On Failure Detection Algorithms in Overlay Networks

INFOCOM‘ 2005

2005/09/30

Outline

- Introduction
- Network Model
- Keep-Alive Algorithms
- Evaluation
- Conclusion

Introduction (1/2)

- Overlay networks are seen as an excellent platform for large scale distributed systems -- one reason is **resilience:** in three aspects
  - Data replication
  - Routing recovery
  - Static resilience

  } rely on accurate and timely detection of node failures
- Failure detection algorithms can be classified as
  - Active approach: periodically send keep-alive messages
  - Passive approach:
    - Use data packets to convey aliveness information,
    - Inadequate in several situations
    - Can be viewed as an optimization of active approach when data traffic is present

Introduction (2/2)

- Two classes of active keep-alive approaches
  - Baseline: each node independently decides whether its neighbors are alive or not
  - Sharing: nodes share aliveness information and thus can reduce the failure detection time
- There is a tradeoff between
  - Minimizing the failure detection time may increase the Probability of false positive (making a false detection)
  - The lower the failure detection time, the higher the cost of control overhead
  - Packet loss rate: packets are lost due to forwarding to a failed neighbor

Goals of this paper

- To examine how keep-alive algorithms can detect failures as soon as possible when a node can no longer communicate with a neighbor
- To examine how the design of various keep-alive approaches affect their performance in
  - Detection time
  - Probability of false positive
  - Control overhead
  - Packet loss rate

Network Model

- An overlay network with *n* nodes
  - *N(A)*: Neighbor set of *A* -- Each node *A* knows *d* other nodes in the network
  - Node *A* maintains its neighbor set by sending ack *"are you alive"* probes every Δ seconds to each neighbor
  - Node failure: assume nodes fail in a failstop manner; assume nodes join according to a Poisson process and fail according to an exponential distribution
  - Packet loss: assume due to
    - Transient problem such as network congestion
    - Network link failures
  - Propagation delay: a node consider a probe lost if it does not receive an ack within T_{to} seconds
  - Probe traffic: a node must bound the aggregate rate of probes received to some reasonable rate *R*

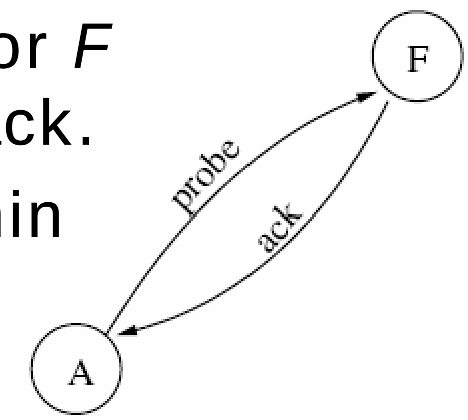
Keep-Alive Algorithms

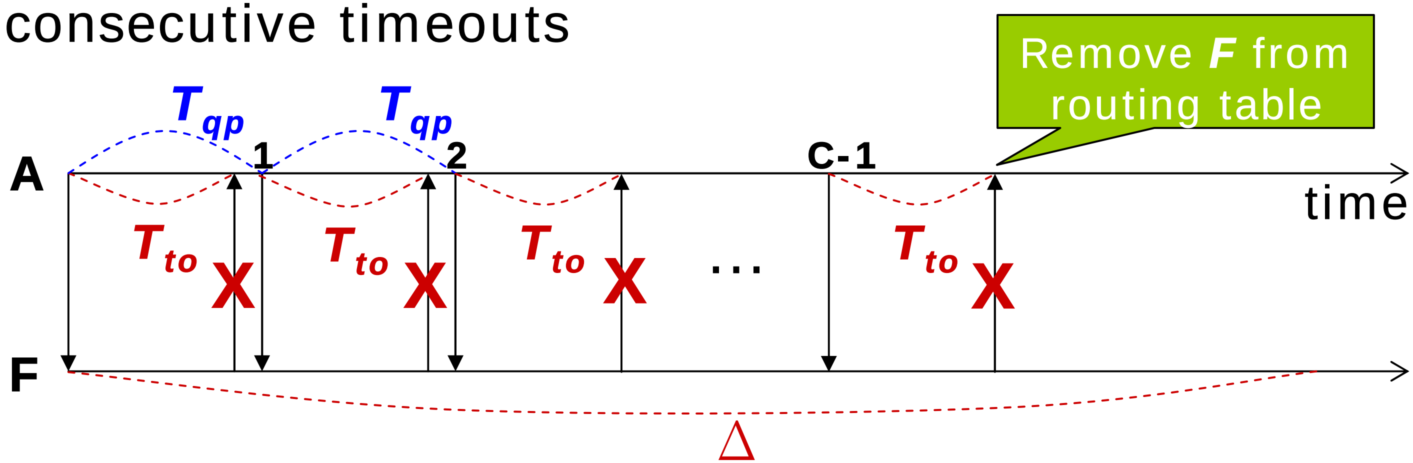
- Five keep-alive algorithms are presented
  - Not to model a specific keep-alive algorithm but rather to capture the essential aspects towards failure detection

Axes	**Baseline**	**SN+ BPTR**	**SN**	**SNP+ BPTR**	**SNP**
Gossip vs. probe	Probe	Probe	Probe	Probe	Probe
Node vs. net failures	both	both	both	both	both
Sharing information	no	yes	yes	yes	yes
Neg vs. pos info	-	neg	neg	both	both
Keep-alive state	no	yes	no	yes	no

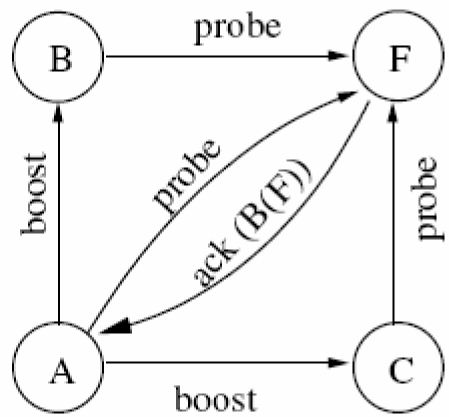
Baseline

- Node A sends a probe to its neighbor F every Δ seconds and waits for an ack.
- If a probe is not acknowledged within T_{to} seconds, it is considered lost
  - Then next probe is sent T_{qp} (> T_{to}) seconds after the previous probe, up to a maximum of c-1 quick probes
  - A node removes a neighbor from its routing table after c consecutive timeouts





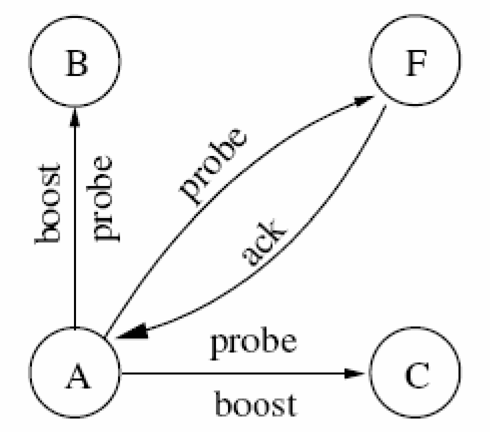
Sharing Negative Information with Backpointer State (SN+BPTR)



- Sharing Negative Information with Backpointer State: share negative (node is down) information among nodes who are interested in a particular neighbor
  - *B(F)*: Backpointer of *F*, the set of nodes which have a node *F* in their neighbors set
  - When a node in *B(F)* experiences *c* consecutive timeouts to *F*, it sends negative information (boost) to all other nodes in *B(F)*
  - As in-degree *b* of a node increases, Δ has to increase proportionally to maintain the aggregate probe rate *R*
    - Reduce the probability of false positive: impose a constraint such that the time span of the last ***k*** boosts must be less than a time window, T_{boost}

Sharing Negative Information (SN)

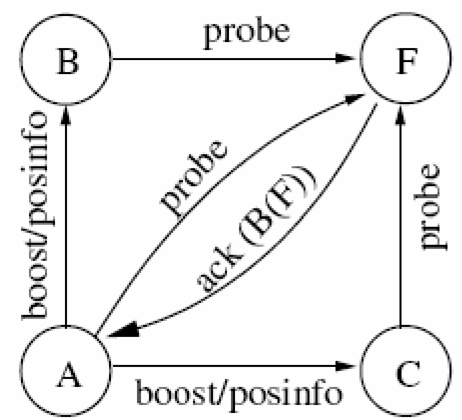
- When a node *A* experience *c* consecutive timeouts to a neighbor *F*, it sends a boost to its other neighbors



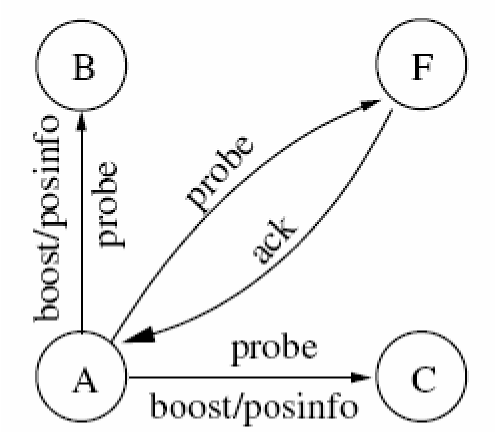
- A node removes a neighbor from its routing table if it experiences *c* consecutive timeouts, or receives *k* consecutive boosts.

Sharing Negative and Positive Information with Backpointer State (SNP+BPTR)

- SNP+BPTR is similar to SN+BPTR, with the addition of sharing positive (node is up) information to reduce the probability of false positive
- When *A* receives an ack from *F* and its boost counter for *F* is nonzero, it sends this positive information (posinfo) to other backpointers (*B* and *C*)
- When *B* receives the posinfo, it resets the boost counter for F to 0
- When *F* is up but the path between it and a node is down, the node will still remove *F* from its routing table because posinfo only resets boost counter and not the timeout counter



Sharing Negative and Positive Information (SNP)

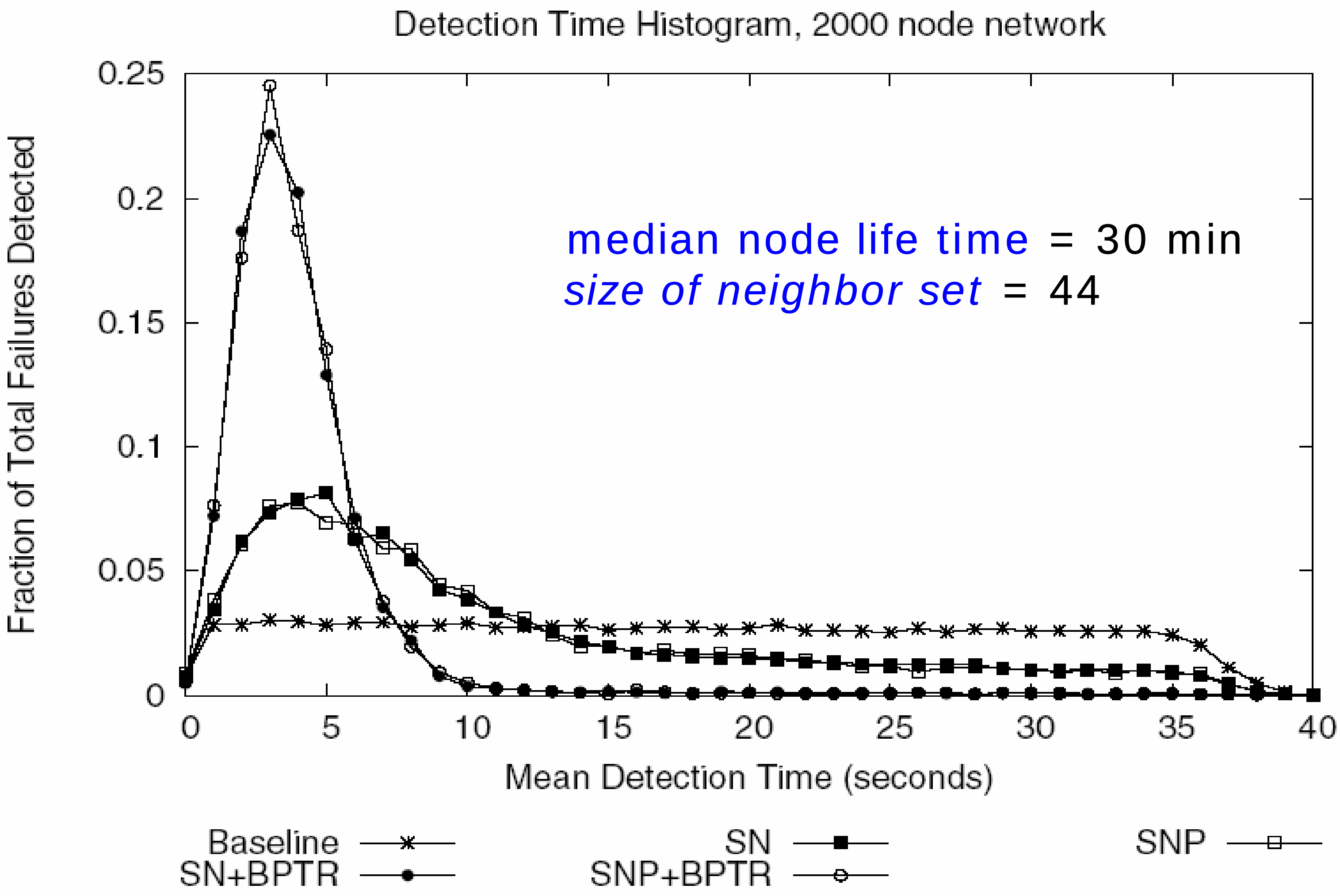


- SNP is similar to SN, with the addition of positive information to reduce the probability of false positive
- When *A* receives an ack from *F* and its boost counter for *F* is nonzero, it sends this posinfo to its other neighbor (*B* and *C*)
- When *B* receives the posinfo and has *F* as a neighbor, it resets the boost counter for *F* to zero

Evaluation

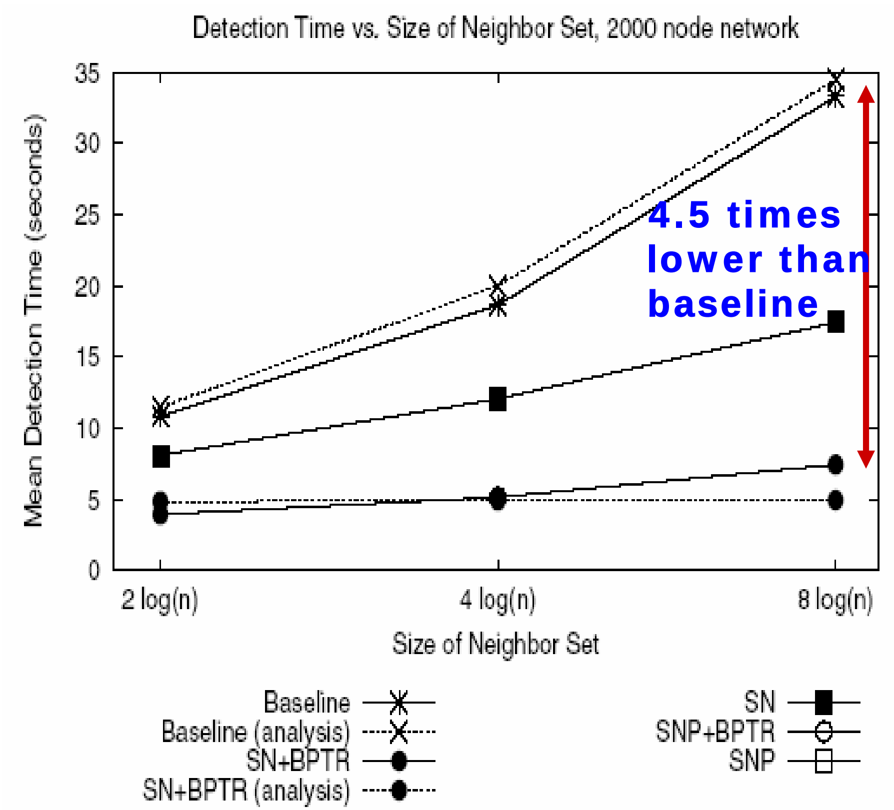
- Simulation and experimental results in the context of Chord
- Methodology
  - Start a Chord network with 2000 nodes
  - Key lookups (packets) are initiated from random sources to random keys, timed by a Poisson process at a rate of 200 per second
  - Two kinds of loss models are evaluated
    - LM1: packet losses are due to transient network problem, each packet traversing an overlay link is dropped independently with fixed probability p = 0.4%
    - LM2: injected network link failures so that the average unavailability of the path is 1.25%

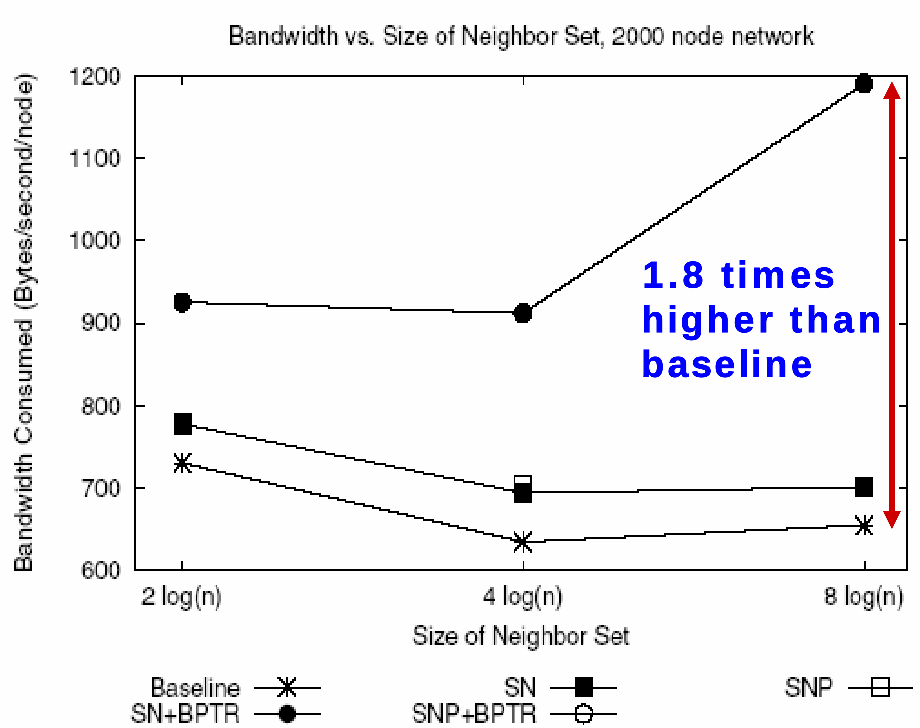
LM1 Results



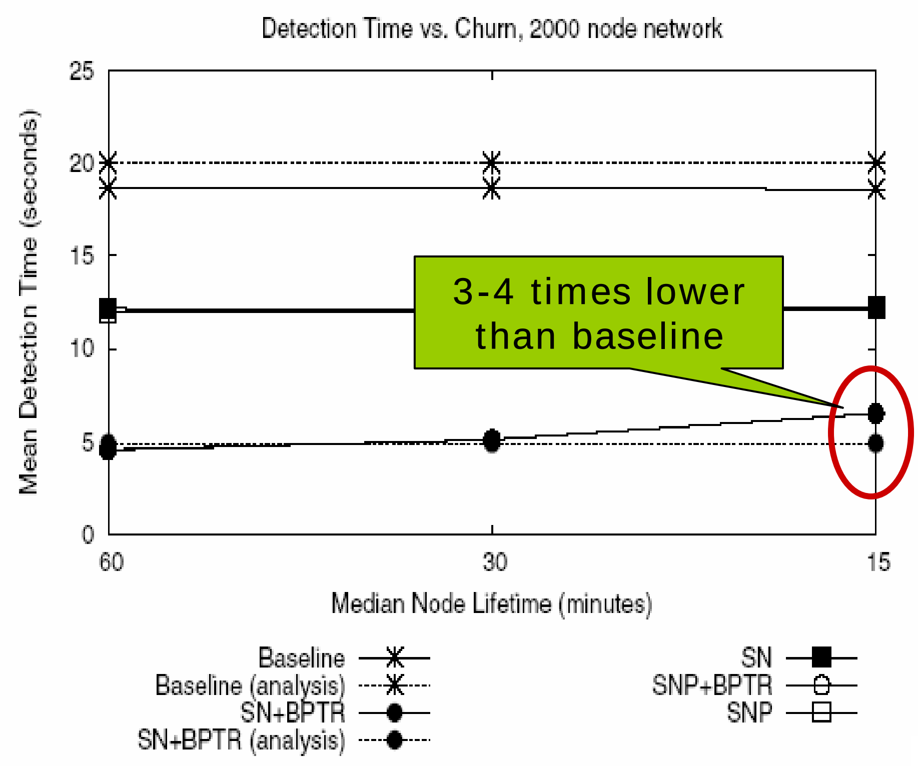
Detection Time Histogram, 2000 node network
median node life time = 30 min
size of neighbor set = 44
Fraction of Total Failures Detected
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
Mean Detection Time (seconds)
Baseline
SN
SNP
SN+BPTR
SNP+BPTR

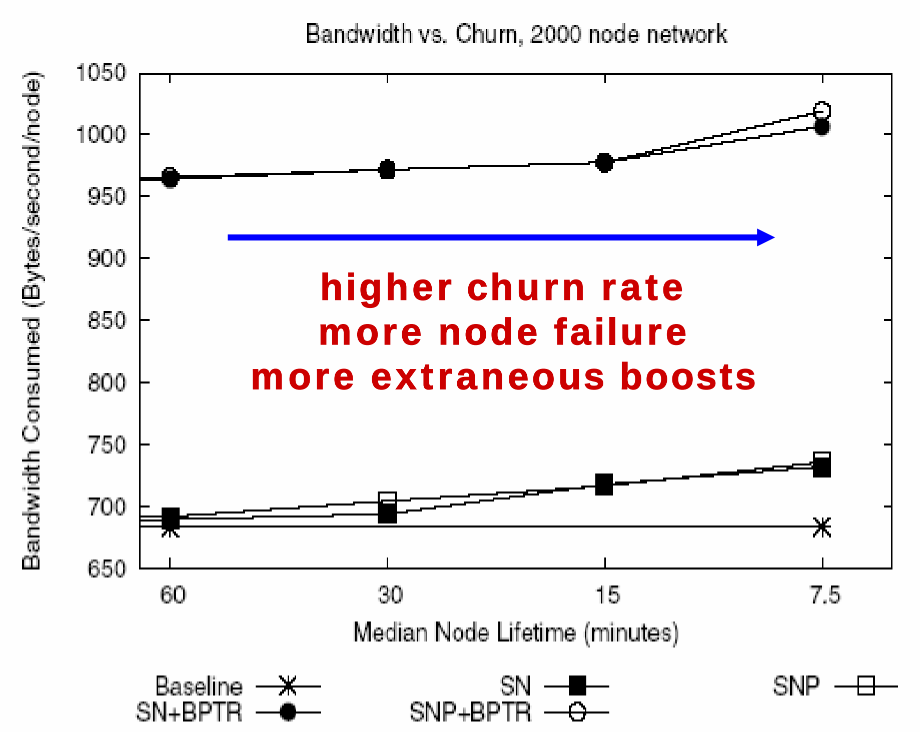
Metrics vs. Size of Neighbor Set





Metrics vs. Churn Rate

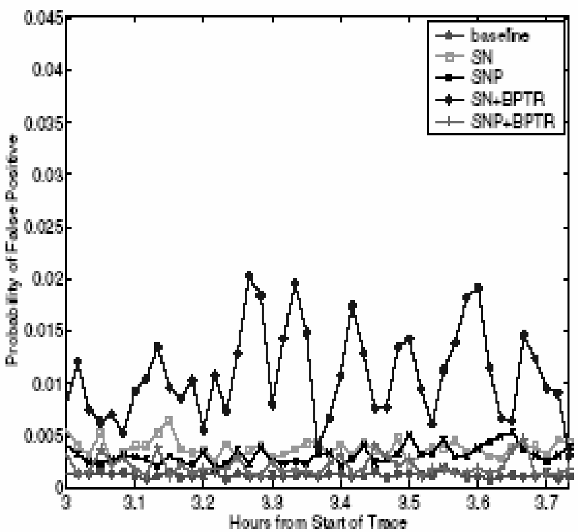




LM2 Results

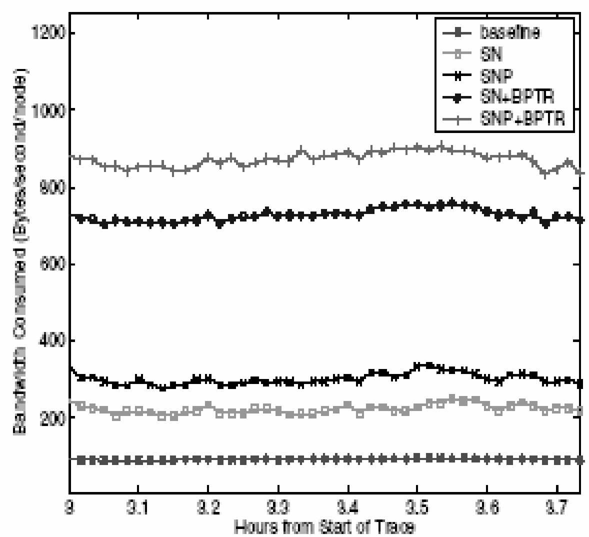
- Simulation with n=1000 nodes, mean lifetime = 22 min, d=128, and p=0.05
- Result for detection time is similar to that under LM1 loss model

Probability of false positive



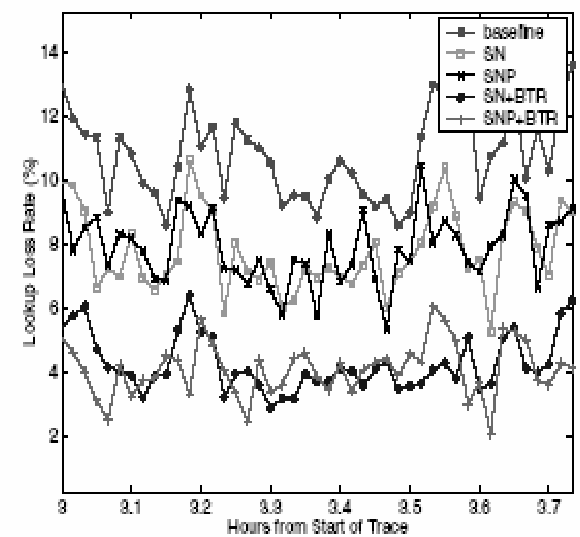
(a)

Control overhead



(b)

Packet loss rate



(c)

Conclusion (1/2)

- Main findings
  - Detection time vs. sharing
    - No network failure: sharing achieves both lower detection time and control overhead than baseline, with comparable probability of false positive
    - With network failure: sharing improves detection time at the cost of increased control overhead
  - Detection time vs. size of neighbor set
    - Improvement in detection time between baseline and sharing becomes more pronounced as size of neighbor set increases

Conclusion (2/2)

- Packet loss vs. size of neighbor set
  - Baseline: packet loss rate is a function of detection time, which increases linearly as degree increases if probe bandwidth stays constant
  - Sharing: packet loss rate is a function of path length, which decreases as the degree increases
- Packet loss rate vs. churn rate
  - For a target packet loss rate, sharing of information allows a network to operate at a higher churn rate than baseline