Designing a DHT for low latency and high throughput

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P2P Information Systems

Overview

I. Introduction to DHT‘s

II. Technical Background

III. Latency

IV. Throughput

V. Summary

Distributed Hash Tables

Hash table

- Data structure that uses hash function to map keys to hash values to determine where the data is stored
- Allows quick access to keys through lookup algorithm

Distributed hash table

- Hash table is distributed over all participating nodes
- Lookup algorithm determines the node responsible for a specific key

Requirements

- Find data
- High availability
- Balance load
- Fast moving of data

Problems

- Link capacity of nodes
- Physical distance of nodes
- Congestion of network and packet loss

Technical Background

DHash++

- Values are mapped to keys using SHA-1 hash function
- Stores key/value pairs (so-called blocks) on different nodes
- Uses Chord and Vivaldi

Chord

- Lookup protocol to find keys with runtime O(log N)

Vivaldi

- Decentralized Network Coordinate System to compute and manage synthetic coordinates which are used to predict inter-node latencies
- No additional traffic because synthetic coordinates can piggy-back on DHash++'s communication patterns

Hardware

- Test-bed of 180 hosts which are connected via Internet2, DSL, cable or T1

Additional testing

- Simulation with delay matrix filled with delays between 2048 DNS Servers

Low latency

Data layout

DHash++ is designed for read-heavy applications that demand low-latency and high throughput.

Examples

SFR (Semantic Free Referencing system)

- Designed to replace DNS (Domain Name System)
- Uses DHT to store small data records representing name bindings

UsenetDHT

- Distributed version of Usenet which splits large articles into small blocks to achieve load balancing

DHash++:

- Can be seen as a Network Storage System with shared global infrastructure
- Uses small blocks of 8kb length
- Uses random distribution of blocks via hash Function

Low latency

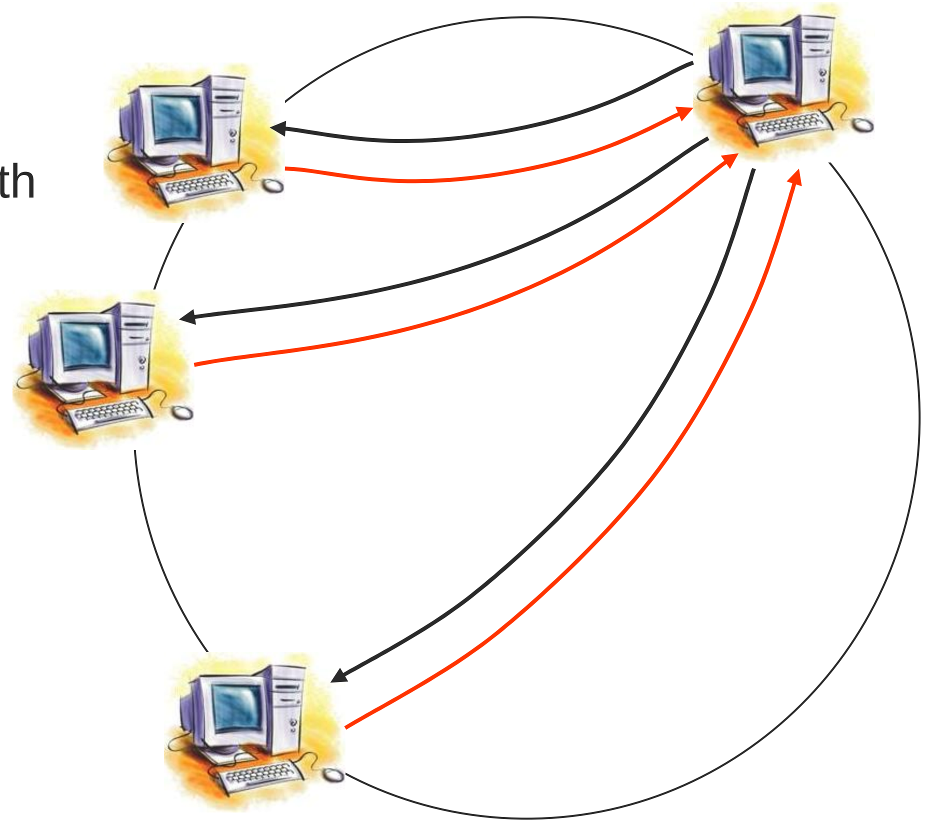
Recursive vs. iterative

Iterative lookup

- Send lookup query to each successive node in lookup path
- Can detect node failure

But

- Must wait for response before proceeding



Low latency

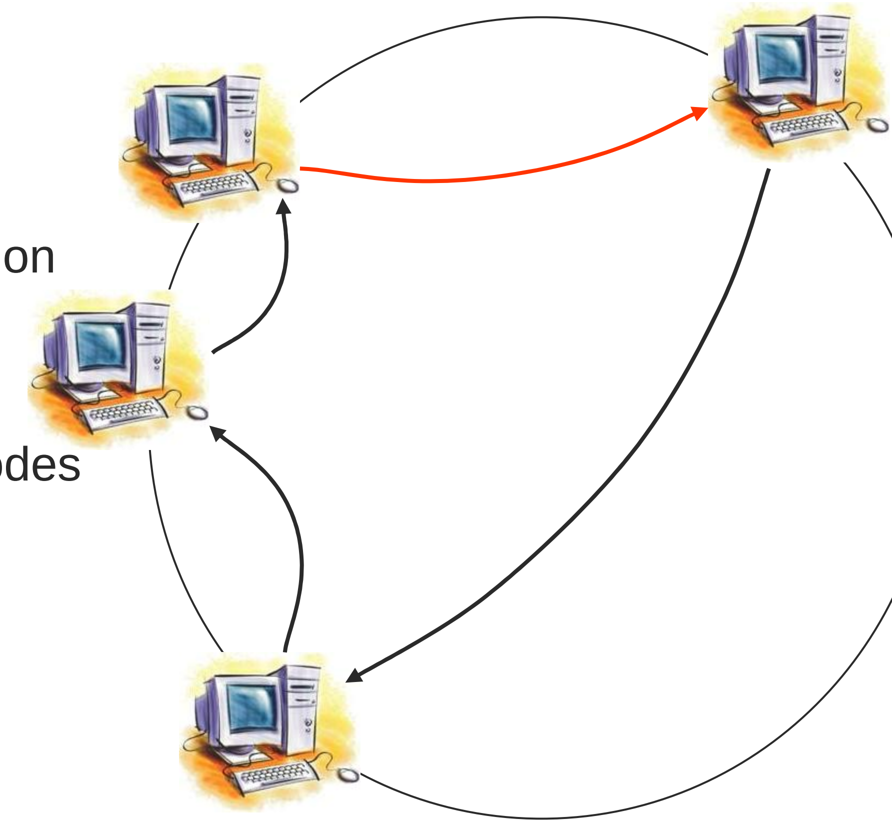
Recursive vs. iterative

Recursive lookup

- Direct query forwarding to next node
- Less queries -> less congestion

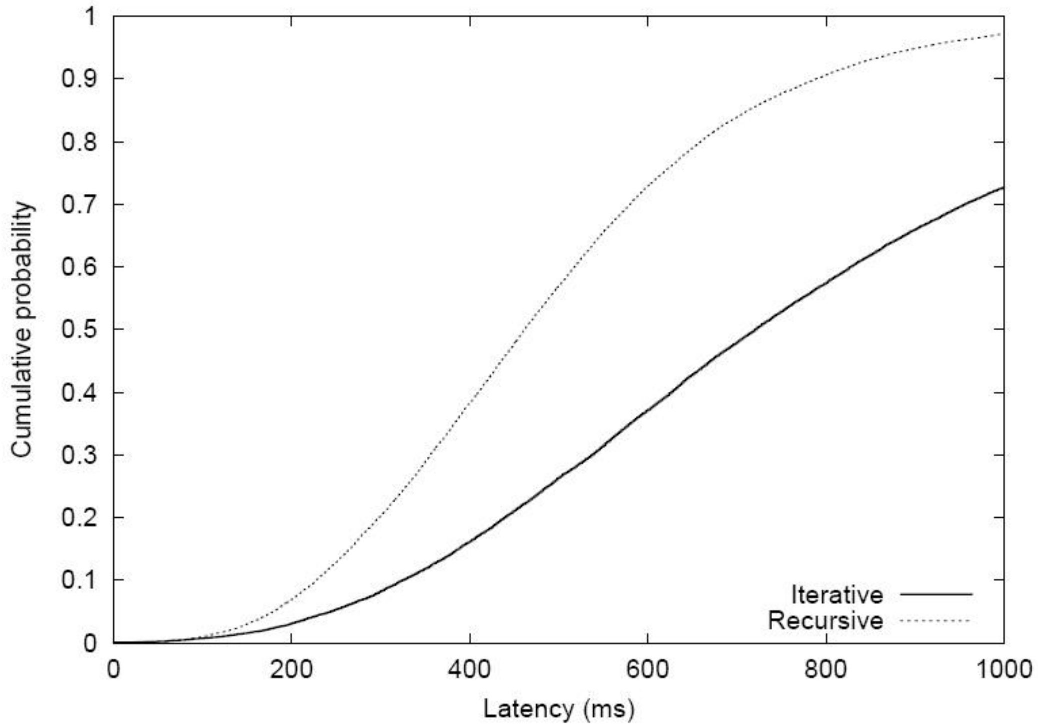
But

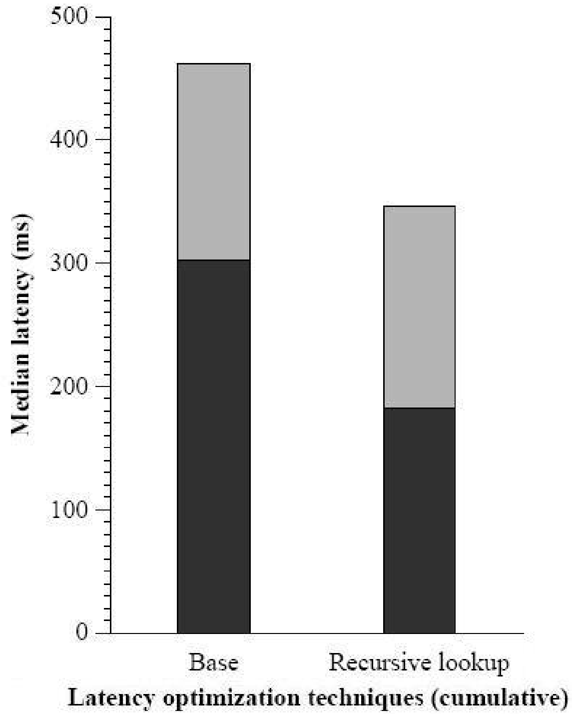
- Impossible to detect failed nodes



Low latency

Recursive vs. iterative





Left Figure: Simulation of 20,000 lookups with random hosts for random keys

- Recursive lookup takes 0.6 times as long as iterative

Right Figure: 1,000 lookups in test-bed

- Result of simulation confirmed

Trade-off: DHash++ uses recursive routing but switches to iterative routing after persistent link failures

Low latency

Proximity neighbor selection

Idea

- Chose nearby nodes to decrease latency

Realisation

- ID-Space range of ith finger table entry of node a:

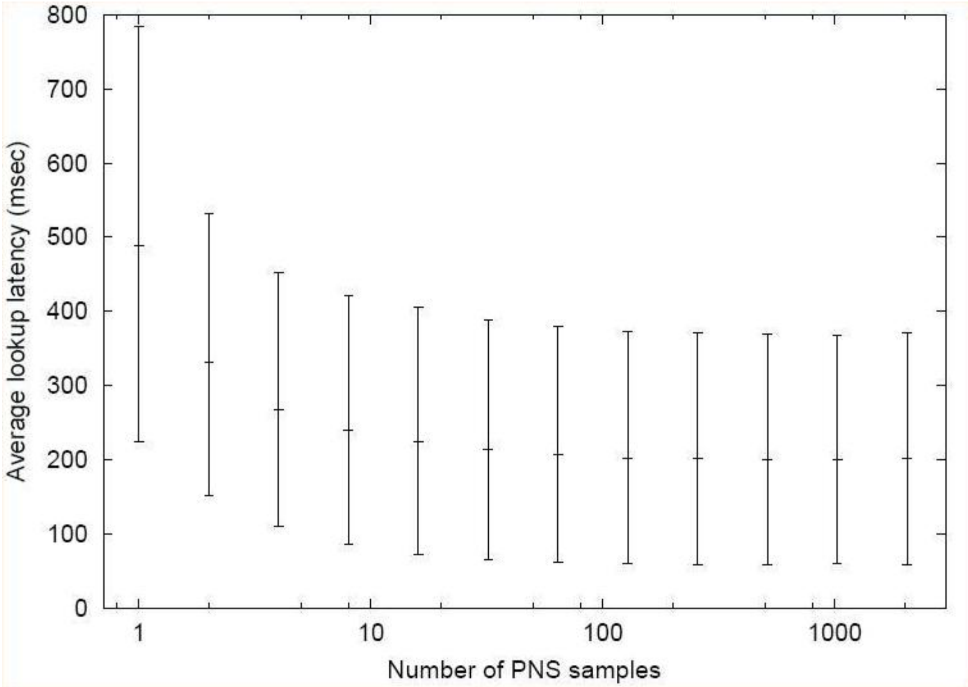
$$a + 2^i \text{ to } a + 2^{i+1} - 1$$

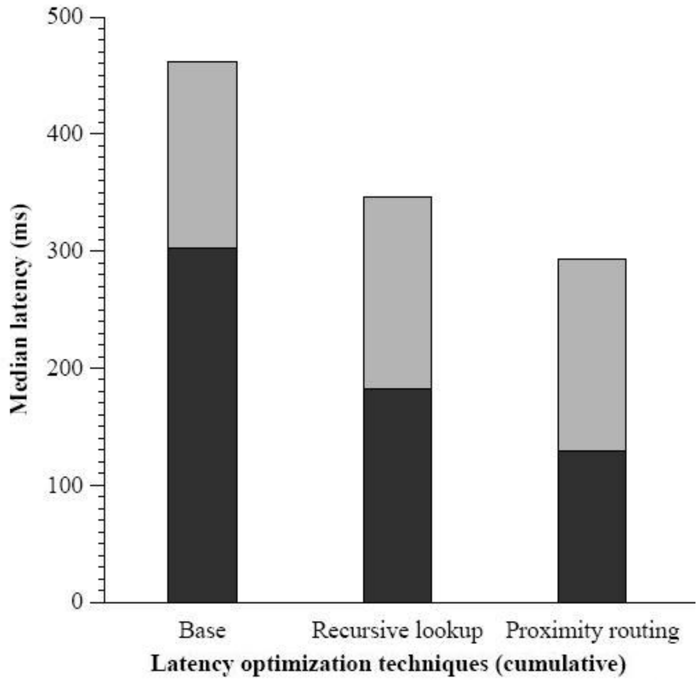
- Every finger table entry points to first available ID in this range
- Get the latency of the the first x available nodes in this ID-Space range from successor list
- Route lookups through node with lowest latency

What is a suitable value for x?

Low latency

Proximity neighbor selection





Right Figure: Simulation of 20 000 lookups with random hosts for random keys

- 1 – 16 Samples: highly decreasing latency
- 16 – 2048 Samples: barely decreasing latency

Right figure: 1 000 lookups in test-bed

- Decreased lookup latency

→ DHash++ uses 16 Samples

Low latency
Erasure-coding vs. replication

Erasure-coding
- Data block split into l fragments
- m different fragments are necessary to reconstruct the block
- Redundant storage of data

Replication
- Node stores entire block
- Special case: $m = 1$ and l is number of replicas
- Redundant information spread over fewer nodes

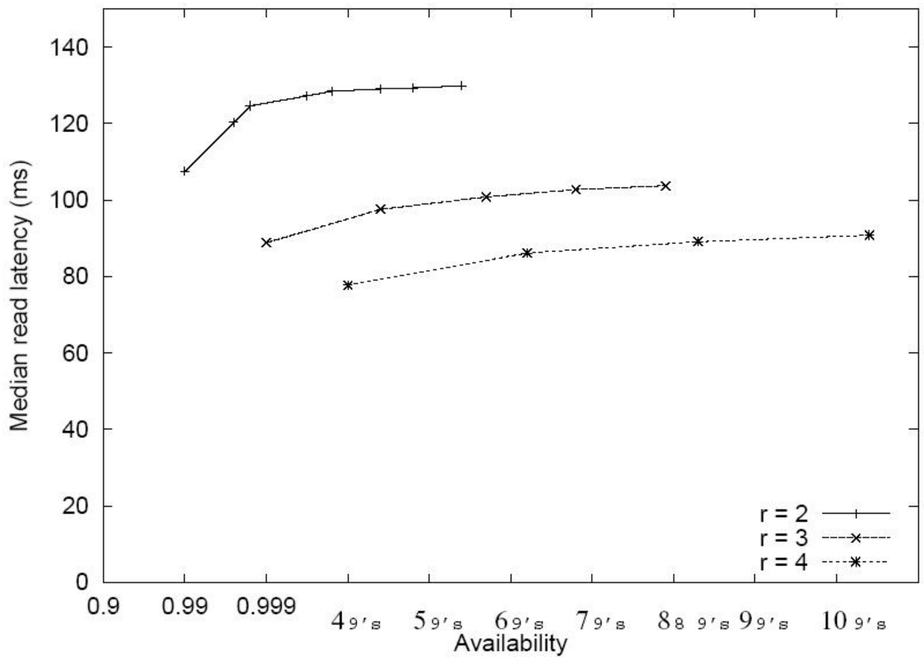
Comparison of both methods
- $r = l / m$ amount of redundancy

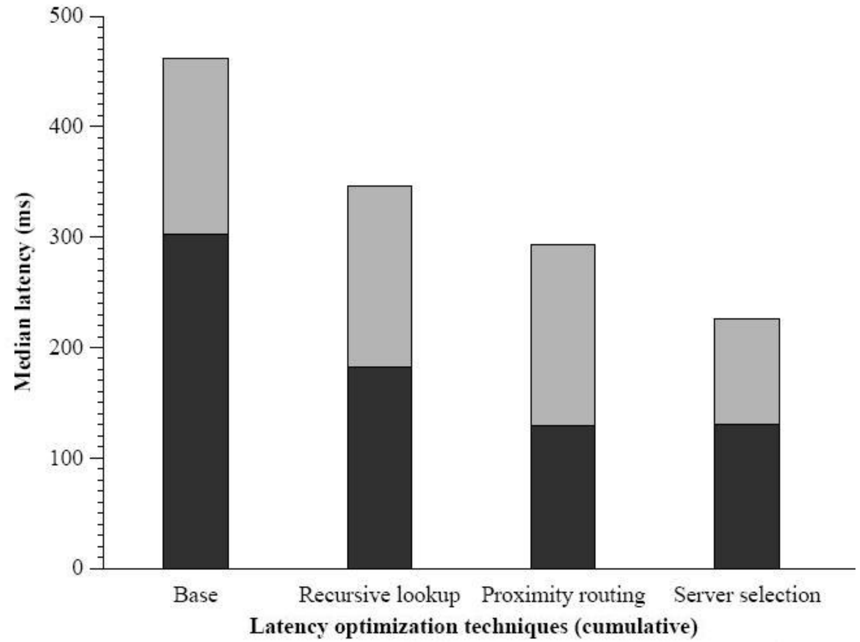
Probability that a block p is available:

$$p_{avail} = \sum_{i=m}^{l} \binom{l}{i} p_0^i (i - p_0)^{l-i}$$

Low latency

Erasure-coding vs. replication





Replication

- Only slightly lower latency than erasure-coding for same r if r is high
- Less congestion than erasure-coding because less files have to be distributed

Erasure-coding

- Higher availability of fragments
- More choice because of more fragments

DHash++ uses Erasure-coding with m = 7 and l = 14

Low latency

Integration

Remember proximity neighbor selection

- Little advantage in the last steps

Also remember last step in lookup procedure

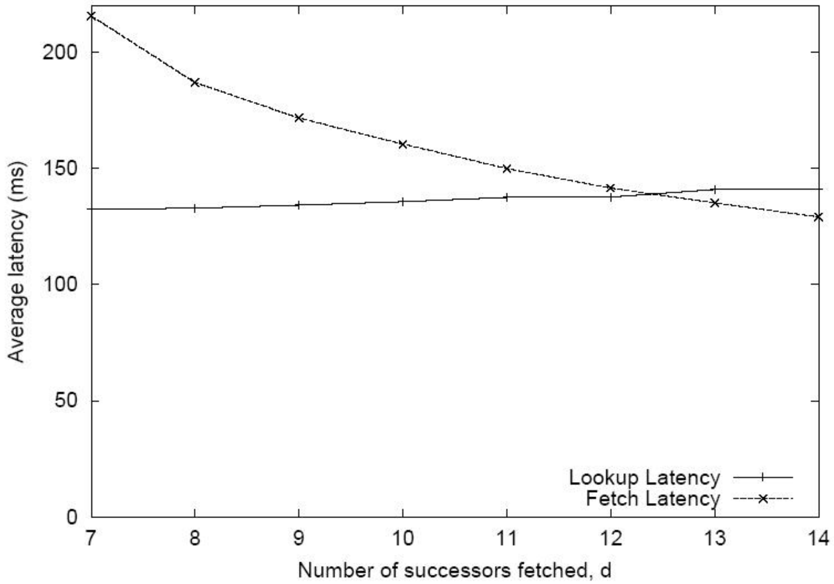
- Originator contacts a key‘s direct predecessor to obtain successor list

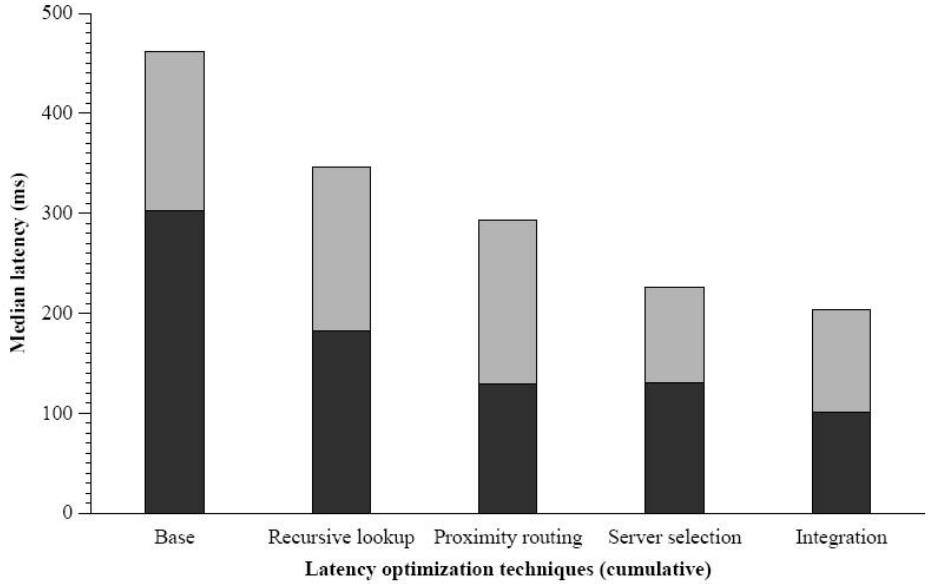
- But full successor list not neccessarily needed

Why?

- List has length s
- l successors store fragments of the block
- m fragments are needed
- s-m predecessors of a key have lists with at least m nodes

Low latency
Integration





d: Number of successors in successor list with needed fragment

Trade-off between lookup time and fetch latency while choosing *d*

- Large *d*: more hops for lookup but more choice between nodes
- Small *d*: less hops but higher fetch latency

Optimum: $d = l$

High throughput

Overview

Requirements for a DHT

- Parallel sending and receiving of data
- Congestion control to avoid packet loss and re-transmissions
- Recover from packet loss
- **Difficulty**: Data is spread over a large set of servers

→ Efficient transport protocol needed

First possibility: Use existing transport protocol

TCP (Transport Control Protocol)

- Provides congestion control, but
- Optimal congestion control and timeout estimation require some time
- Imposes start-up latency
- Number of simultaneous connections limited

Approach by DHash++

- Small number of TCP connections to neighbours
- Whole communication over these neighbours

High throughput
STP

Second Possibility: Design alternative transport protocol

STP (Striped Transport Protocol)
- Receiving and transmitting data directly to other nodes in single instance
- No per-destination states, decisions based on recent network behavior and synthetic coordinates (Vivaldi)

Remote Procedure Call (RPC)
- Calls a procedure that is located at another host on the network
- Example: lookup calls procedure on host to retrieve finger table entry

Round-trip-time (**RTT**)
- The time it takes to send a packet to a host and receive a response
- Used to measure delay on a network

High throughput
STP

Congestion Window Control

- *w* simultaneous RPCs
- New RPC only when old is finished
- Congestion: If RPC is answered *w* is increased by 1/*w*, otherwise *w* is decreased by *w*/2

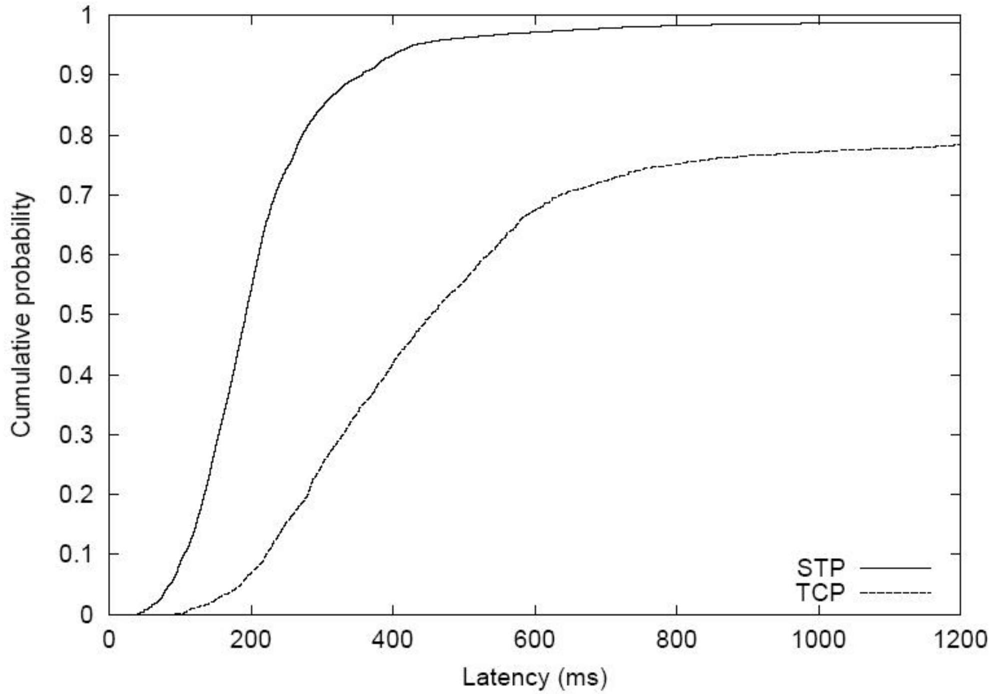
Retransmit timers

- TCP predicts new RTT with deviation of old RTTs
- In general no repeated sending of RPCs to the same node
  → must predict RTT before sending, therefore uses Vivaldi

Retransmit policy

- No direct resending if timer expires
- Notifies application (DHash++)
  → On lookup: send to next-closest finger
  → On fetch: query successor that is next-closest in predicted latency

High throughput
TCP vs. STP



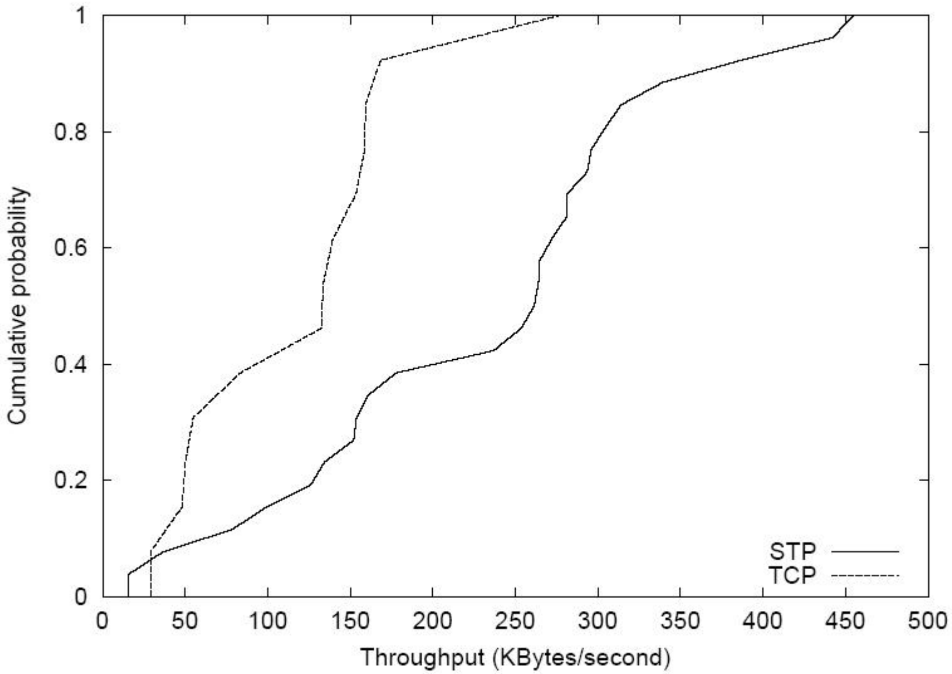
- Sequence of single random fetches of 24 nodes
- Median fetch time: 192 ms with STP, 447ms with TCP
- On average: 3 hops to complete lookup

But

- TCP fetch through 3 TCP connections consecutively
- STP fetch through 1 single STP connection

High throughput

TCP vs. STP



- Simultaneous fetches of different nodes
- Median throughput: 133 KB/s with TCP, 261 KB/s with STP
- Same reason for result as in previous slide

Summary

Different design decisions

- **Recursive routing** → reducing number of sent packets
- **Proximity neighbor selection** → searching nearby nodes
- **Erasure-coding** → increasing availability of data
- **Integration** → reducing number of hops for lookup

Result:

Reduced the lookup and fetch latency up to a factor of 2

Alternative Transport Protocol **STP**

- Fitted to the needs of DHash++
- Direct connection between nodes
  →Higher throughput than TCP
  →Lower latency than TCP

Result:

Further reduced latency and optimized throughput by factor 2

Thanks for Your Attention