Handling Churn in a DHT

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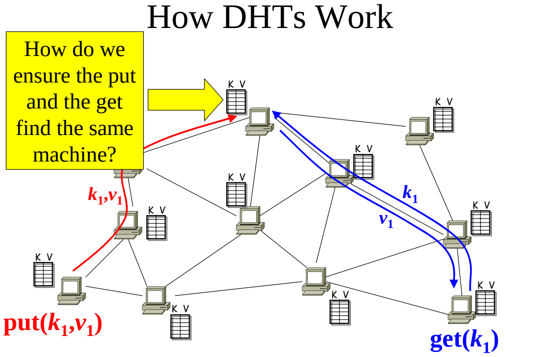
What's a DHT?

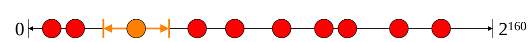
- Distributed Hash Table
  - Peer-to-peer algorithm to offering put/get interface
  - Associative map for peer-to-peer applications
- More generally, provide *lookup* functionality
  - Map application-provided hash values to nodes
  - (Just as local hash tables map hashes to memory locs.)
  - Put/get then constructed above lookup
- Many proposed applications
  - File sharing, end-system multicast, aggregation trees

How DHTs Work



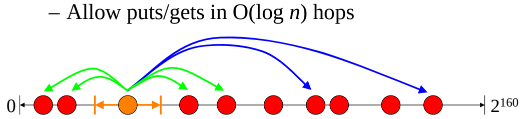
Step 1: Partition Key Space

- Each node in DHT will store some *k*,*v* pairs
- Given a key space *K*, *e.g.* $[0, 2^{160})$:
  - Choose an identifier for each node, $id_i \in K$, uniformly at random
  - A pair *k*,*v* is stored at the node whose identifier is closest to *k*



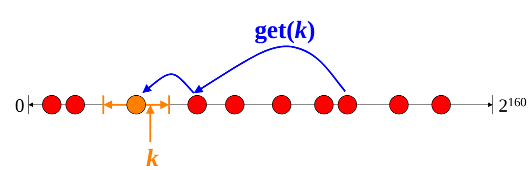
Step 2: Build Overlay Network

- Each node has two sets of neighbors
- **Immediate neighbors in the key space**
  - Important for correctness
- **Long-hop neighbors**
  - Allow puts/gets in O(log *n*) hops



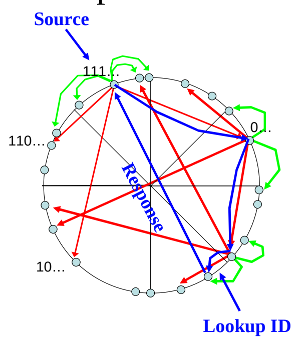
Step 3: Route Puts/Gets Thru Overlay

- Route greedily, always making progress

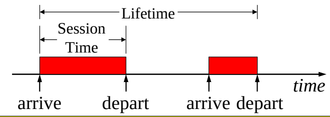


How Does Lookup Work?

- Assign IDs to nodes
  - Map hash values to node with closest ID
- Leaf set is successors and predecessors
  - All that's needed for correctness
- Routing table matches successively longer prefixes
  - Allows efficient lookups



How Bad is Churn in Real Systems?



An hour is an incredibly short MTTF!

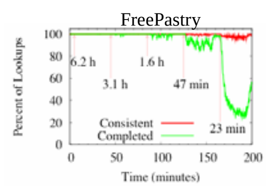
Authors	*Systems Observed*	*Session Time*
SGG02	Gnutella, Napster	50% < 60 minutes
CLL02	Gnutella, Napster	31% < 10 minutes
SW02	FastTrack	50% < 1 minute
BSV03	Overnet	50% < 60 minutes
GDS03	Kazaa	50% < 2.4 minutes

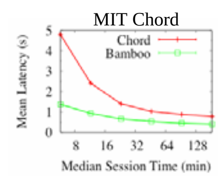
Can DHTs Handle Churn? A Simple Test

- Start 1,000 DHT processes on a 80-CPU cluster
  - Real DHT code, emulated wide-area network
  - Models cross traffic and packet loss
- Churn nodes at some rate
- Every 10 seconds, each machine asks:
  "Which machine is responsible for key *k*?"
  - Use several machines per key to check consistency
  - Log results, process them after test

Test Results

- In Tapestry (the OceanStore DHT), overlay partitions
  - Leads to very high level of inconsistencies
  - Worked great in simulations, but not on more realistic network
- And the problem isn't limited to Tapestry:





The Bamboo DHT

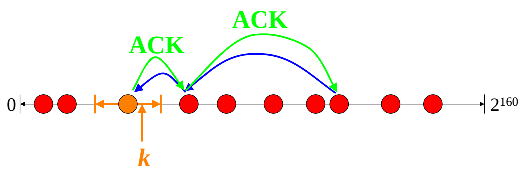
- Forget about comparing Chord-Pastry-Tapestry
  - Too many differing factors
  - Hard to isolate effects of any one feature
- Instead, implement a new DHT called Bamboo
  - Same overlay structure as Pastry
  - Implements many of the features of other DHTs
  - Allows testing of individual features independently

How Bamboo Handles Churn (Overview)

1. Chooses neighbors for network proximity
   - Minimizes routing latency in non-failure case
2. Routes around suspected failures quickly
   - Abnormal latencies indicate failure or congestion
   - Route around them before we can tell difference
3. Recovers failed neighbors periodically
   - Keeps network load independent of churn rate
   - Prevents overlay-induced positive feedback cycles

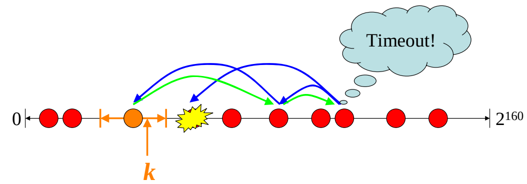
Routing Around Failures

- Under churn, neighbors may have failed
- To detect failures, acknowledge each hop



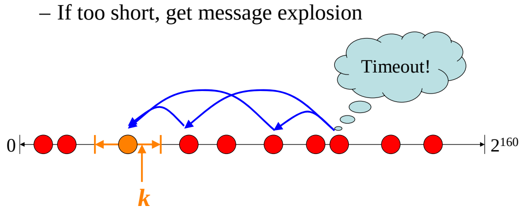
Routing Around Failures

- If we don't receive an ACK, resend through different neighbor



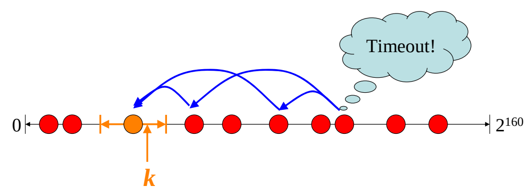
Computing Good Timeouts

- Must compute timeouts carefully
  - If too long, increase put/get latency
  - If too short, get message explosion



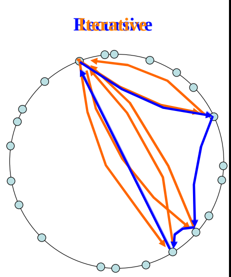
Computing Good Timeouts

- Chord errs on the side of caution
  - Very stable, but gives long lookup latencies



Calculating Good Timeouts

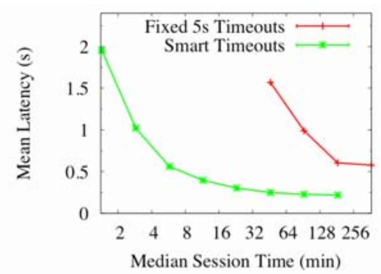
- Use TCP-style timers
  - Keep past history of latencies
  - Use this to compute timeouts for new requests
- Works fine for *recursive* lookups
  - Only talk to neighbors, so history small, current
- In *iterative* lookups, source directs entire lookup
  - Must potentially have good timeout for *any* node



Computing Good Timeouts

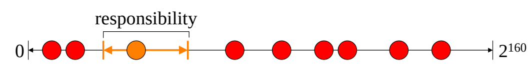
- Keep past history of latencies
  - Exponentially weighted mean, variance
- Use to compute timeouts for new requests
  - timeout = mean + 4 × variance
- When a timeout occurs
  - Mark node "possibly down": don't use for now
  - Re-route through alternate neighbor

Timeout Estimation Performance



Recovering From Failures

- Can't route around failures forever
  - Will eventually run out of neighbors
- Must also find new nodes as they join
  - Especially important if they're our immediate predecessors or successors:



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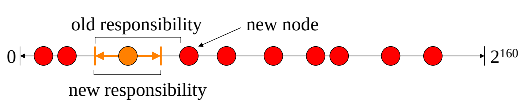
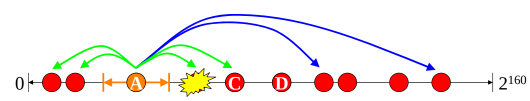


Recovering From Failures

- Obvious algorithm: *reactive* recovery
  - When a node stops sending acknowledgements, notify other neighbors of potential replacements
  - Similar techniques for arrival of new nodes



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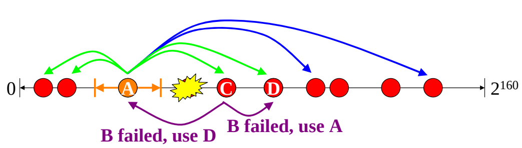
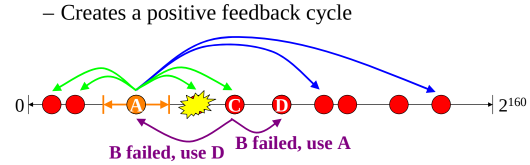


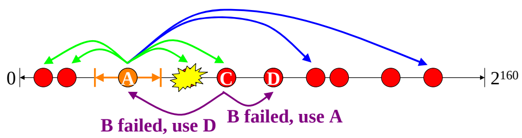
The Problem with Reactive Recovery

- What if B is alive, but network is congested?
  - C still perceives a failure due to dropped ACKs
  - C starts recovery, further congesting network
  - More ACKs likely to be dropped
  - Creates a positive feedback cycle



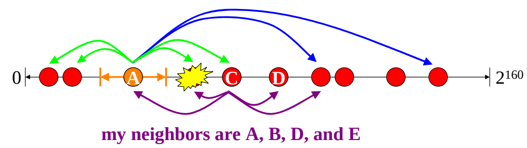
The Problem with Reactive Recovery

- What if B is alive, but network is congested?
- This was the problem with Pastry
  - Combined with poor congestion control, causes network to partition under heavy churn



Periodic Recovery

- Every period, each node sends its neighbor list to each of its neighbors



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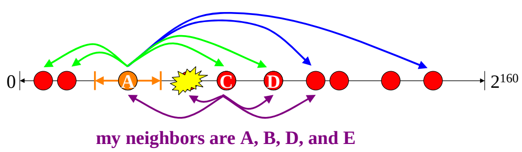
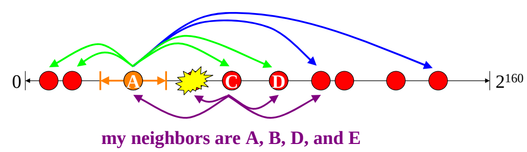


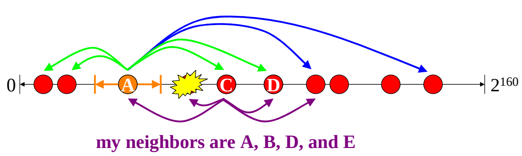
Periodic Recovery

- Every period, each node sends its neighbor list to each of its neighbors
  - Breaks feedback loop



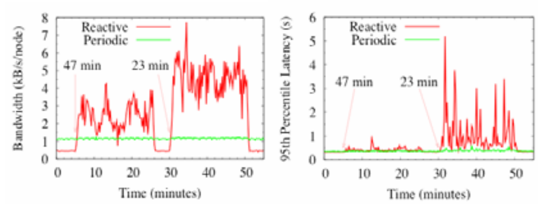
Periodic Recovery

- Every period, each node sends its neighbor list to each of its neighbors
  - Breaks feedback loop
  - Converges in logarithmic number of periods



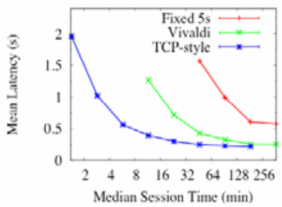
Periodic Recovery Performance

- Reactive recovery expensive under churn
- Excess bandwidth use leads to long latencies



Virtual Coordinates

- Machine learning algorithm to estimate latencies
  - Distance between coords. proportional to latency
  - Called Vivaldi; used by MIT Chord implementation
- Compare with TCP-style under recursive routing
  - Insight into cost of iterative routing due to timeouts



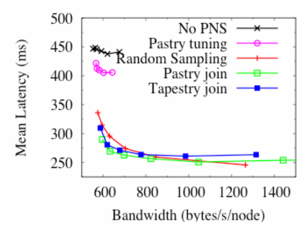
Proximity Neighbor Selection (PNS)

- For each neighbor, may be many candidates
  - Choosing closest with right prefix called PNS
  - One of the most researched areas in DHTs
  - Can we achieve good PNS under churn?
- Remember:
  - leaf set for correctness
  - routing table for efficiency?
- Insight: extend this philosophy
  - Any routing table gives O(log N) lookup hops
  - Treat PNS as an optimization only
  - Find close neighbors by simple random sampling

PNS Results

(very abbreviated--see paper for more)

- Random sampling almost as good as everything else
  - 24% latency improvement free
  - 42% improvement for 40% more b.w.
  - Compare to 68%-84% improvement by using good timeouts
- Other algorithms more complicated, not much better



Conclusions/Recommendations

- Avoid positive feedback cycles in recovery
  - Beware of “false suspicions of failure”
  - Recover periodically rather than reactively
- Route around potential failures early
  - Don’t wait to conclude definite failure
  - TCP-style timeouts quickest for recursive routing
  - Virtual-coordinate-based timeouts not prohibitive
- PNS can be cheap and effective
  - Only need simple random sampling

For code and more information:
bamboo-dht.org