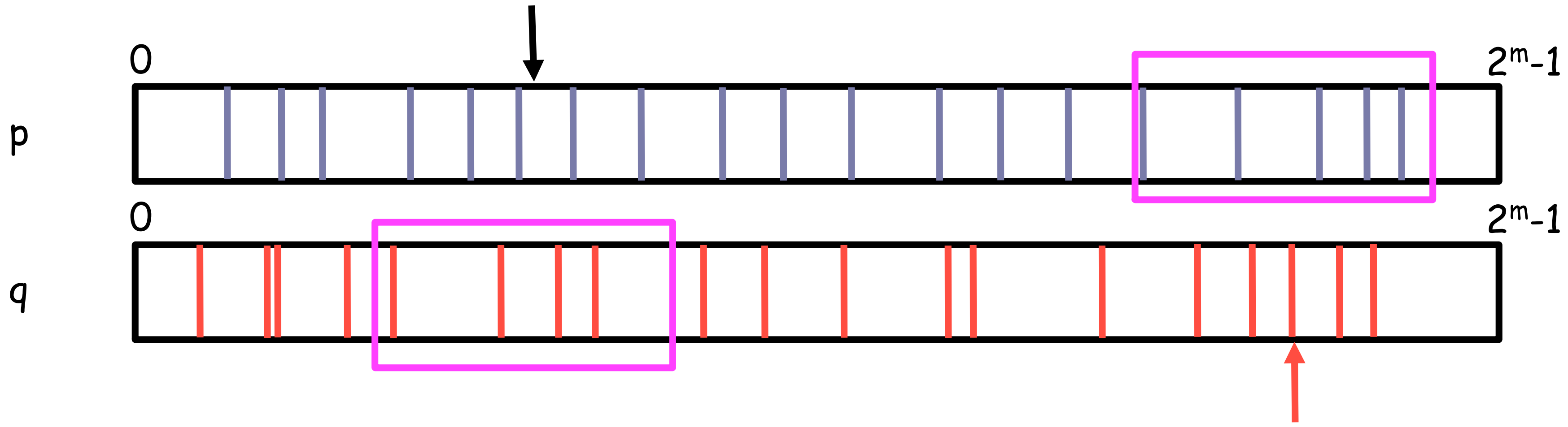
Sorted Line / Ring

- **Directional ranking function over the ring defined as follows:**
  - Distance function, line: $d(a,b)=|a-b|$
  - Distance function, ring: $d(a,b)=min(|a-b|, 1-|a-b|)$
- **Given a collection (view) of nodes and a node *x*, return**
  - the $r/2$ nodes "smaller" than x that are closest to x
  - the $r/2$ nodes "larger" than x that are closest to x

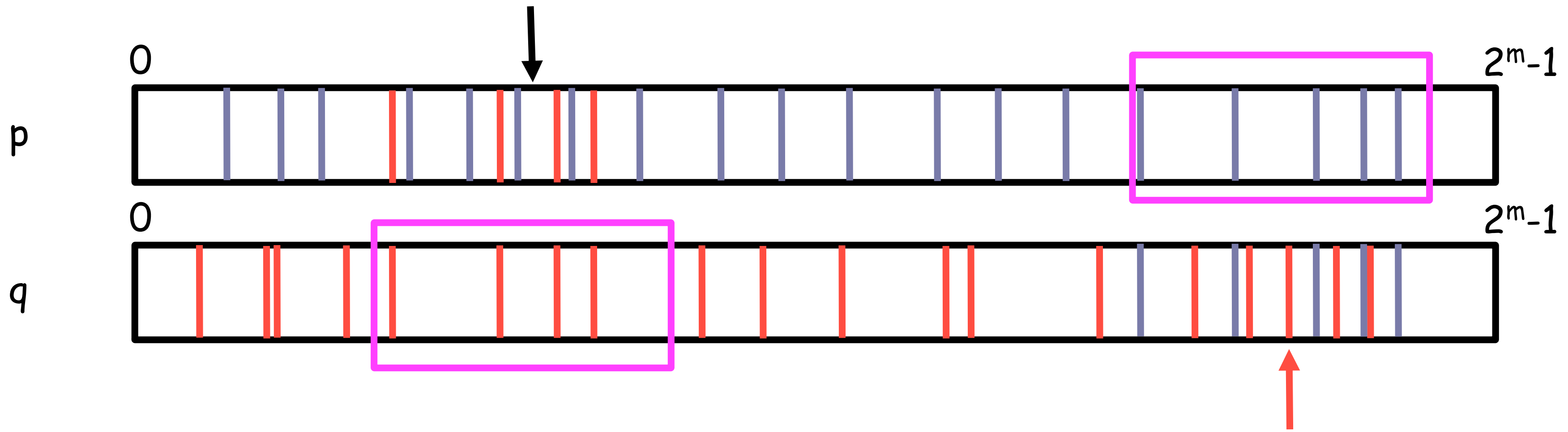
Sorted Line



Sorted Ring



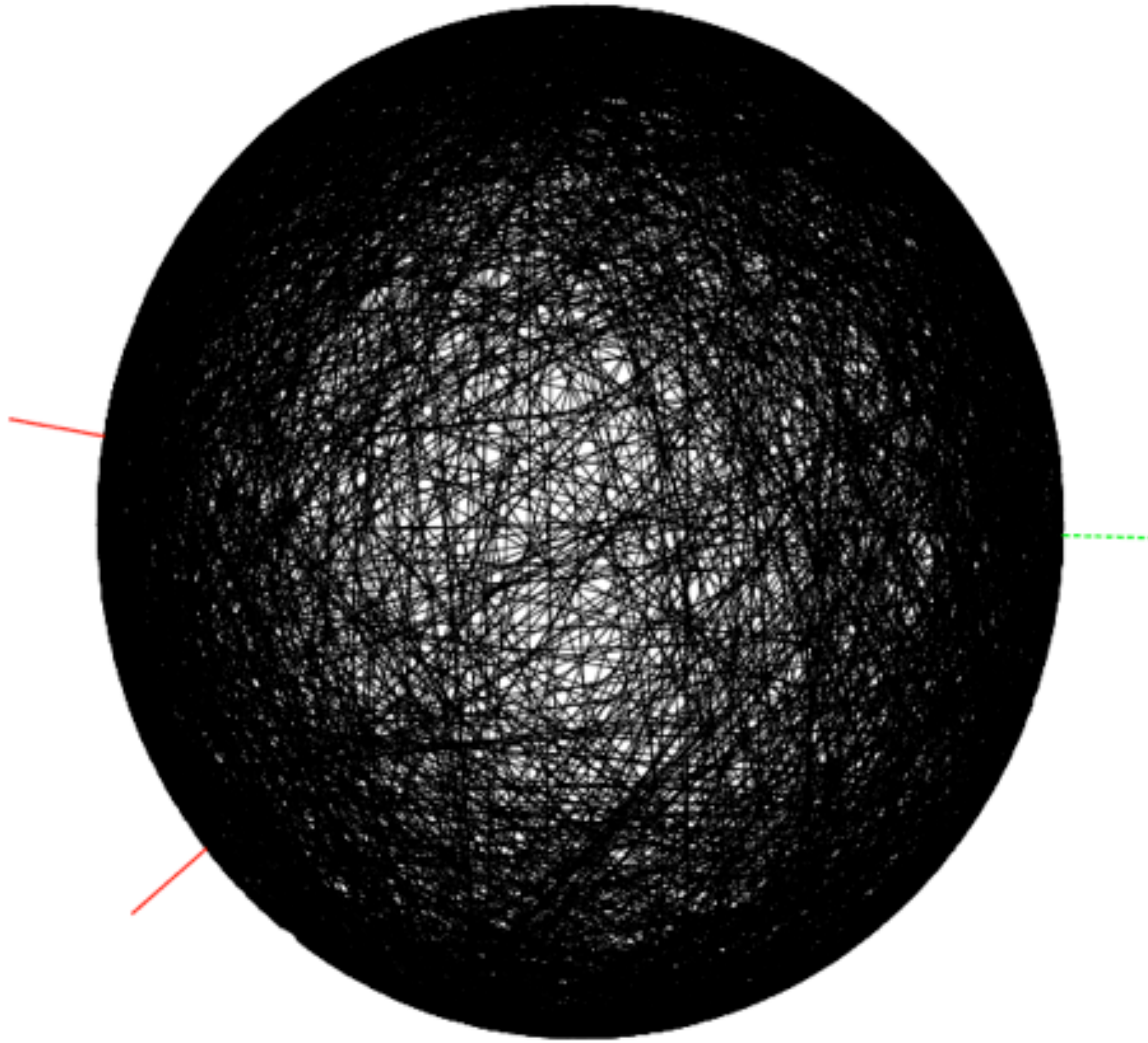
Sorted Ring



T-Man: The movie!

Nodes: 1000
Showing 1 successor,
1 predecessor

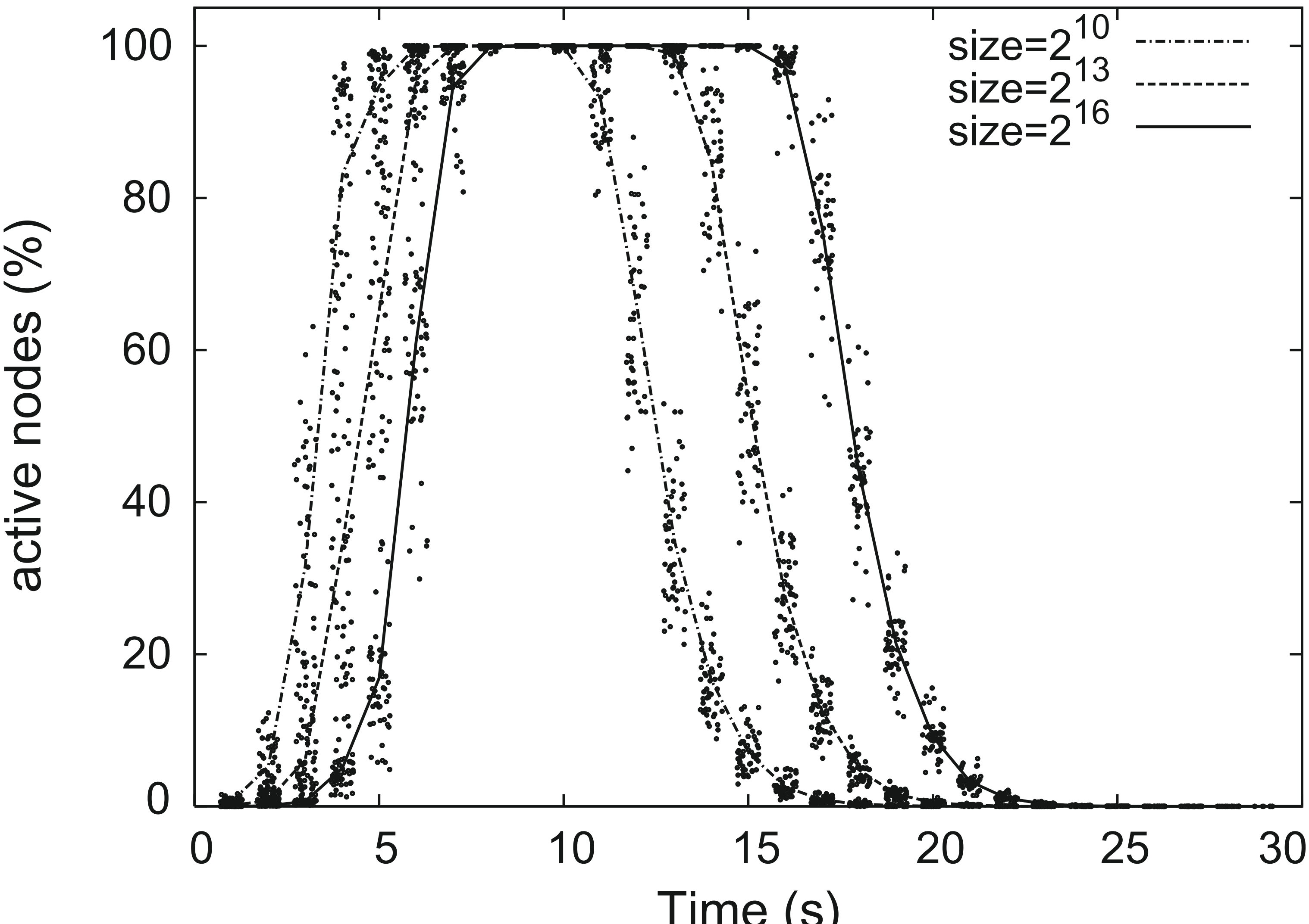
Cycles 00.000 Nodes



Start / stop

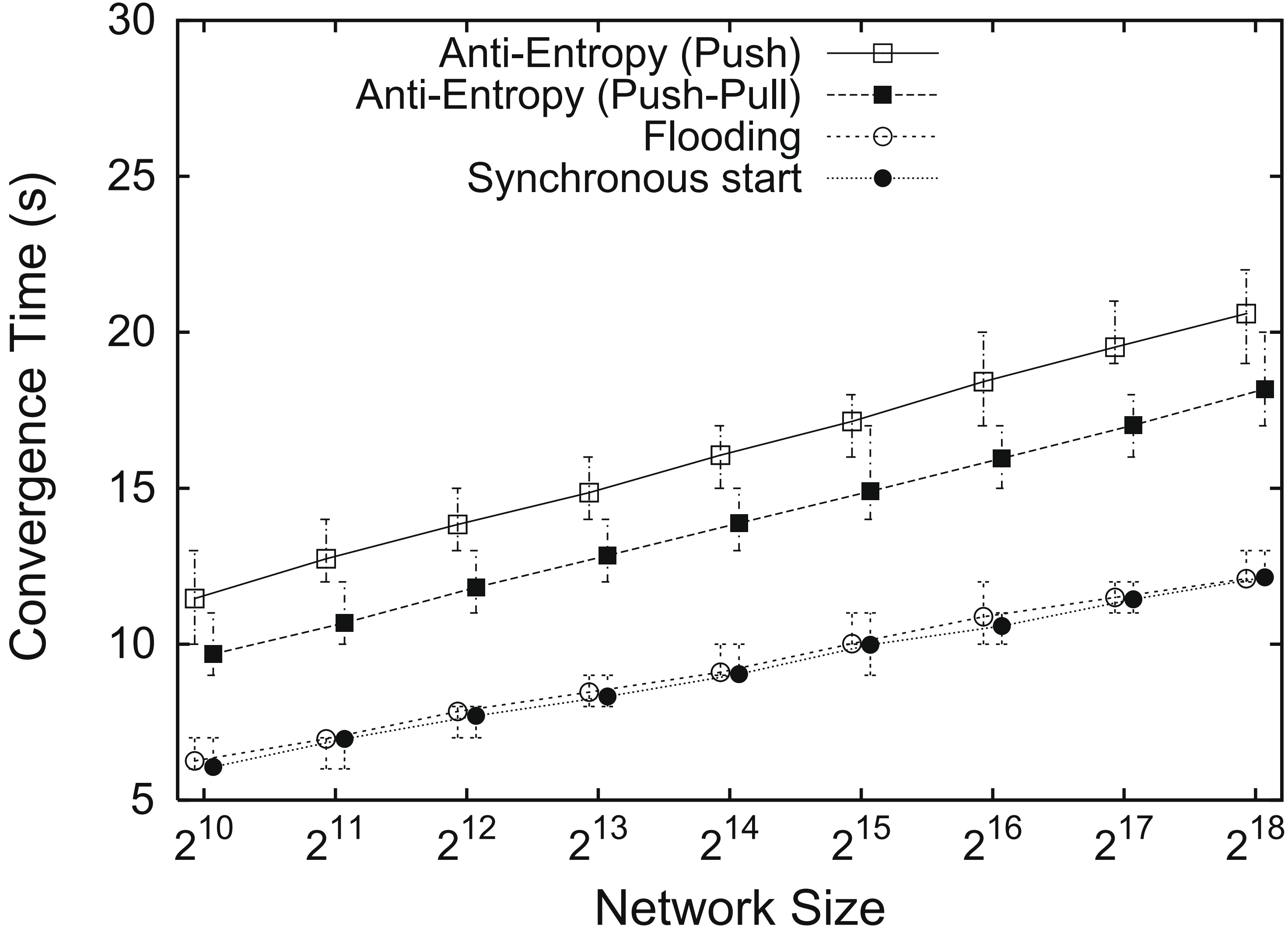
- **In the previous animation**
  - Nodes starts simultaneously
  - Convergence is measured globally
- **In reality**
  - We must start the protocol at all nodes
    - Broadcasting, using the random topology obtained through the peer sampling services
  - We must stop the protocol
    - Local condition: when a node does not observe any view change for a predefined period, it stops
    - *Idle*: number of cycles without variations

Start / stop

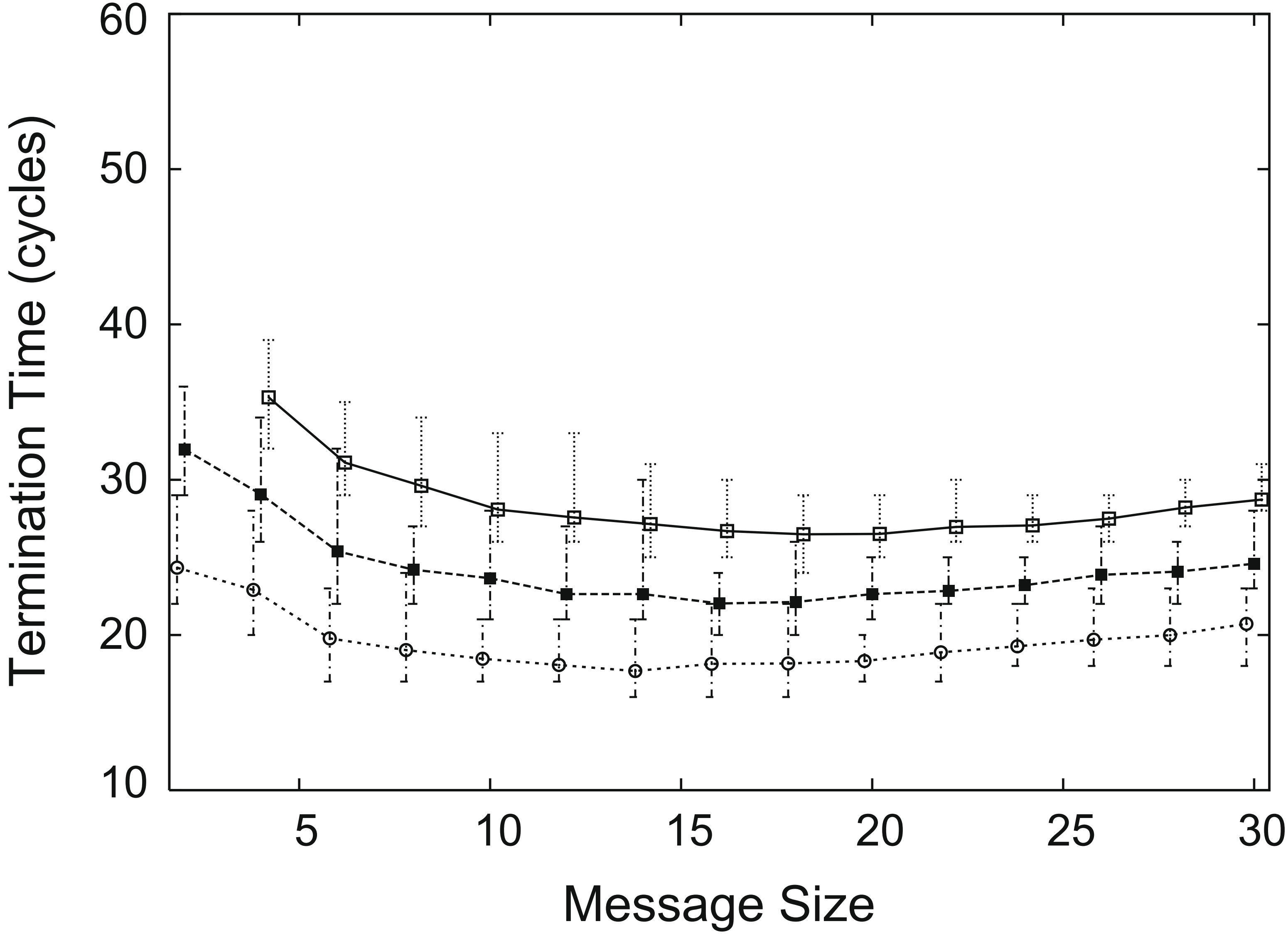


size=2^{10}
size=2^{13}
size=2^{16}
active nodes (%)
Time (s)
0
20
40
60
80
100
0
5
10
15
20
25
30

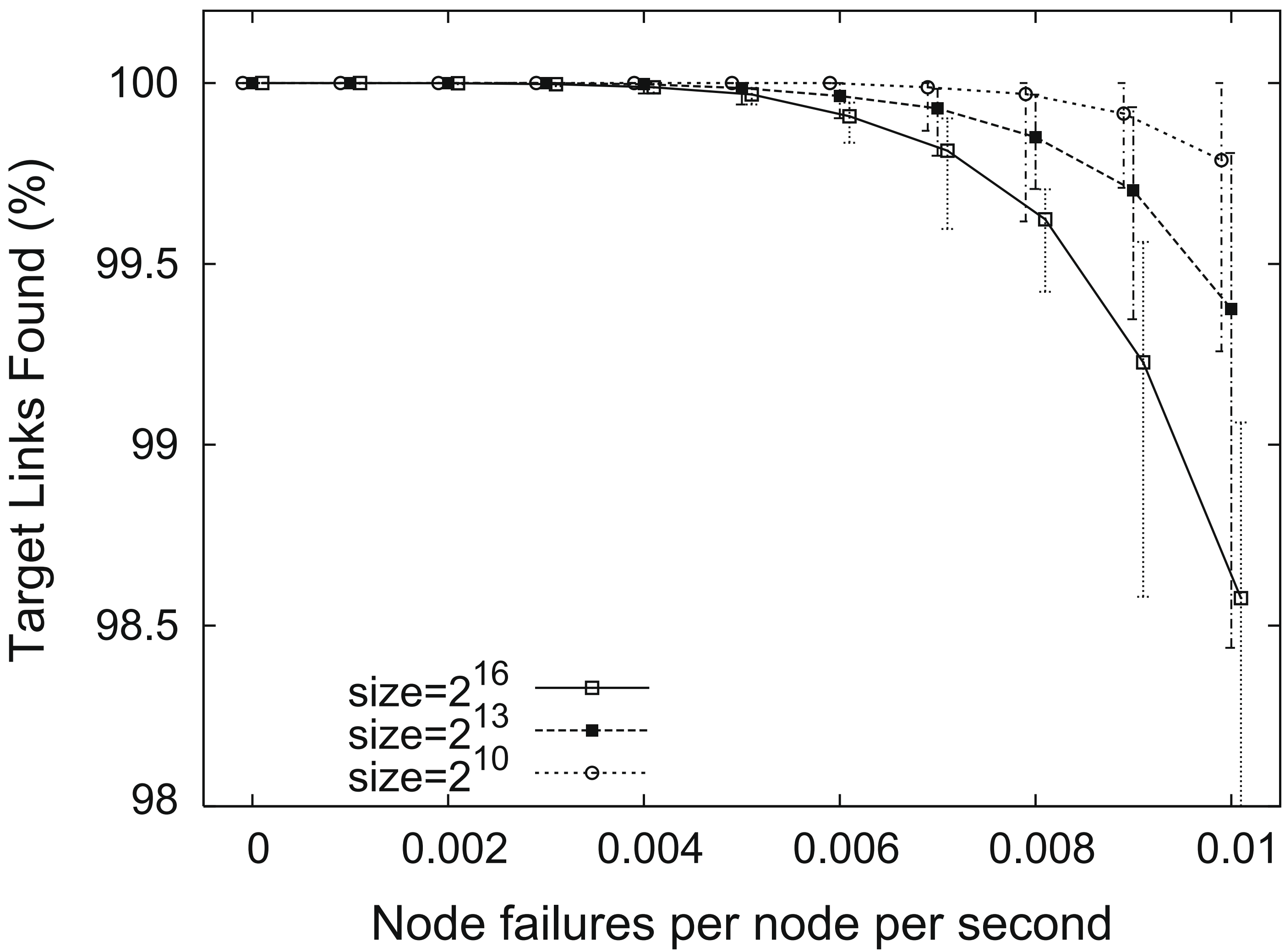
T-Man: Scalability



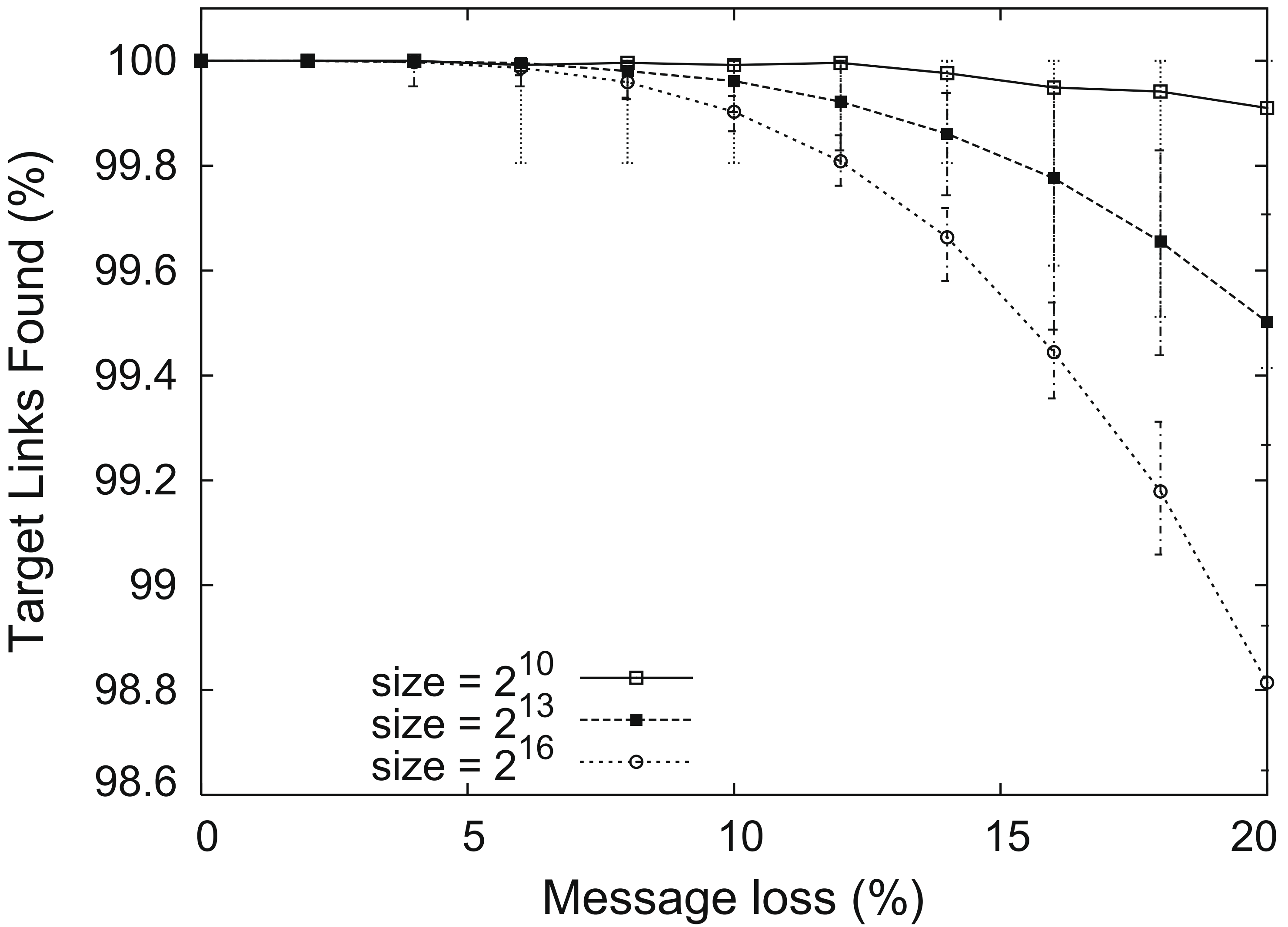
T-Man: Message costs



T-Man: Robustness to crashes

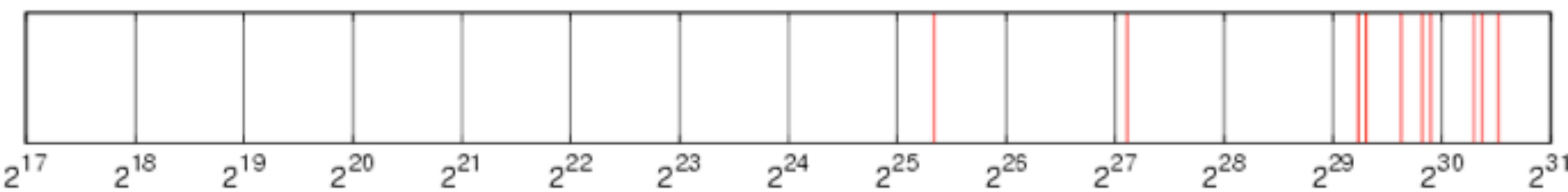


T-Man: Robustness to message losses

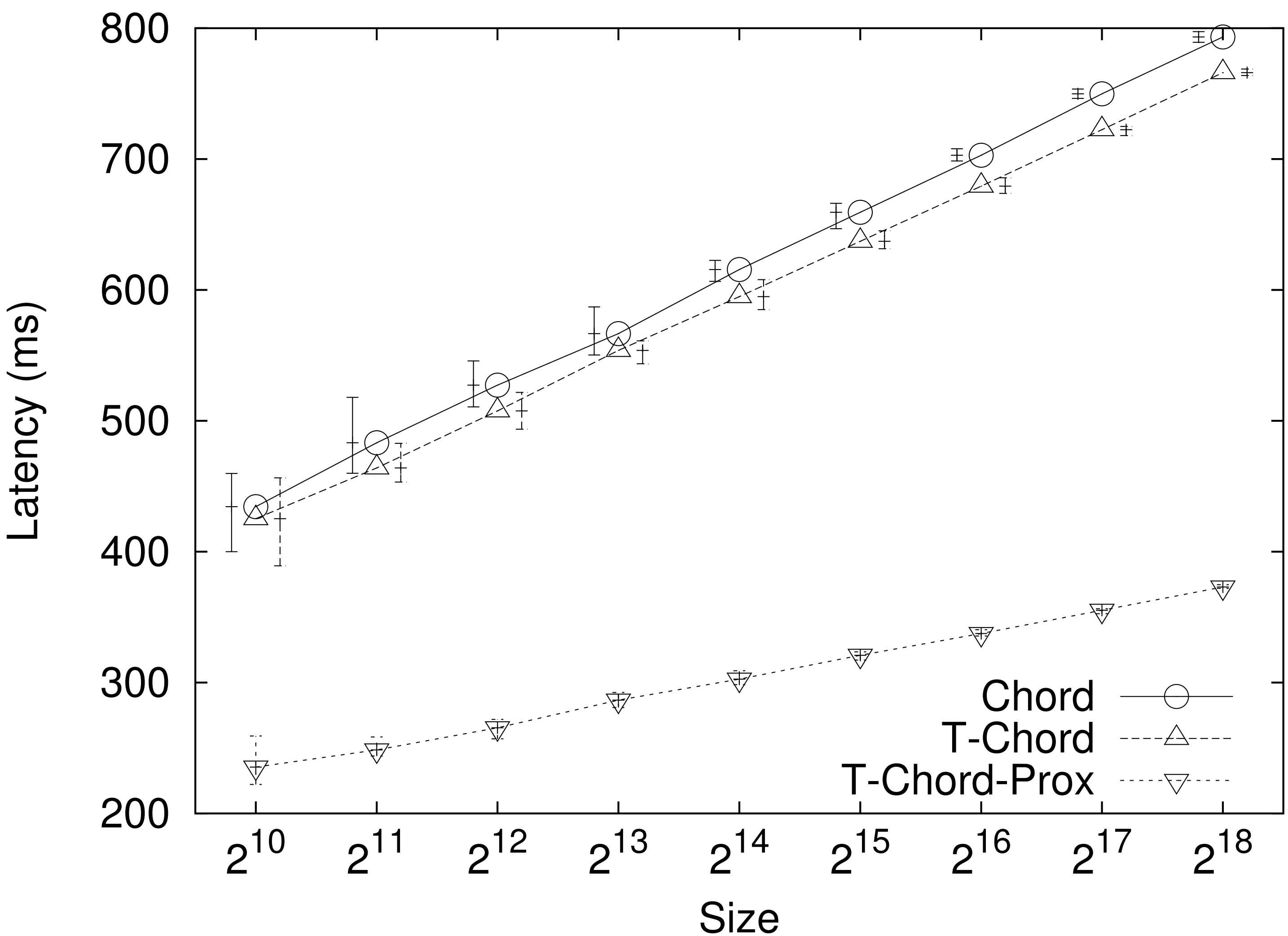


T-Chord

- **How it works?**
  - Node descriptor contains node ID in a $[0..2^t[$ space
  - Nodes are sorted over the ring defined by IDs
  - Final output is the Chord ring
  - As by-product, many other nodes are discovered
- **Example:**
  - t=32, size=2^{14}, msg size=20

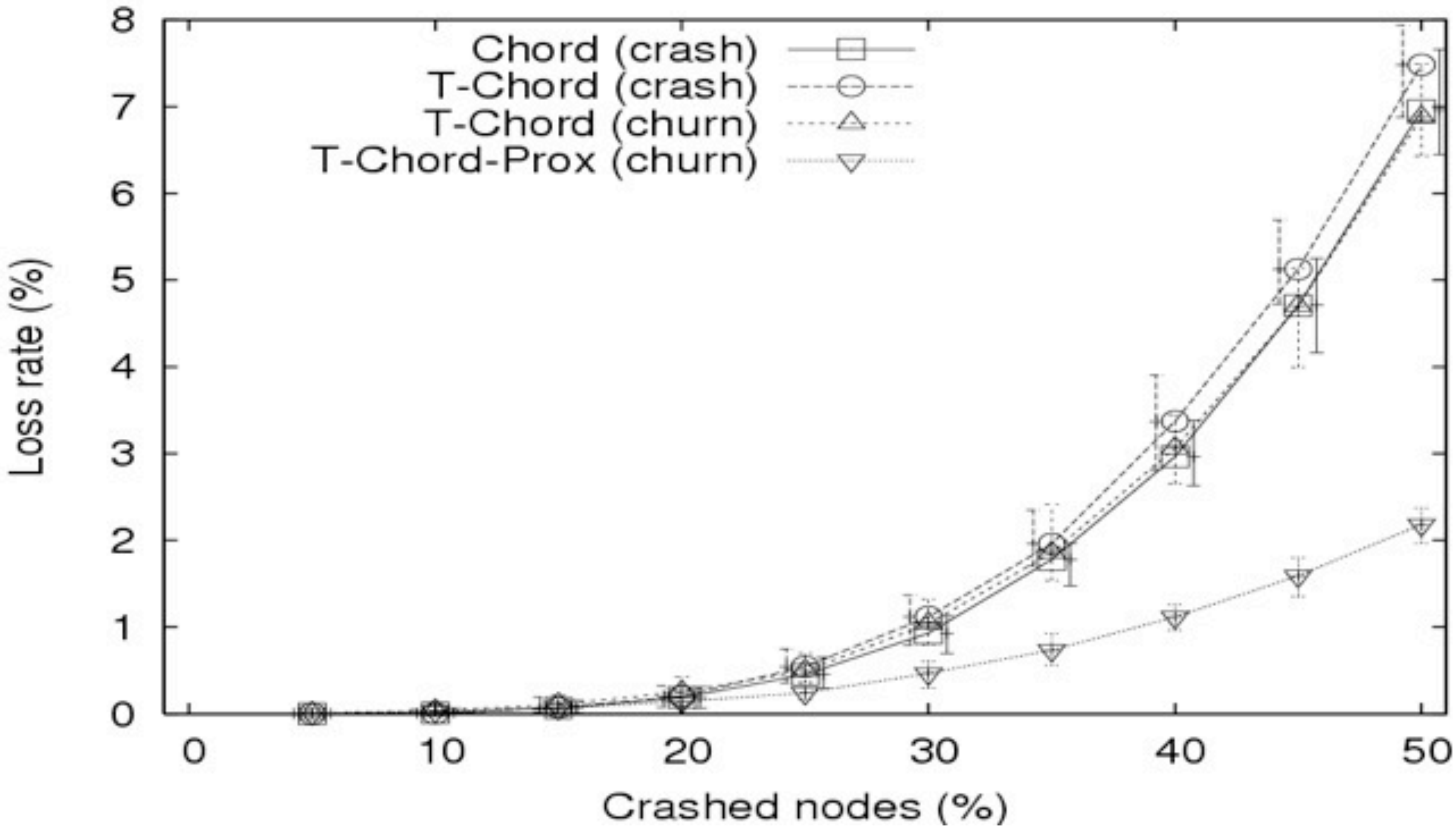


T-Chord

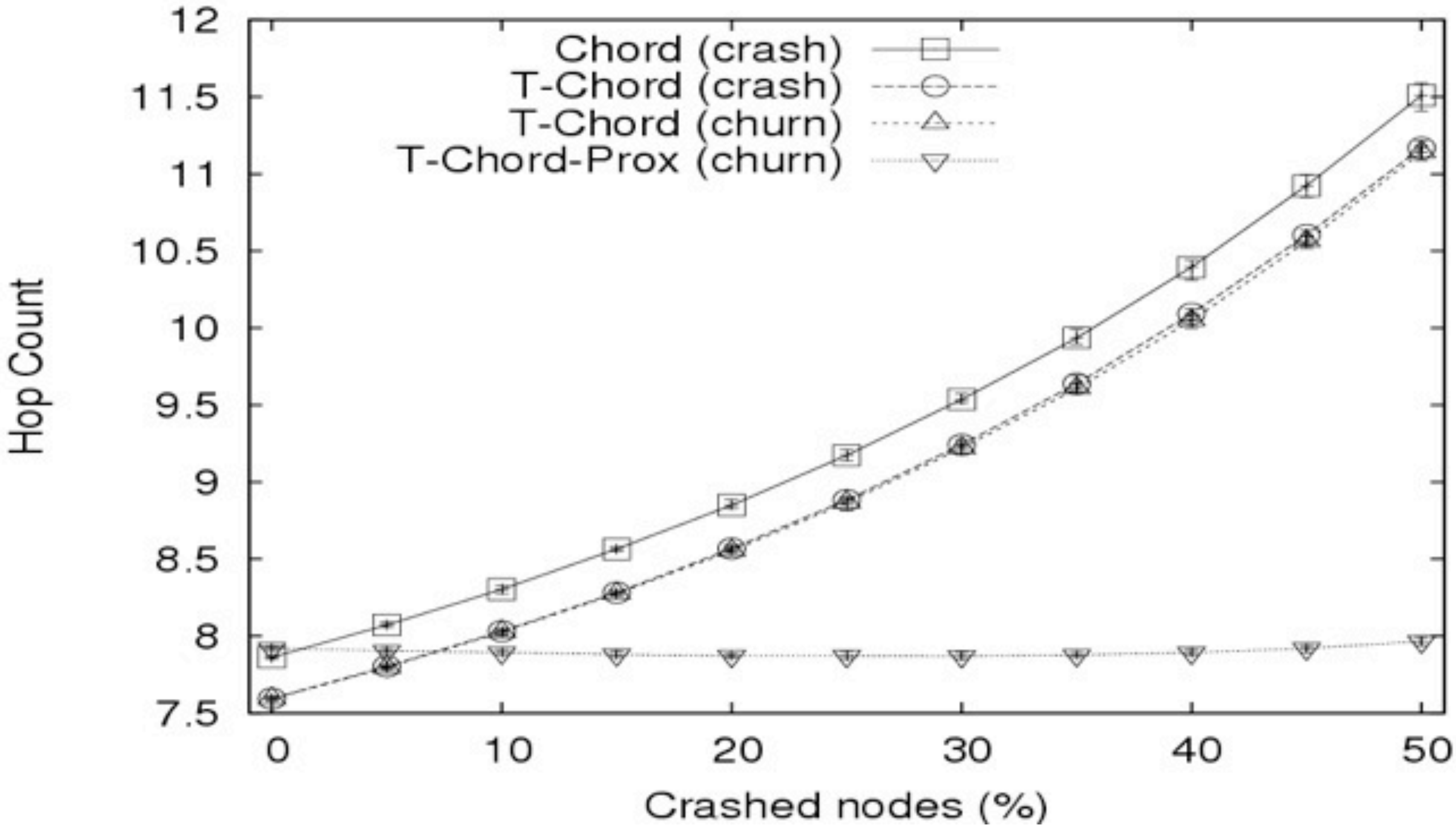


Latency (ms)
800
700
600
500
400
300
200
2^{10}
2^{11}
2^{12}
2^{13}
2^{14}
2^{15}
2^{16}
2^{17}
2^{18}
Size
Chord
T-Chord
T-Chord-Prox

Robustness to failures



Robustness to failures



Conclusions

- **This mechanism to build Chord is tightly tailored on the particular structure of Chord**
- **A more generic approach:**
  - Define a ranking function where nodes have a preference for successors and predecessors AND fingers
  - Approx. same results, only slightly more complex to explain
- **Can be used for Pastry, for example:**
  - Define a ranking function where nodes have a preference for successors and predecessors AND nodes in the prefix-based routing table

- **Bibliography**

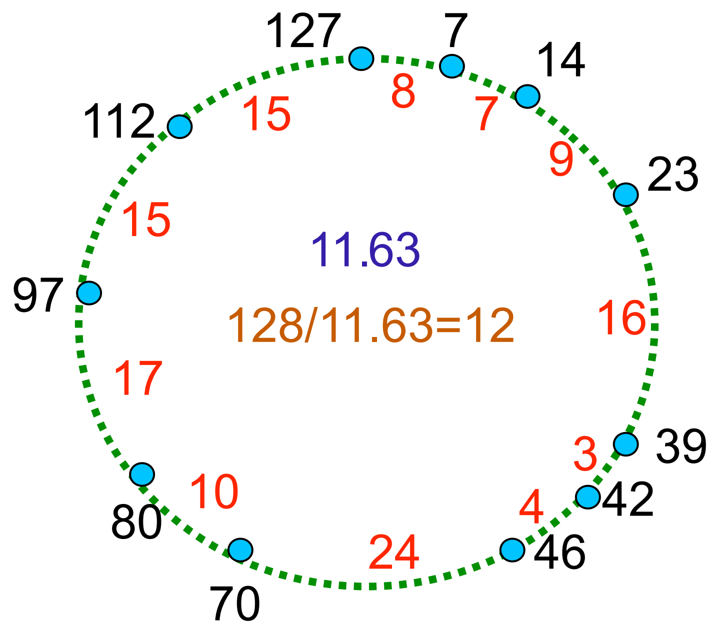
  - A. Montresor and A. Ghodsi. *Towards robust peer counting*. In Proc. of the 9th Int. Conference on Peer-to-Peer (P2P'09), pages 143-146, Seattle, WA, September 2009

Network size estimation at runtime

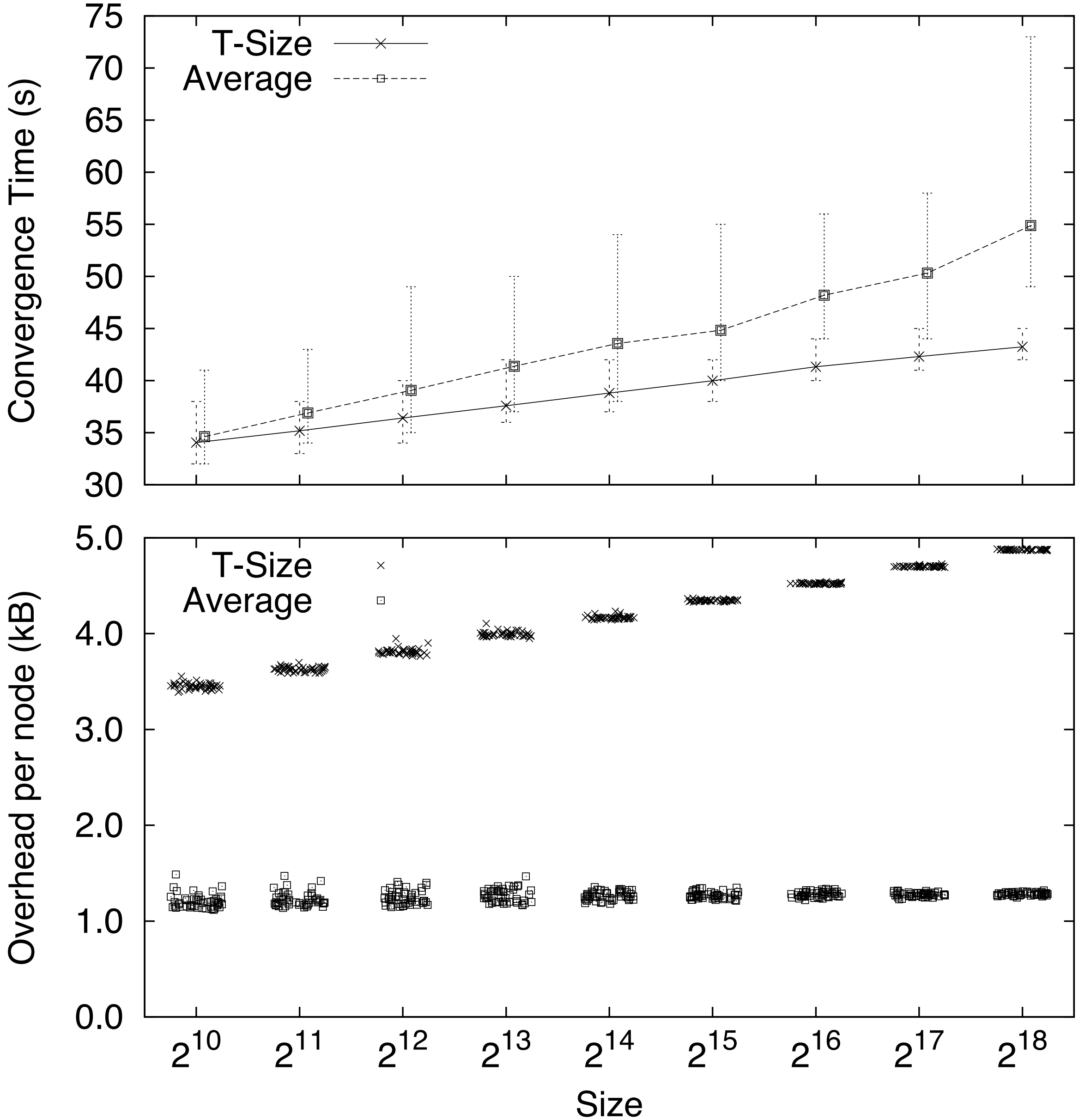
- **Why**
  - *f(n)* routing pointers
    - to bound the hop count
    - to provide churn resilience
  - build group of size *f(n)*
    - Slicing
  - *f(n)* messages
    - to reduce overhead in gossip protocols
- **How**
  - Combine and improve existing protocols
  - Compared to existing systems:
    - More precise, more robust, slightly more overhead
  - Simple idea → short paper

A brief explanation

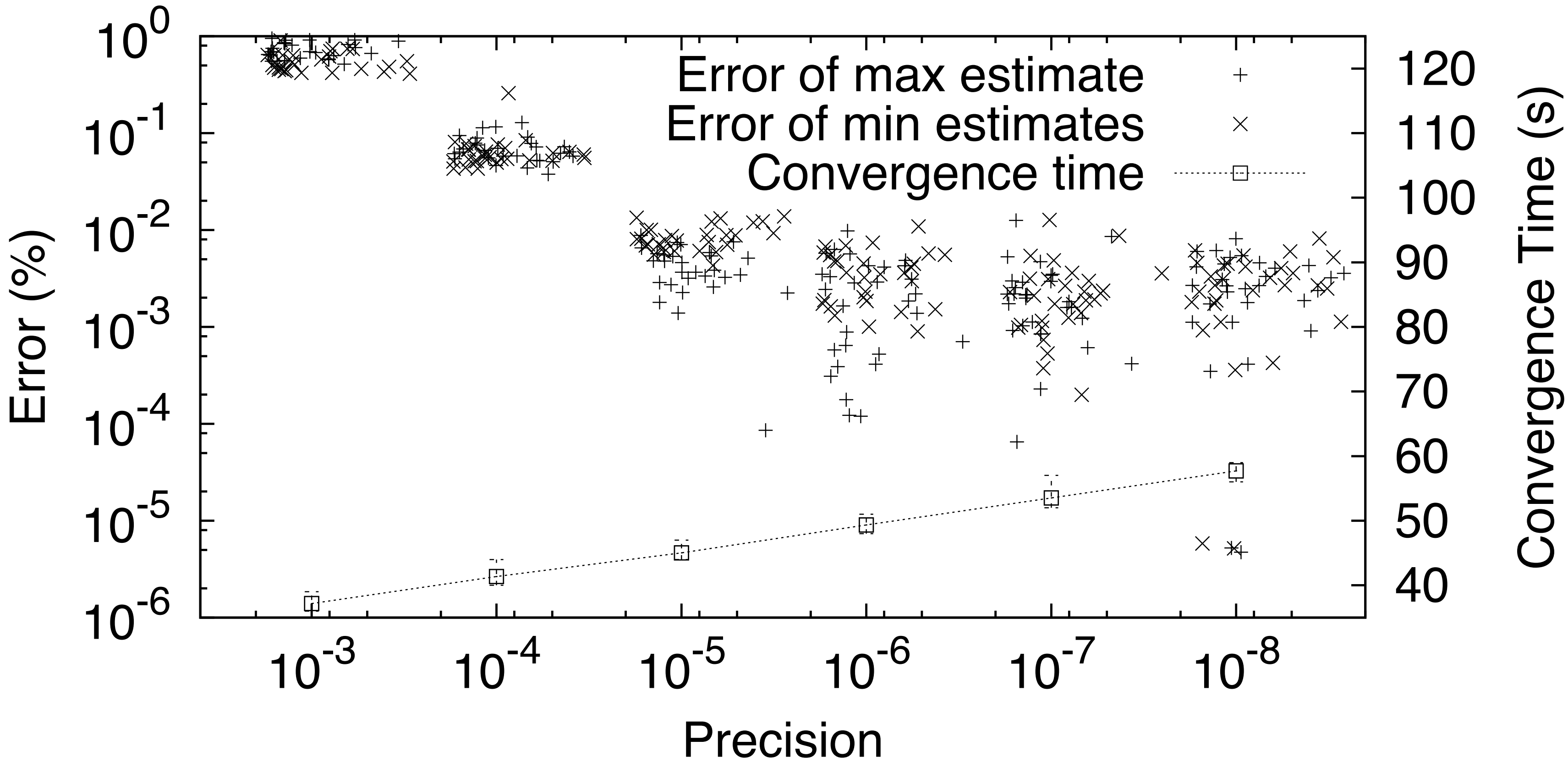
- **Assign random numbers in *[0, d[***
  - Locally; here, *d=127*
- **Build a ring topology**
  - Gossip topology construction (T-Man)
- **Compute the distance to the successor**
  - Locally
- **Compute the average distance *a***
  - *Gossip aggregation*
- ***Compute size***
  - $d / a = n$



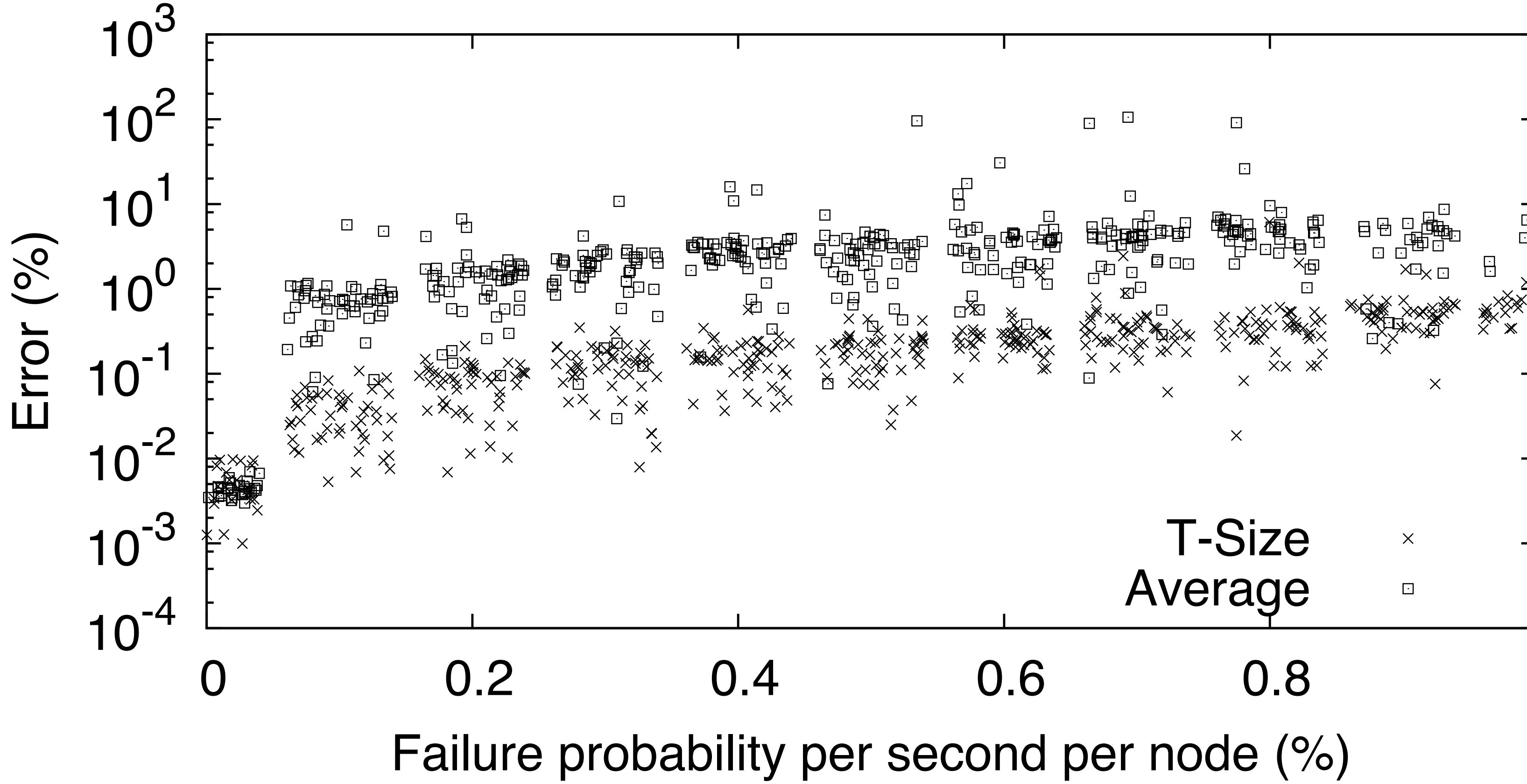
Scalability



Accuracy – w.r.t. parameter Precision



Robustness



10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Error (%)
0
0.2
0.4
0.6
0.8
1
Failure probability per second per node (%)
T-Size
Average

Absolute slicing

- **Bibliography**

  - A. Montresor and R. Zandonati. Absolute slicing in peer-to-peer systems. In Proc. of the 5th International Workshop on Hot Topics in Peer-to-Peer Systems (HotP2P'08), Miami, FL, USA, April 2008.

Introduction

- **System model**
  - An huge collection of networked nodes (resource pool)
  - Potentially owned/controlled by a single organization that deploys massive services on them
- **Examples**
  - ISPs that place smart modems / set-top boxes at their customers' homes
  - BT, France Telecom
- **Note: similar to current P2P systems, but with some peculiar differences**

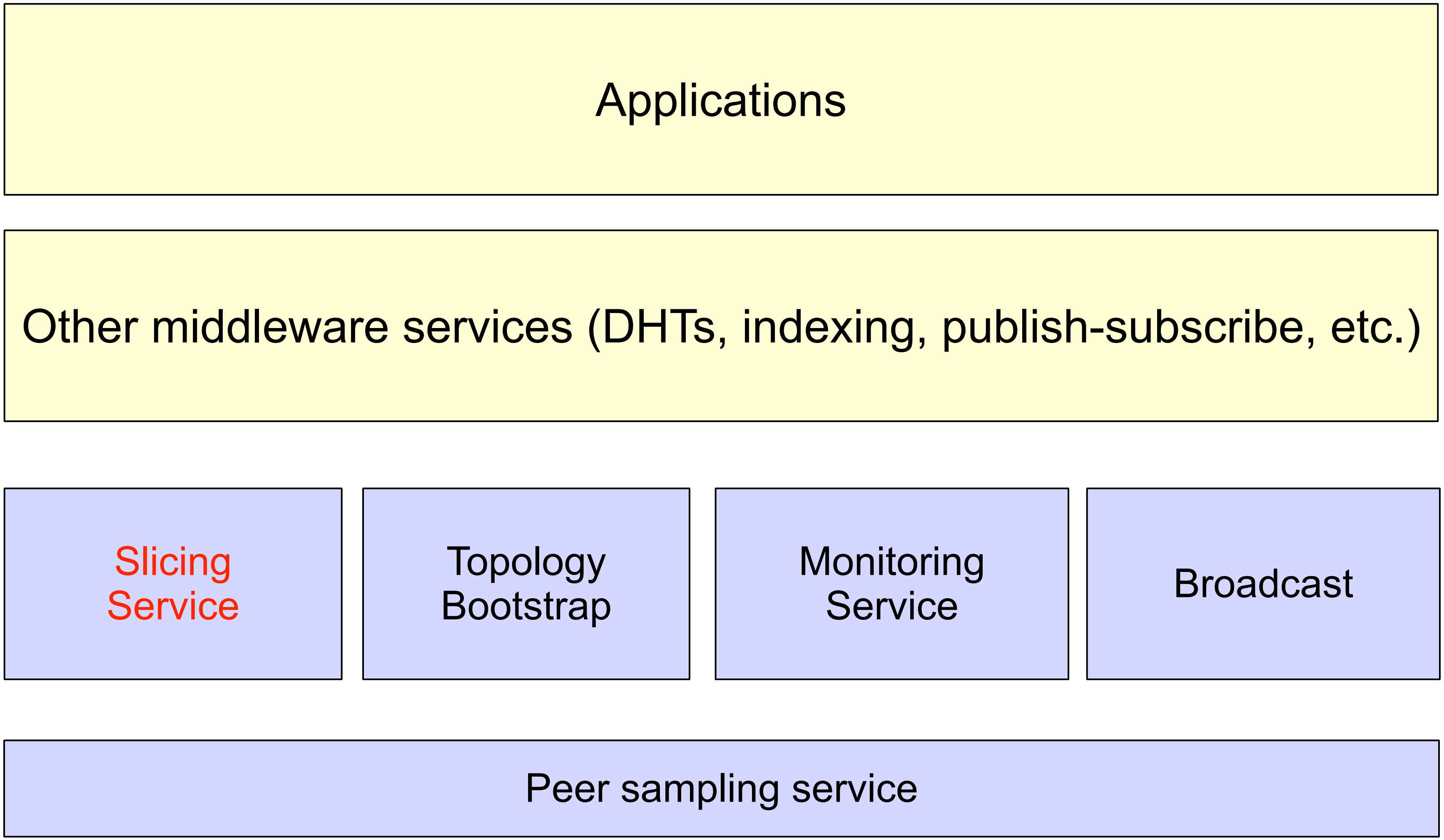
Introduction: possible scenarios

- **Multiple-services architecture**
  - Nodes must be able to host a large number of services, potentially executed by third-party entities
- **On-demand services**
  - A subset of the nodes can be leased temporally and quickly organized into an overlay network
- **Adaptive resource management**
  - Resource assignments of long-lived services could be adapted based on QoS requirements and changes in the environment

Overview

- **What we need to realize those scenarios?**
  - Maintain a dynamic membership of the network (peer sampling)
  - Dynamically allocate subset of nodes to applications (*slicing*)
  - Start overlays from scratch (bootstrap)
  - Deploy applications on overlays (broadcast)
  - Monitor applications (aggregation)
- **This while dealing with massive dynamism**
  - Catastrophic failures
  - Variations in QoS requirements (flash crowds)

Architecture: a decentralized OS



The problem

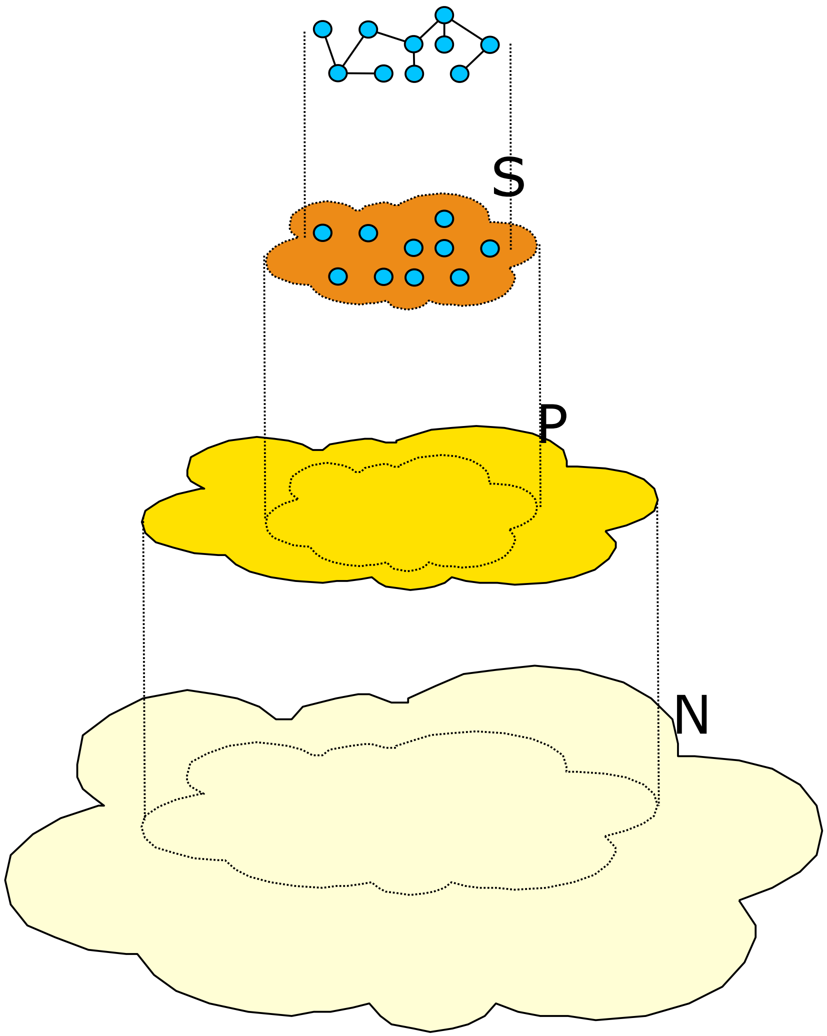
- **Distributed Slicing**
  - Given a distributed collection of nodes, we want to allocate a subset ("slice") of them to a specific application, by selecting those that satisfy a given condition over group or node attributes
- **Ordered Slicing (Fernandez et al., 2007)**
  - Return top *k*% nodes based on some attribute ranking
- **Absolute slicing**
  - Return *k* nodes and maintain such allocation in spite of churn
- **Cumulative slicing**
  - Return nodes whose attribute total sum correspond to a target value

Problem definition

- **We considere a dynamic collection N of nodes**
- **Each node $n_i \in N$ is provided with an attribute function**
  - $f_i: A \rightarrow V$
- **Slice $S(c,s)$: a dynamic subset of N such that**
  - c is a first-order-logic condition defined over attribute names and values, identifying the potential member of the slice
  - s is the desired slice size
- **Slice quality:**

$$\frac{|S(c,s)| - s}{s}$$

Problem definition



Slice nodes
(total slice size ~ *s*)

Potential nodes
(each node satisfying *c*)

Total nodes

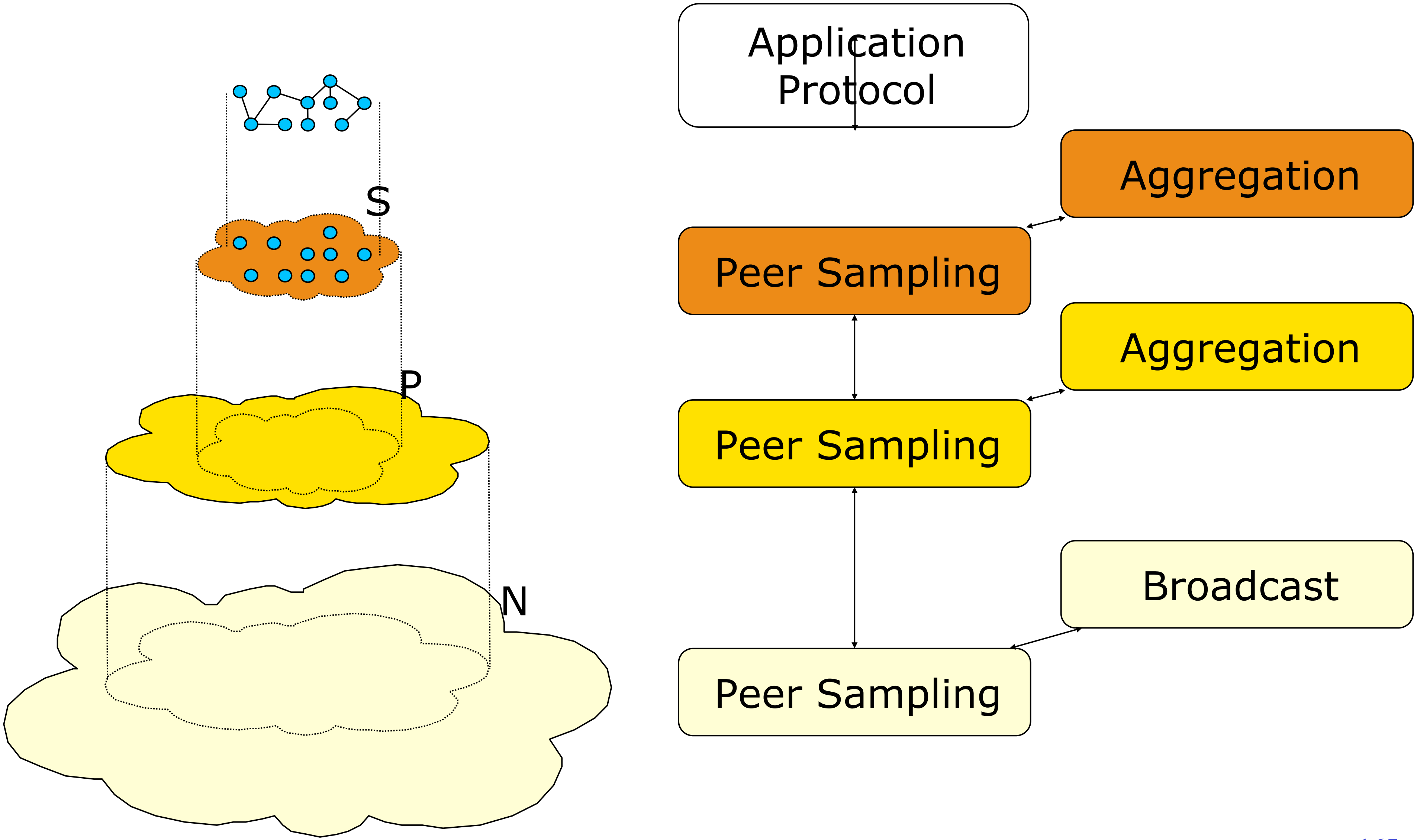
Issues

- **What we mean with "return a slice"?**
  - We cannot provide each node with a complete view of large scale subset
  - Slice composition may continuously change due to churn
- **How we compute the slice size?**
  - without a central service that does the counting?
- **How do we inform nodes about the current slice definition?**
  - Multiple slices, over different conditions, with potentially changing slice sizes

Gossip to the rescue

- **Turns out that all services listed so far can be implemented using a gossip approach**
  - *Peer sampling*: continuously provides uniform random samples over a dynamic large collection of nodes
    - random samples can be used to build other gossip protocols
    - side-effect: strongly connected random graph
  - *Aggregation*: compute aggregate information (average, sum, total size, etc.) over large collection of nodes
    - we are interested in size estimation
  - *Broadcast*: disseminate information
- **Gossip beyond dissemination**
  - Information is not simply exchanged, but also manipulated

Architecture of the absolute slicing protocol



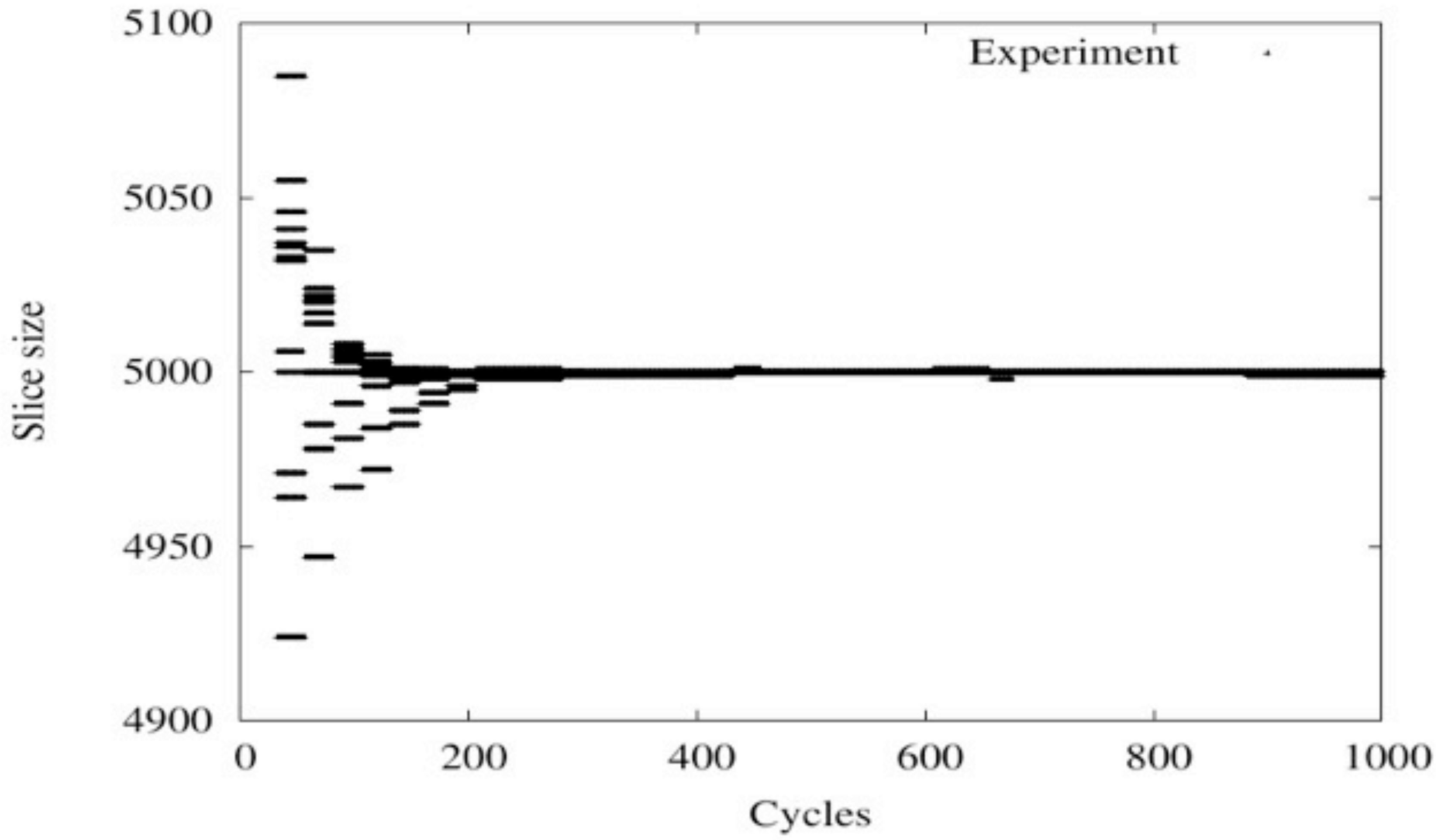
The slicing algorithm

- **Total group**
  - All nodes participate in the peer sampling protocol to maintain the total group
- **Potential group**
  - Nodes that satisfy the condition *c* join the potential group peer sampling
    - Means: inject their identifier into message exchanged at the 2nd peer sampling layer
- **Aggregation**
  - Estimate the size of the potential group *size(P)*

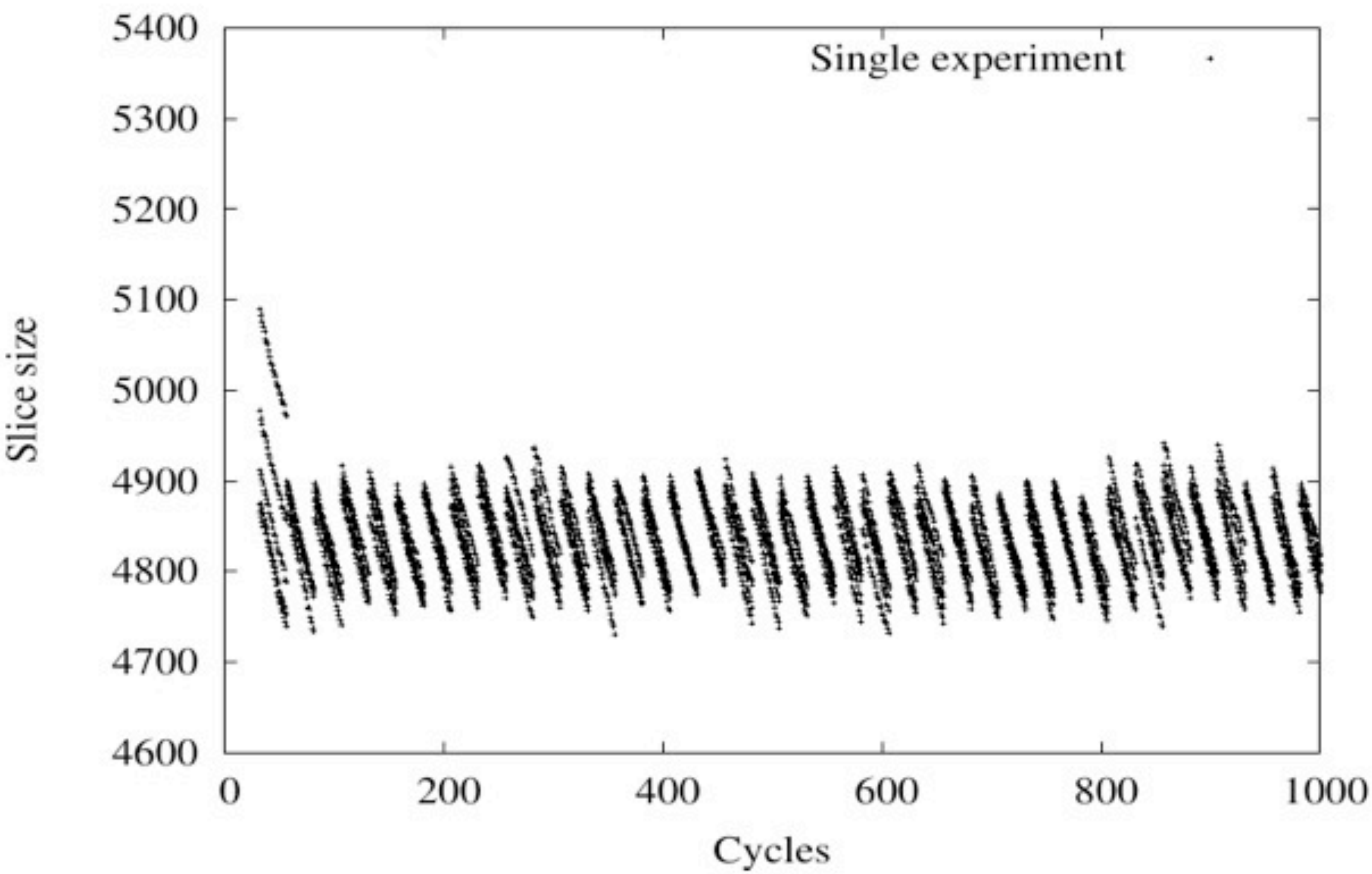
The slicing algorithm

- **Slice group**
  - Nodes that “believe to belong” to the slice join the slice peer sampling
    - Means: inject their identifier into messages exchanged at the 3rd peer sampling layer
- **Aggregation**
  - Estimate the size of the slice *size(S)*
- **Nodes “believe to belong” or not to the slice**
  - join the slice with prob. *(s-size(S)) / (size(P)-size(S))*
  - leave the slice with prob. *(size(S)-s) / size(S)*

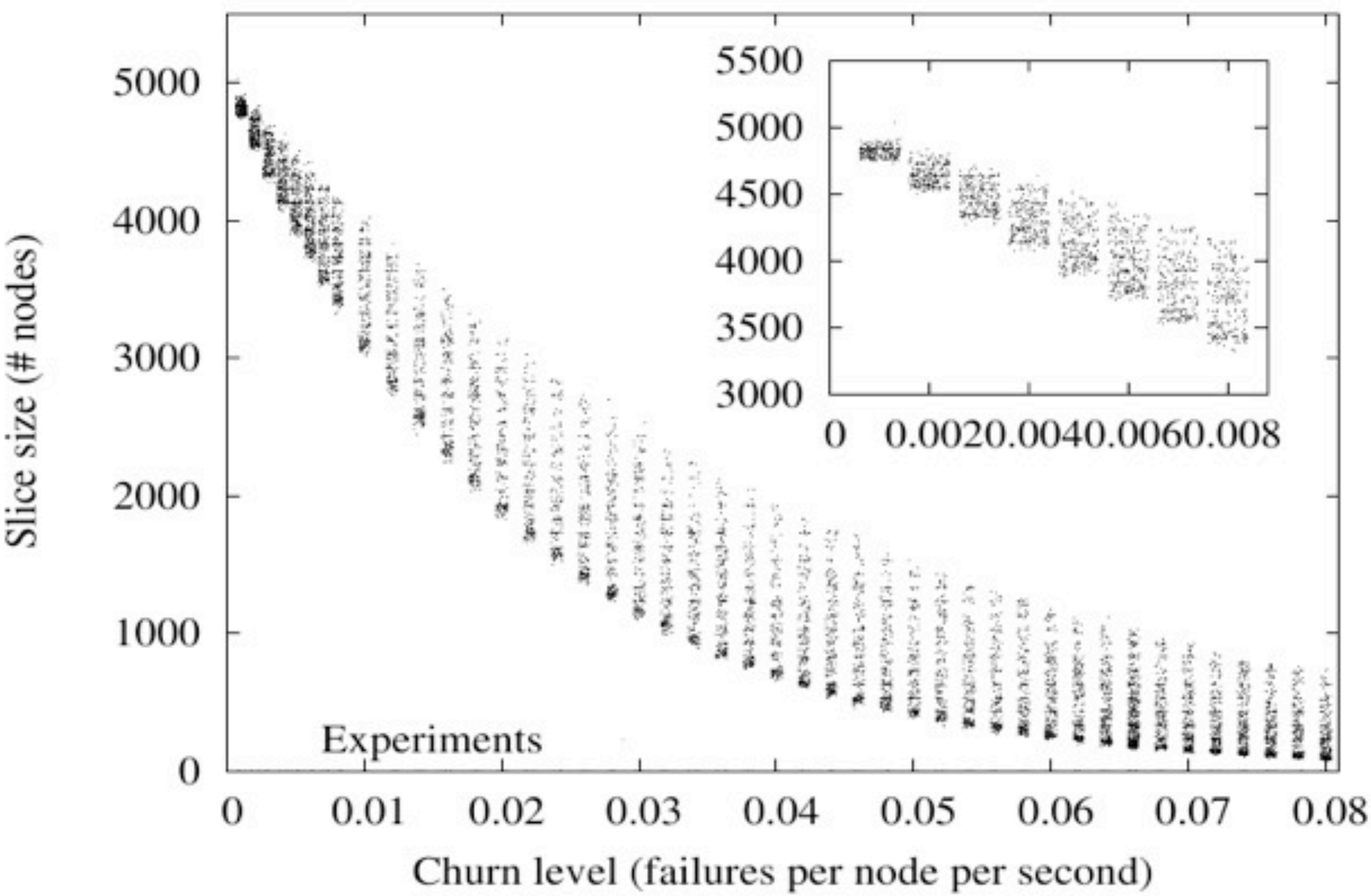
Experimental results: actual slice size



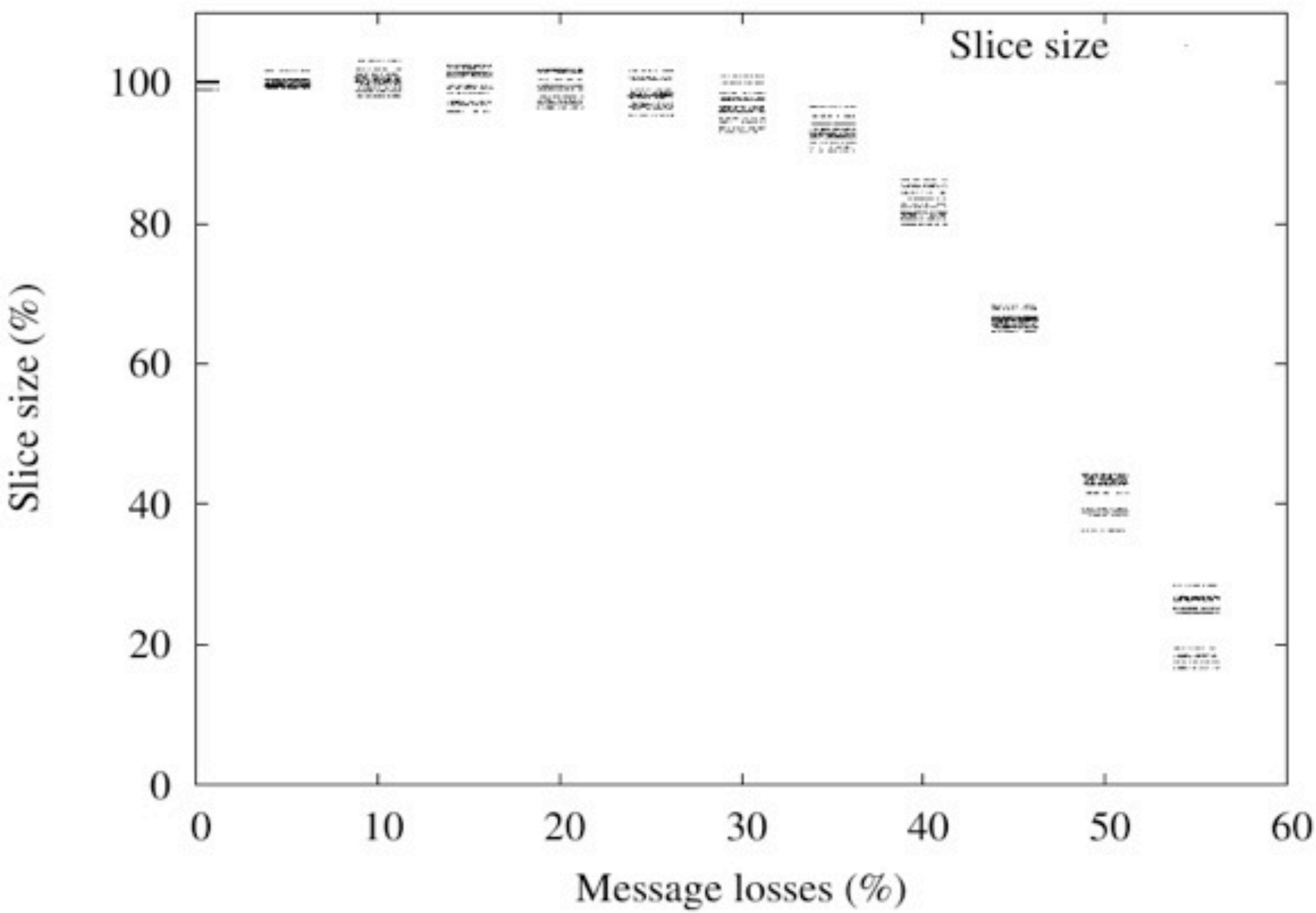
Experimental results: churn 10^{-4} nodes/s



Experimental results: variable churn



Experimental results: message losses



Slicing - conclusion

- **Absolute slicing protocol**
  - Extremely robust (high level of churn, message losses)
  - Low cost (several layers, but each requiring few bytes per sec)
  - Large precision
- **The message**
  - Gossip can solve many problems in a robust way
  - Customizable to many needs
- **What's next?**
  - Cumulative slicing:
    - very similar, but it's a knapsack problem

- **Bibliography**

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- **Additional bibliography**

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  - M. Biazzini, B. Bánhelyi, A. Montresor, and M. Jelasity. *Distributed hyper-heuristics for real parameter optimization*. In Proceedings of the 11th Genetic and Evolutionary Computation Conference (GECCO'09), pages 1339-1346, Montreal, Québec, Canada, July 2009.

Particle swarm optimization

- **Input:**
  - A multi-dimensional function
  - A multi-dimensional space to be inspected
- **Output:**
  - The point where the minimum is located, together with its value
- **Approximation problem**

Particle swarm optimization

- **A *solver* is a swarm of particles spread in the domain of the objective function**
- **Particles evaluate the objective function in a point p, looking for the minimum**
- **Each particle knows the best points**
  - found by itself (b_p)
  - found by someone in the swarm (b_g)
- **Each particle updates its position p as follows:**
  - $v = v + c_1 * rand() * (b_p - p) + c_2 * rand() * (b_g - p)$
  - $p = p + v$

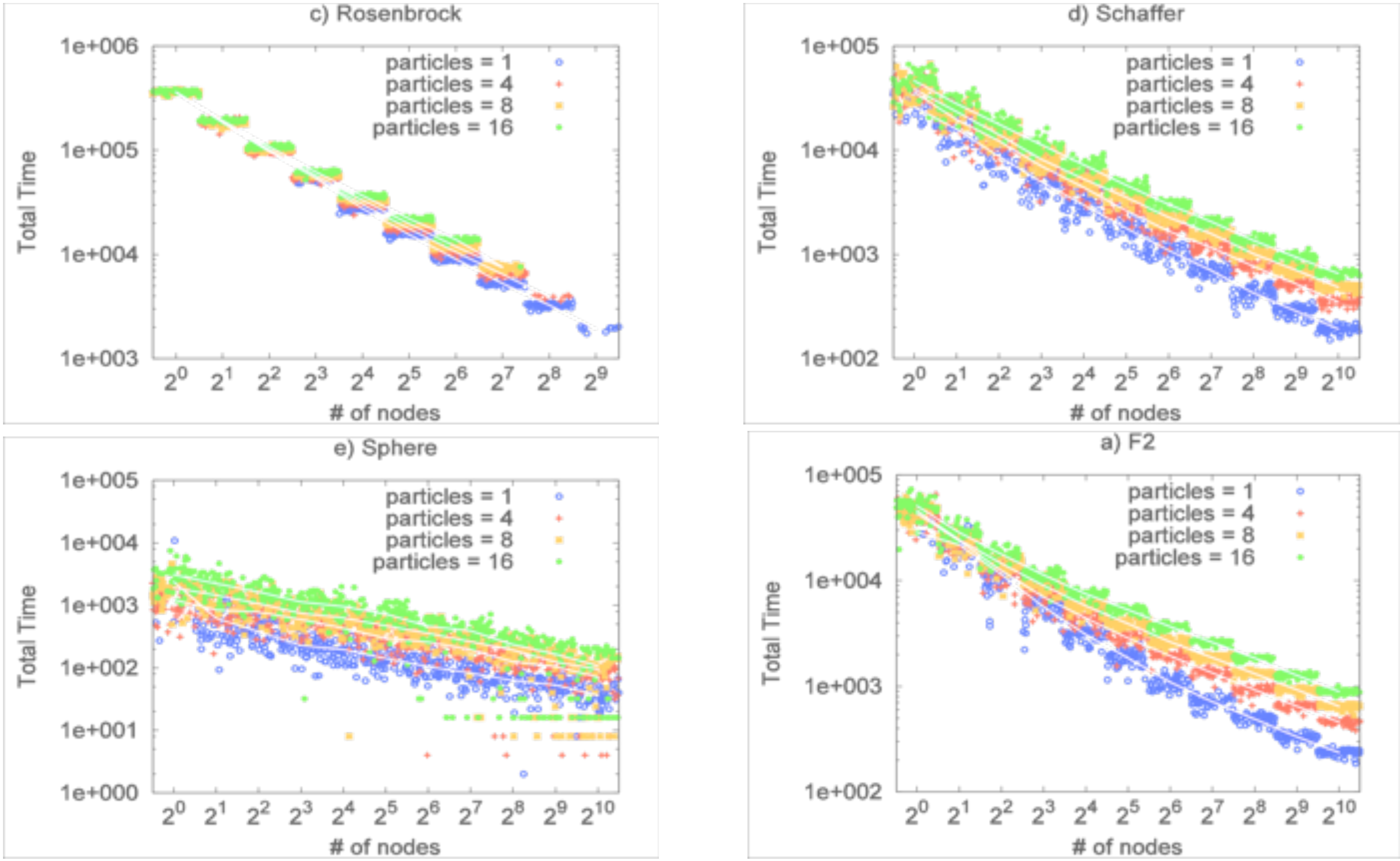
Particle swarm optimization

- **Modular architecture for distributed optimization:**
- **The topology service (NEWSCAST)**
  - creates and maintains an overlay topology
- **The function optimization service (D-PSO)**
  - evaluates the function over a set of points
  - Local/remote history driven choices
- **The coordination service (gossip algorithm)**
  - determines the selection of points to be evaluated
  - spread information about the global optimum

Particle swarm optimization

- **Communication failures are harmless**
  - Losses of messages just slow down the spreading of (correct) information
- **Churning is inoffensive**
  - Nodes can join and leave arbitrarily and this does not affect the consistency of the overall computation

Scalability



Gossip Lego, reloaded

- **The baseplate**
  - Peer sampling
- **The bricks**
  - Slicing (group management)
  - Topology bootstrap
  - Aggregation (monitoring)
  - Load balancing (based on aggregation)
- **Applications**
  - Function optimization
  - P2P video streaming
  - Social networking

Conclusions

- **We only started to discover the power of gossip**
  - Many other problems can be solved
- **The right tool for**
  - large-scale
  - dynamic systems
- **Caveat emptor: security**
  - We only started to consider the problems related to security in open systems

Shameless advertisement

- **PeerSim - A peer-to-peer simulator**
  - Written in Java
  - Specialized for epidemic protocols
  - Configurations based on textual file
  - Light and fast core
- **Some statistics**
  - 15.000+ downloads
  - 150+ papers written with PeerSim

PeerSim: A Peer-to-Peer Simulator

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Introduction top

Peer-to-peer systems can be of a very large scale such as millions of nodes, which typically join and leave continously. These properties are very challenging to deal with. Evaluating a new protocol in a real environment, especially in its early stages of development, is not feasible.

PeerSim has been developed with extreme scalability and support for dynamicity in mind. We use it in our everyday research and chose to release it to the public under the GPL open source license. It is written in Java and it is composed of two simulation engines, a simplified (cycle-based) one and and event driven one. The engines are supported by many simple, extendable, and pluggable components, with a flexible configuration mechanism.

The cycle-based engine, to allow for scalability, uses some simplifying assumptions, such as ignoring the details of the transport layer in the communication protocol stack. The event-based engine is less efficient but more realistic. Among other things, it supports transport layer simulation as well. In addition, cycle-based protocols can be run by the event-based engine too.

PeerSim started under EU projects BISON and DELIS DELIS. The PeerSim development in Trento (Alberto Montresor, Gian Paolo Jesi) is now partially supported by the Napa-Wine project.

People top

The main developers of PeerSim are:

Márk Jelasity, Alberto Montresor,

Gian Paolo Jesi, Spyros Voulgaris

Other contributors and testers (in alphabetical order):

- Stefano Arteconi
- David Hales
- Andrea Marcozzi
- Fabio Picconi

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- **For some slides:**
  - Spyros
- **Those who invited me:**
  - Marinho, Luciano and Lisandro
- **And finally:**
  - You for listening!