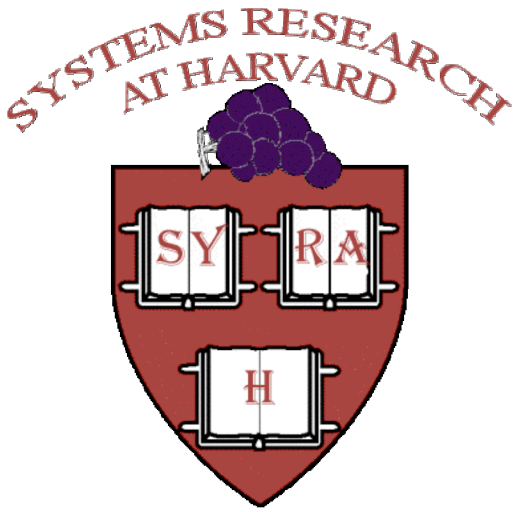
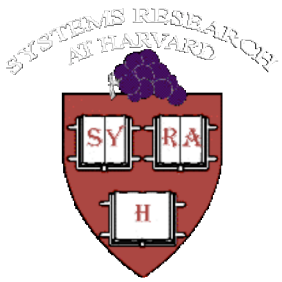
Distributed, Secure Load Balancing with Skew, Heterogeneity, and Churn



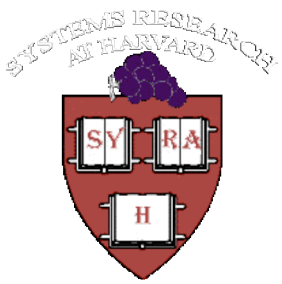
Jonathan Ledlie and Margo Seltzer

INFOCOM 2005 - March 16, 2005



Motivation - Why balance DHTs?

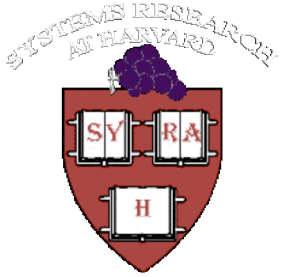
- Distributed hash tables (DHTs):
  - Becoming “off-the-shelf” distributed data structures
  - Was: backup storage; now: ALM, resource discovery
- DHTs must be versatile:
  - Handle variety of loads - low msg loss
    - Allocate network capacity
  - Realistic network conditions
  - Reasonably secure
- Numerous load balancing proposals in literature
  - Unrealistic assumptions
  - Poor performance



Problematic Assumptions

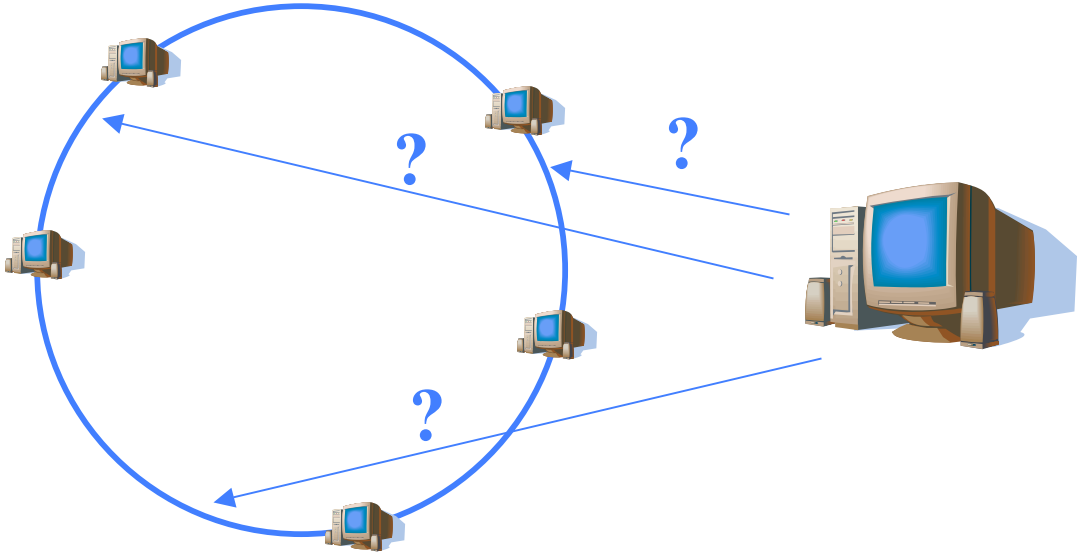
	Assumption	Reality
Physical Nodes	Uniform Capacity	Broad Heterogeneity
Workload	Uniform	Hotspots (Skew)
Membership	Stable	Lots of Churn
Security	Pick any ID	Malicious participants

Current load balancing algorithms are insufficient

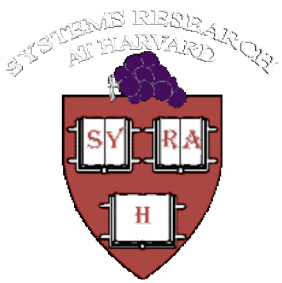


k-Choices Algorithm

- Support variation in skew, node heterogeneity, and churn
- Make IDs verifiable



1. **Sample**
2. **Cost fn**
3. **Join**

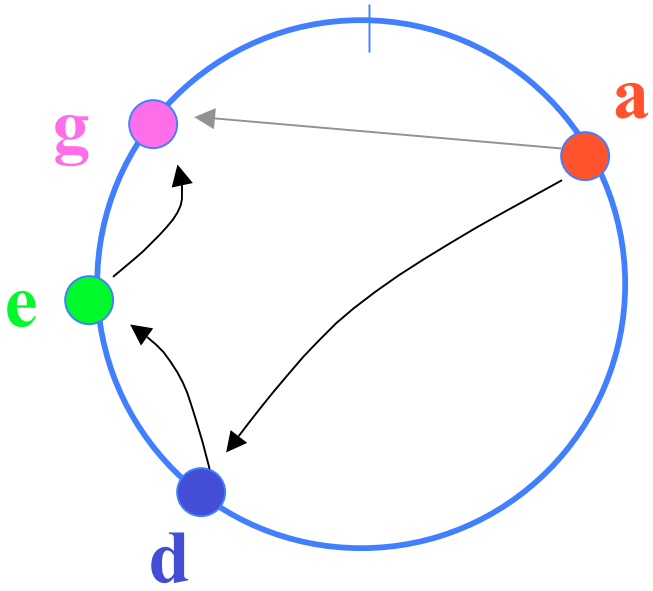


Talk Outline

- Overview
- Preliminaries
  - DHTs
  - Security
  - Network Characteristics
- k-Choices
- Prior Techniques
- Evaluation
- Conclusion

DHTs - Refresher

- Each node has one or more virtual servers (VSs).
- Each virtual server has an ID namespace (*e.g.,* (0,1], (0,2^{160}]).
- Msgs via O(log(N)) hops between any two VSs.



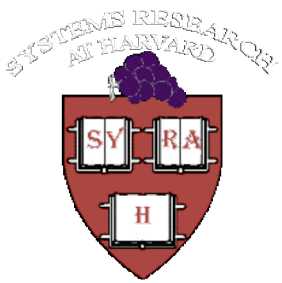

(a,b,c)


(d)

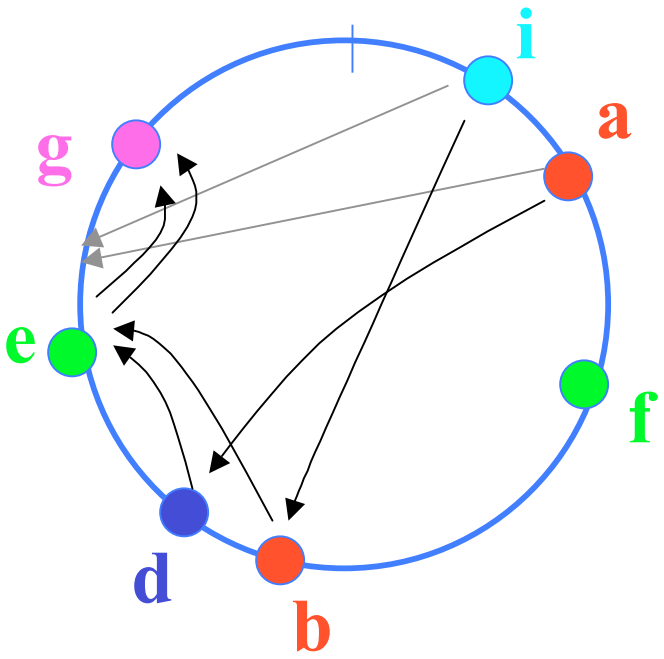

(e,f)


(g,h)

Chord-like routing



DHTs - Load




(a,b,c)

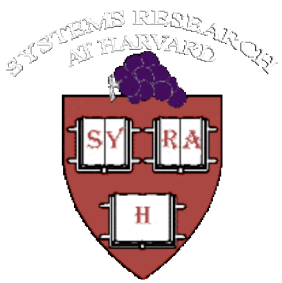

(d)


(e,f)

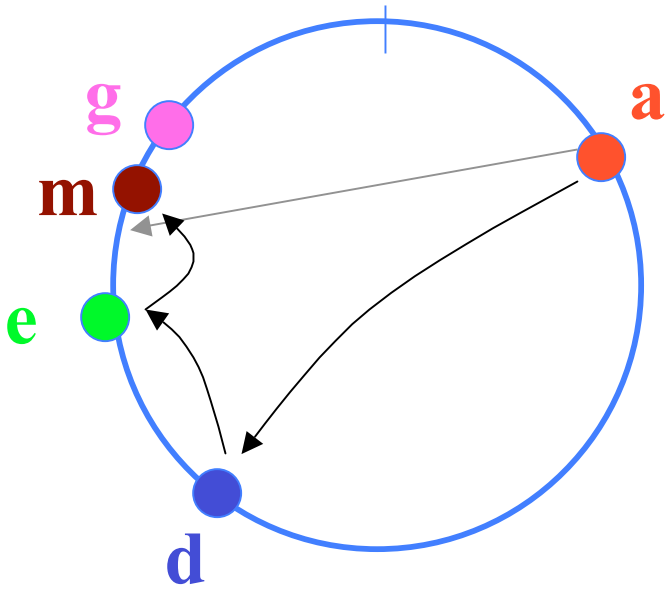

(g,h)


(i,j)

Load



Sybil Attacks



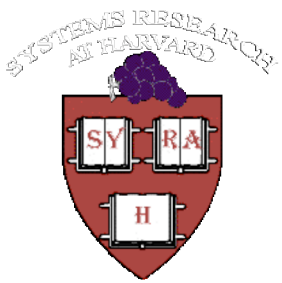

(a,b,c)


(d)


(e,f)

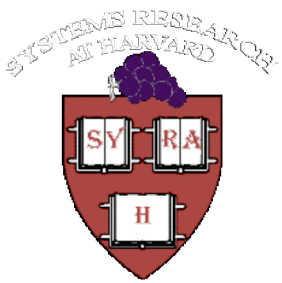

(m)

Unsecured IDs–>Take over portions of ring



Sybil Attack - Solution

- Central authority certifies each ID [Castro02]
- k-Choices uses similar scheme to generate limited set of certified IDs.



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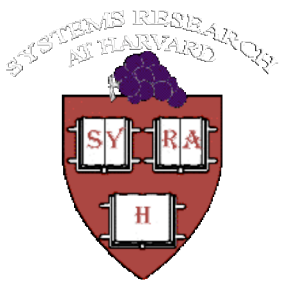
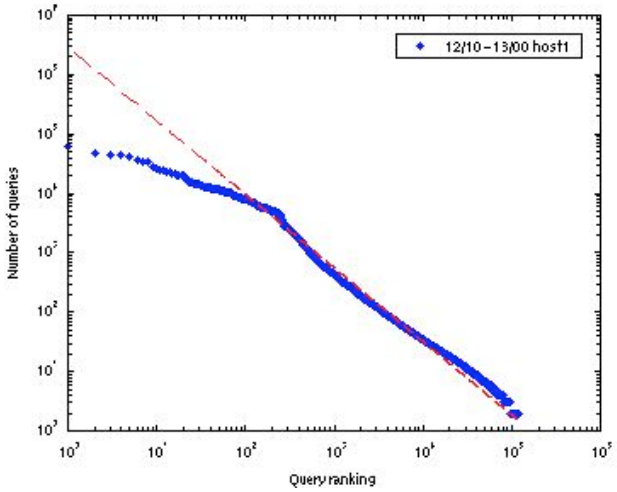
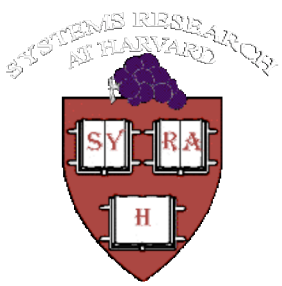


Characteristics - Skew

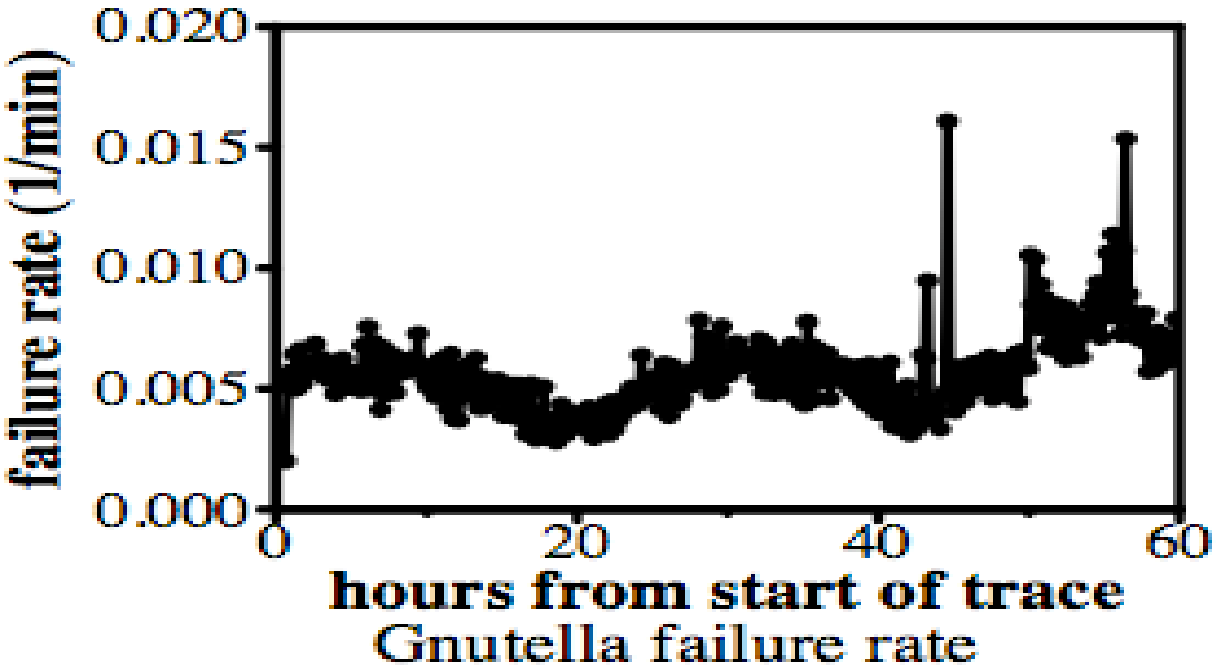
- Skew: hotspots popular content
- Typically Zipf popularity
- E.g., Gnutella queries (log-log scale):



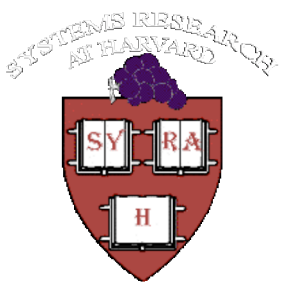


Characteristics - Churn

- Churn: pattern of participant join and departure.
- Pareto (memory-full) distribution (60 minute avg).

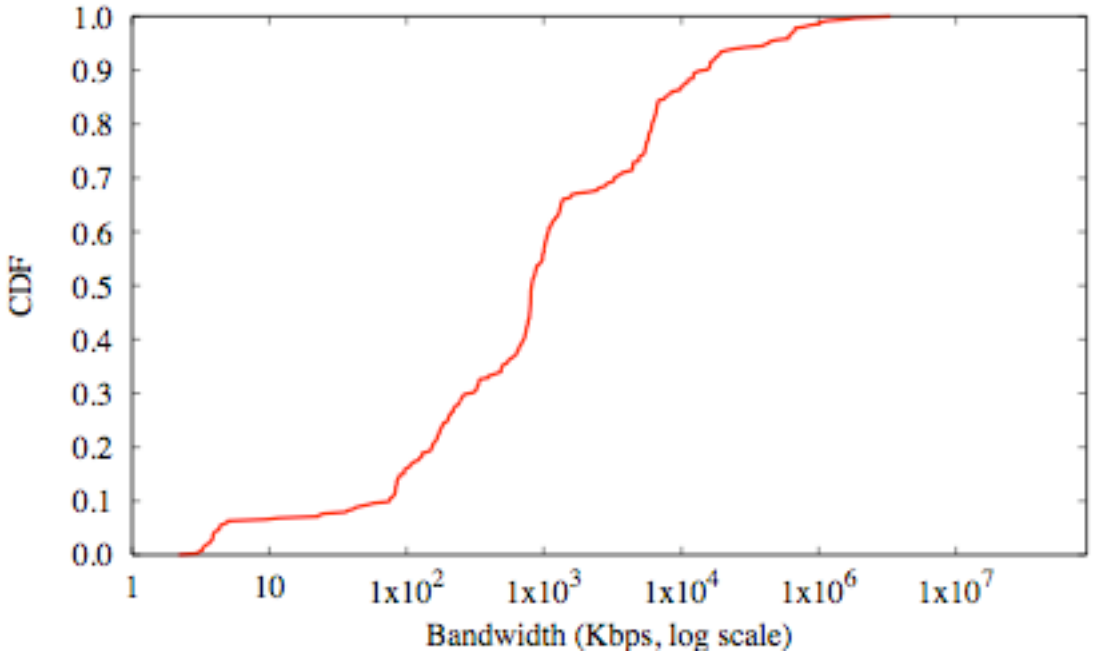


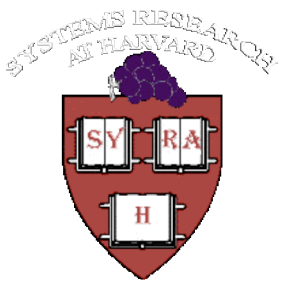
Gnutella failure rate



Characteristics - Heterogeneity

- Network bandwidths vary by five orders-of-magnitude.
- Routing capacity varies widely.





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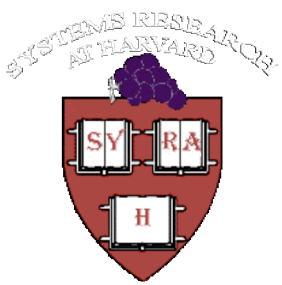
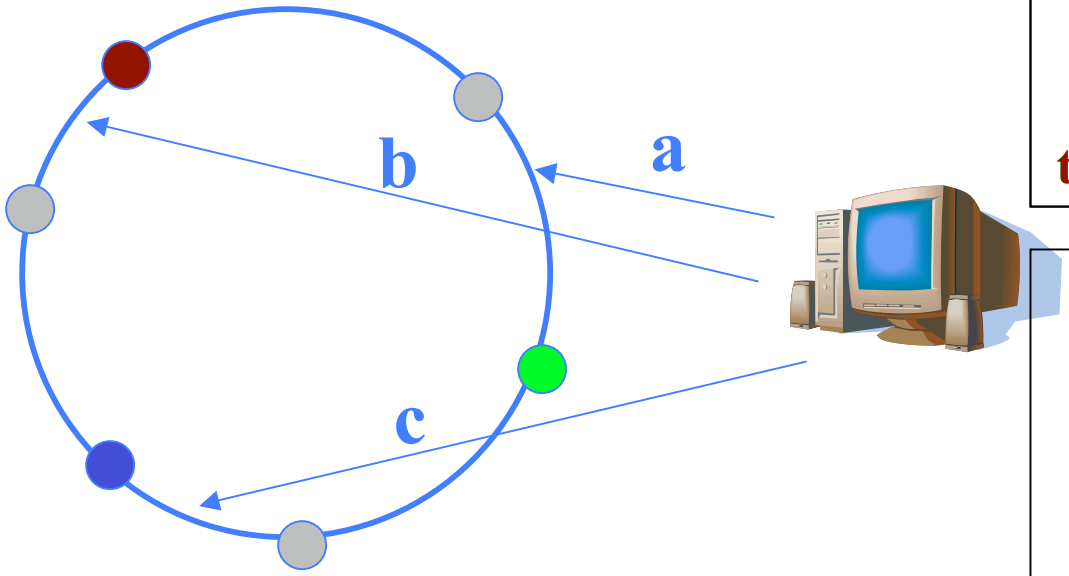


k-Choices - Steps

1. Probe
2. Evaluate Cost Function
3. Join

k-Choices - Sample

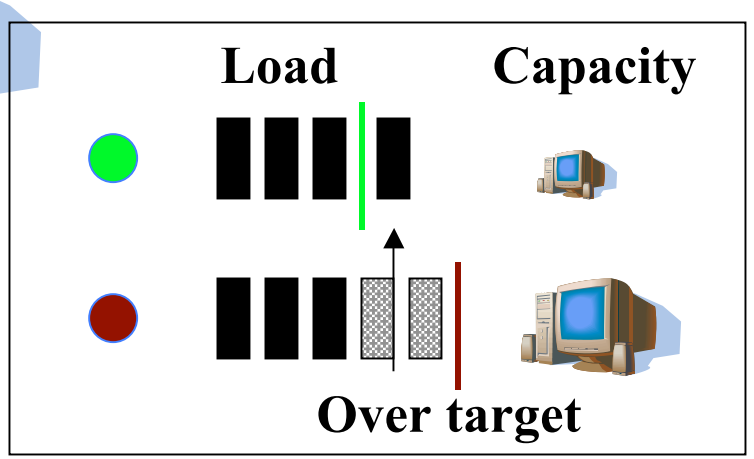
k=3



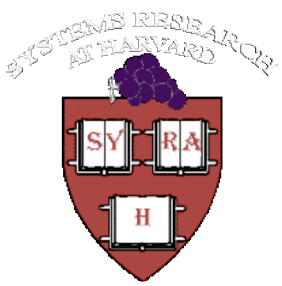
Sample ID b:

Learn succ(b) actual load,

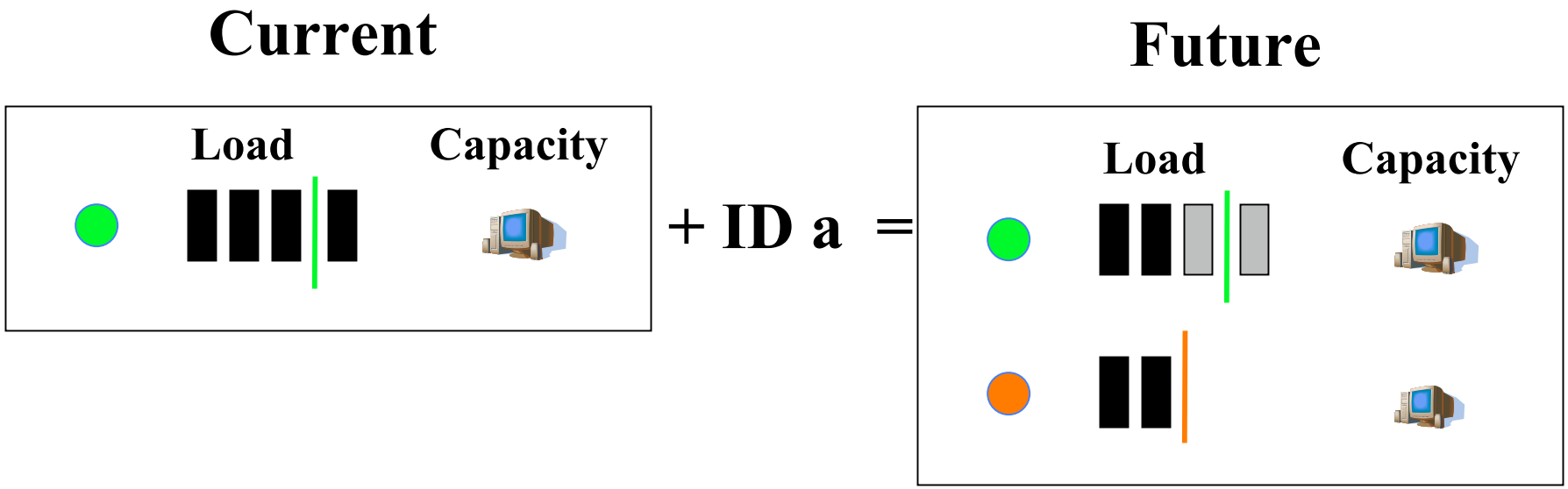
target load, and node capacity.



Discover load and capacity at each ID

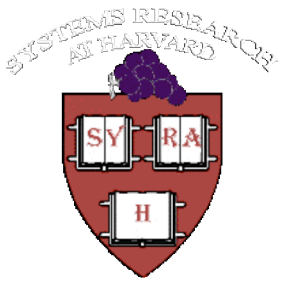


k-Choices - Cost Function



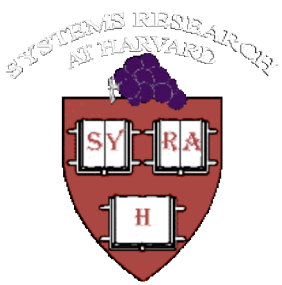
… + ID b = …

Choose ID that minimizes mismatch between target and load normalized by capacity.



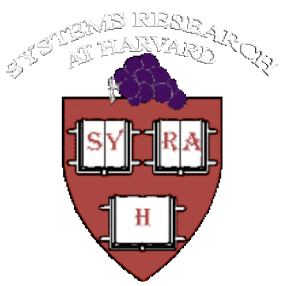
k-Choices - Properties

- Incorporates workload skew and node heterogeneity.
- Proactive load balancing - join time
- Reactive load balancing - reselect ID
- Verifiable IDs



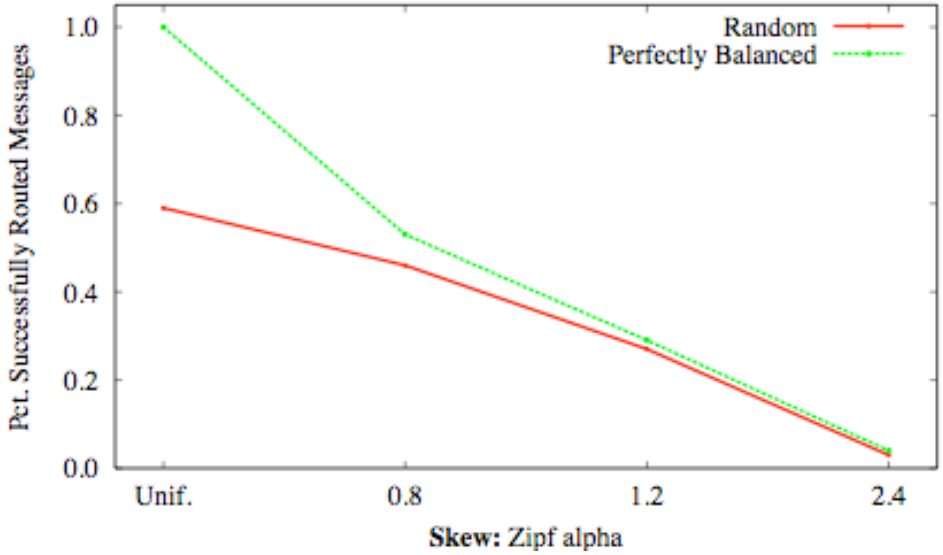
Outline

- Overview
- Preliminaries
- k-Choices
- Prior Techniques
  - log(N) virtual servers
  - Transfer
  - Proportion
  - Threshold
- Evaluation
- Conclusion

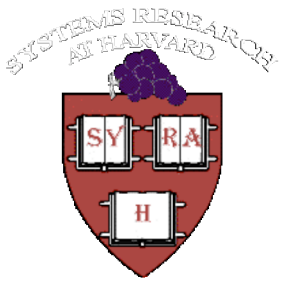


Prior Work - log(N) VS

- Namespace balancing (e.g. [Karger97])
- Central Limit Theorem
  - Total namespace for each node approximately equal



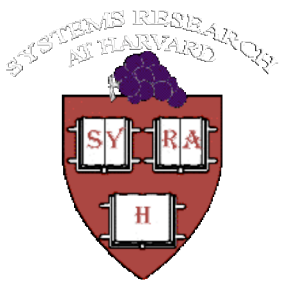
Namespace balancing does not equal load balancing.



Prior Work - Transfer

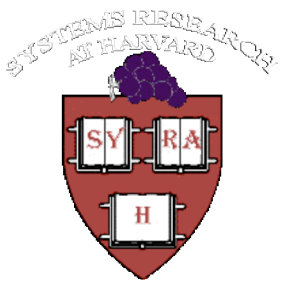
- Overload:
  a) >1 VS: attempt to transfer
  b) 1 VS: split first, then transfer
- Pros: Simple, Good Performance
- Cons: Unsecure
  – Split to arbitrary ID (cut in half)
  – Transfer to anyone

[Rao03,Godfrey04]



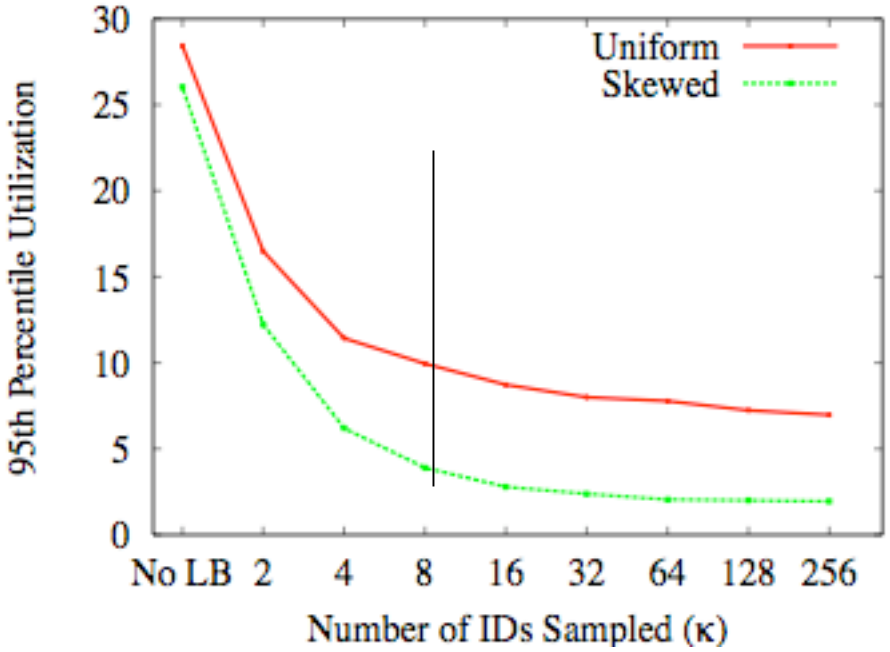
Evaluation

- Trace Driven Simulation
- Results
  - Determining k
  - Vary applied load
  - Vary churn
  - Vary skew
- Pastry Implementation
  - Throughput
  - Heterogeneous real node bandwidths (Emulab)

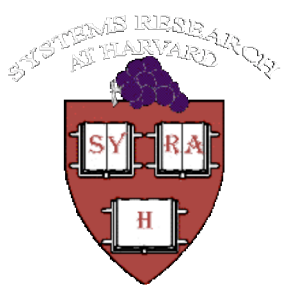


Results - Choosing k

4k nodes, avg capacity=100 m/s, 60 min avg lifetime

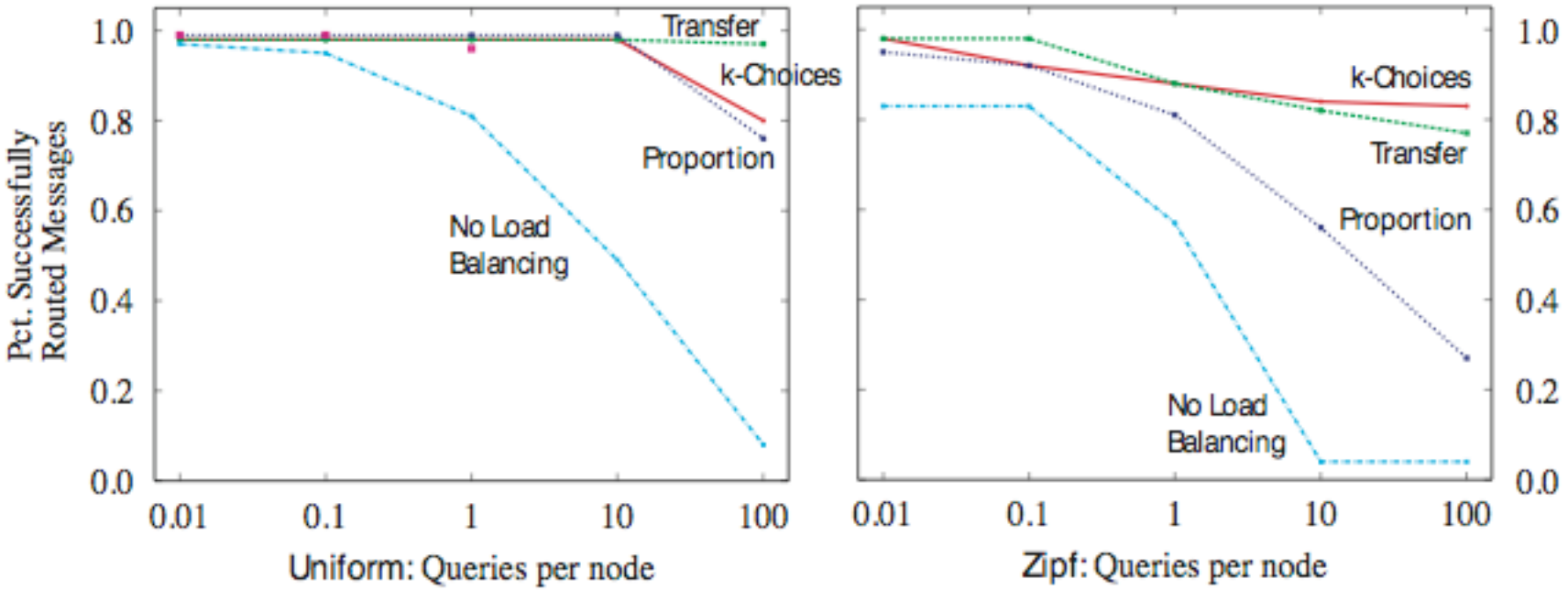


k=8 sufficiently reduced utilization.

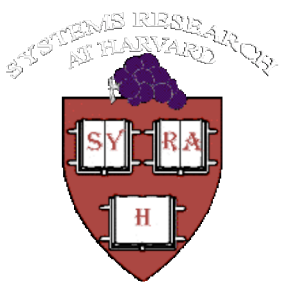


Results - Trace

5508 nodes; median capacity: 191 msgs/sec

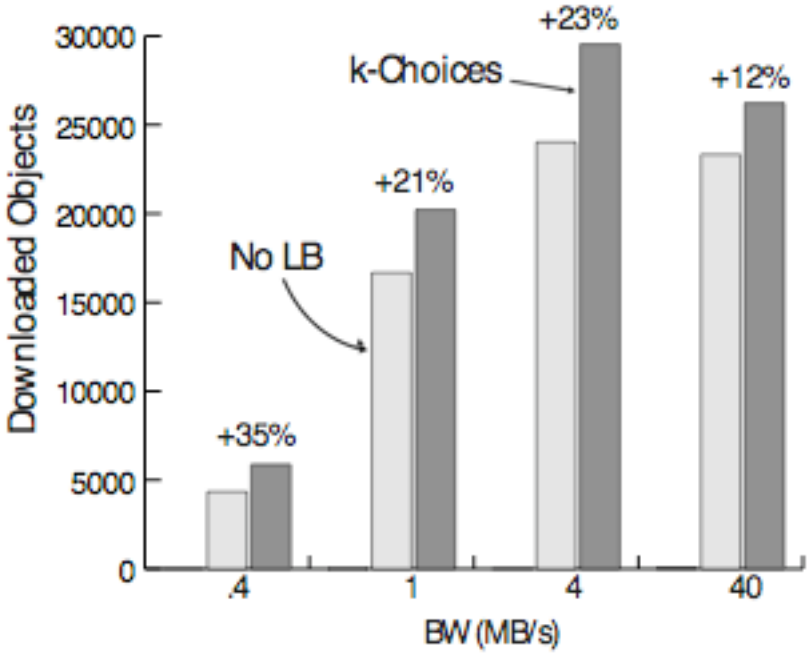


k-Choices and Transfer performed equally well with skewed workloads.

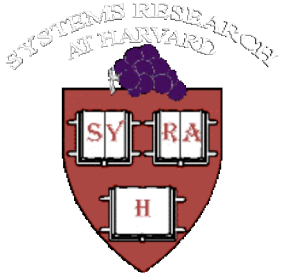


Results - Implementation

Pastry; "lookup+download"; 64x4 nodes - last mile limited

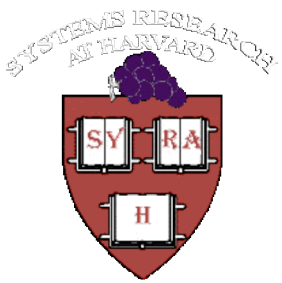


k-Choices: 20% throughput improvement



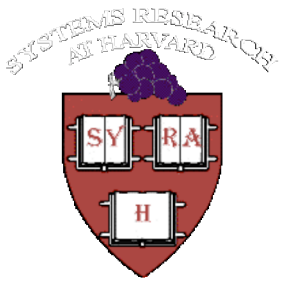
Conclusion

- k-Choices:
  - Approx. same performance as Transfer
  - Doesn't change security properties
  - Not the final word - range queries
- Design for empirical system
  - Namespace balancing?
  - Skew, wide capacity distribution, churn
  - Security: Sybil attacks



Questions?

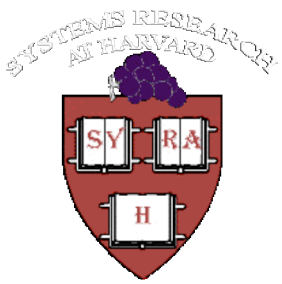
- Thanks!
- Contact:
  - Jonathan Ledlie
  - jonathan@eecs.harvard.edu



Prior Work - Threshold

- If our utilization has increased beyond threshold
  - Compare utilization to neighbors
  - Shift their IDs?
- Else
  - Compare to set of log(N) random VSs
  - Move best to be our new predecessor

[Ganesan04]



Prior Work - Proportion

- Overload: shed VSs
- Underload: create them

- Pros: No communication
- Cons:
  - Large number of VSs created
  - New lowest common denominator
  - Cascading deletes

[Dabek01]