Peer-to-Peer Networks
05: Chord

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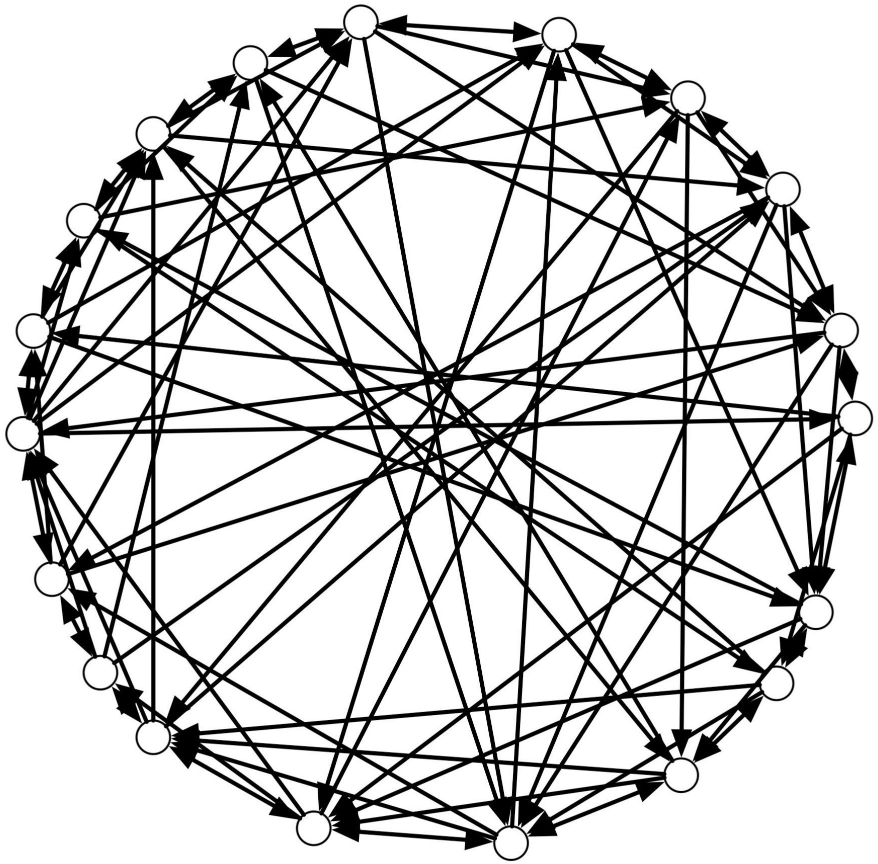
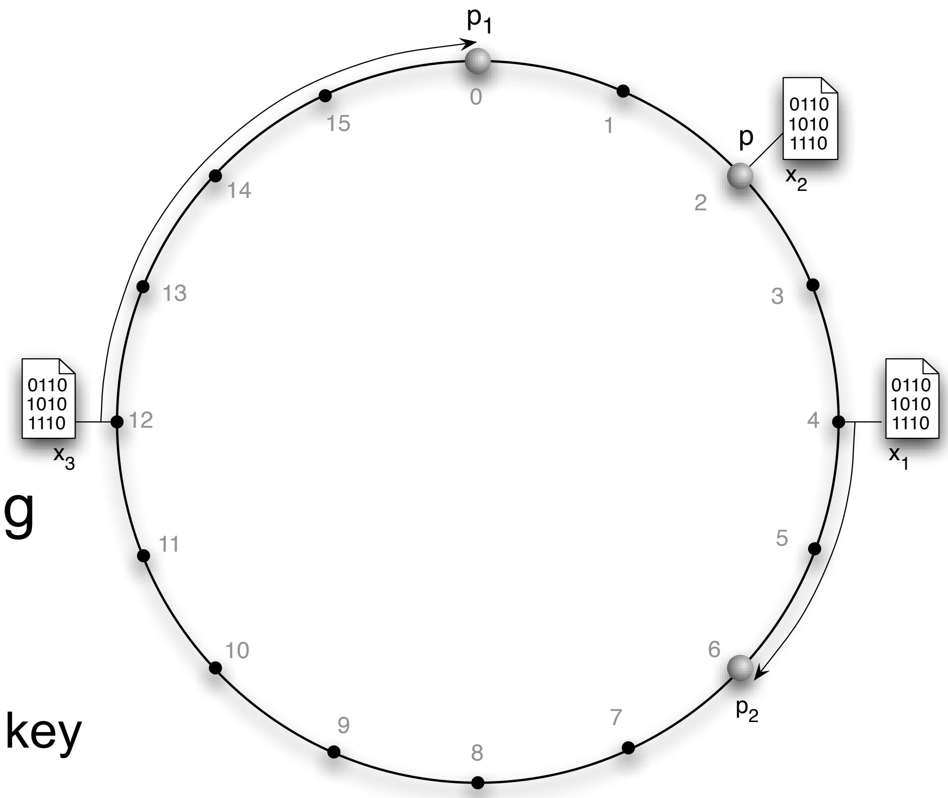
Chord

- Ion Stoica, Robert Morris, David Karger, M. Frans Kaashoek and Hari Balakrishnan (2001)
- Distributed Hash Table
  - range {0,..,2^m-1}
  - for sufficient large m
- Network
  - ring-wise connections
  - shortcuts with exponential increasing distance



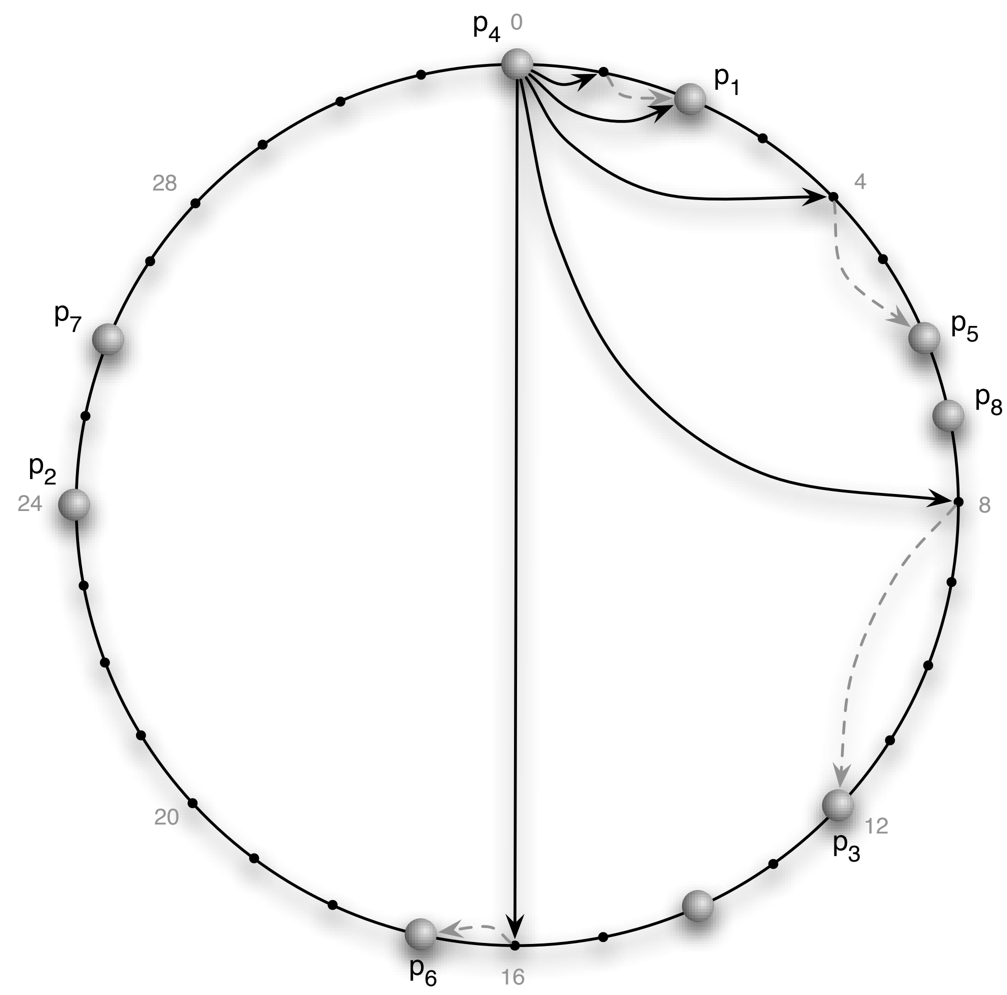
Chord as DHT

- n number of peers
- V set of peers
- k number of data stored
- K set of stored data
- m: hash value length
  - $m \geq 2 \log \max\{K,N\}$
- Two hash functions mapping to $\{0,..,2^{m-1}\}$
  - $r_V(b)$: maps peer to $\{0,..,2^{m-1}\}$
  - $r_K(i)$: maps index according to key i to $\{0,..,2^{m-1}\}$
- Index i maps to peer $b = f_V(i)$
  - $f_V(i) :=$ $\arg\min_{b \in V}\{(r_V(b)-r_K(i)) \bmod 2^m\}$



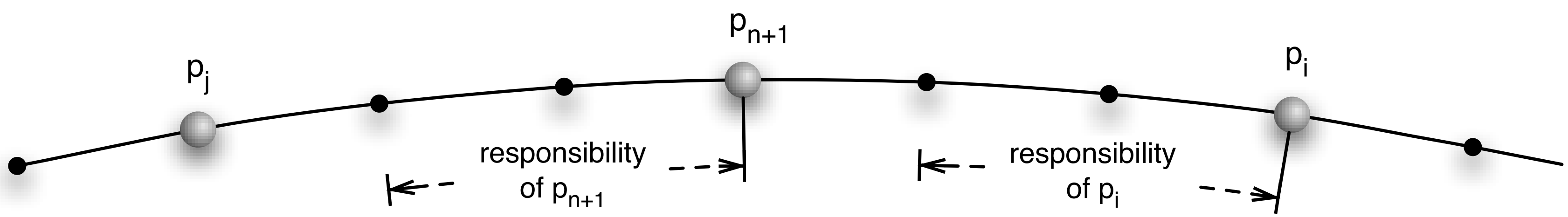
Pointer Structure of Chord

- For each peer
  - successor link on the ring
  - predecessor link on the ring
  - for all i ∈ {0,..,m-1}
    - Finger[i] := the peer following the value $r_V(b+2^i)$
- For small i the finger entries are the same
  - store only different entries
- Lemma
  - The number of different finger entries is O(log n) with high probability, i.e. $1-n^{-c}$.



Balance in Chord

- Theorem
  - We observe in Chord for n peers and k data entries
    - Balance&Load: Every peer stores at most O(k/n log n) entries with high probability
    - Dynamics: If a peer enters the Chord then at most O(k/n log n) data entries need to be moved
- Proof
  - …



Properties of the DHT

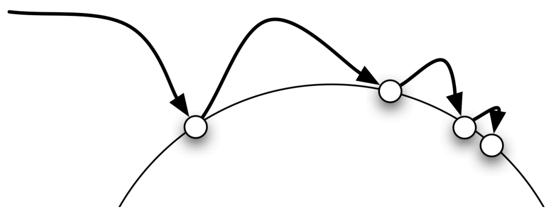
- Lemma
  - For all peers b the distance $|r_V(b.succ) - r_V(b)|$ is
    - in the expectation $2^m/n$,
    - $O((2^m/n) \log n)$ with high probability (w.h.p.)
    - at least $2^m/n^{c+1}$ für a constant $c>0$ with high probability
  - In an interval of length $w\ 2^m/n$ we find
    - $\Theta(w)$ peers, if $w=\Omega(\log n)$, w.h.p.
    - at most $O(w \log n)$ peers, if $w=O(\log n)$, w.h.p.
- Lemma
  - The number of nodes who have a pointer to a peer b is $O(\log_2 n)$ w.h.p.

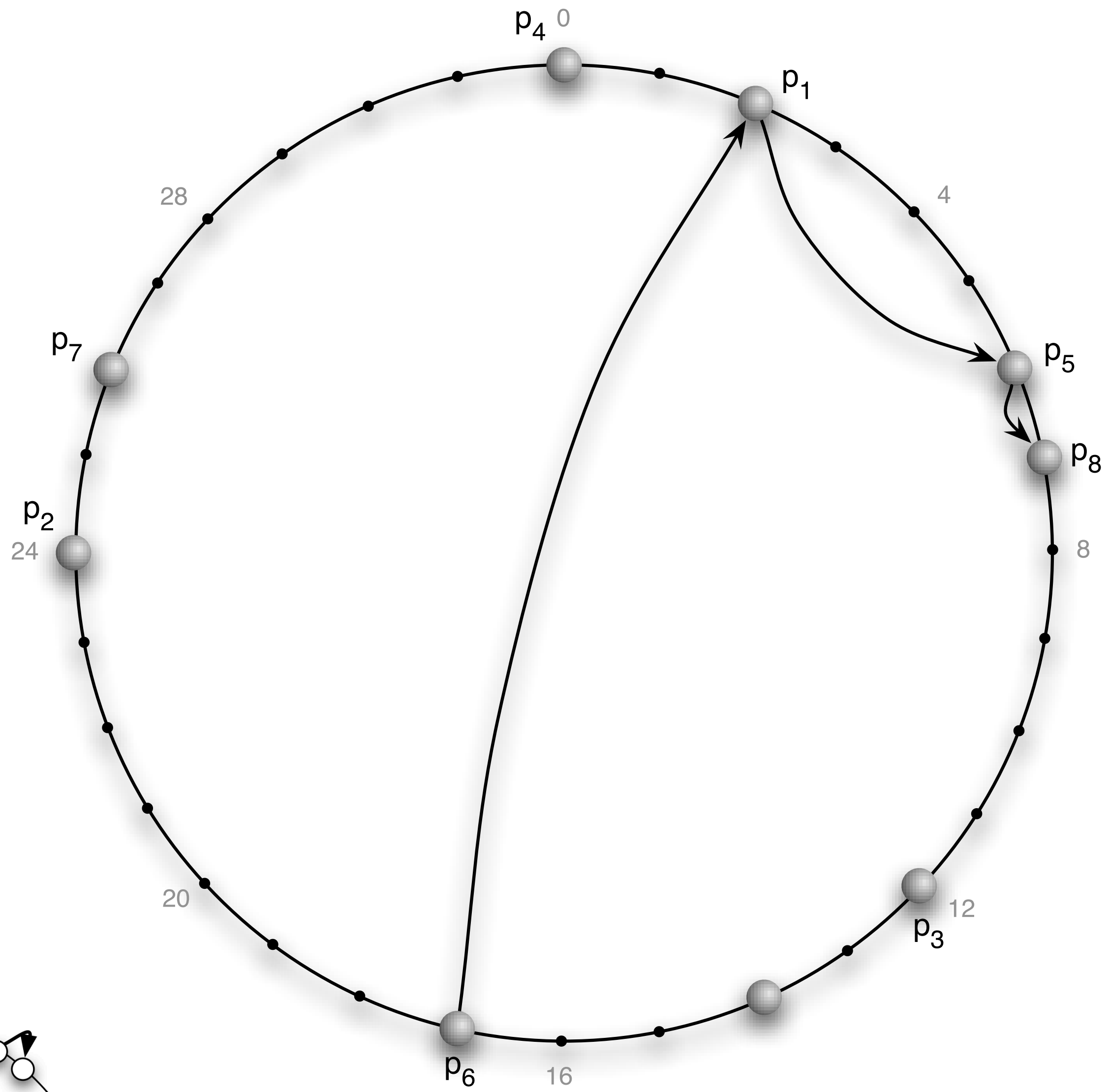
Lookup in Chord

- Theorem
  - The Lookup in Chord needs O(log n) steps w.h.p.
- Lookup for element s
  - Termination(b,s):
    - if peer b,b'=b.succ is found with $r_K(s) \in [r_V(b), r_V(b'))$
  - Routing:
    Start with any peer b
    - while not Termination(b,s) do
      - for i=m downto 0 do
        - if $r_K(s) \in [r_V(b.finger[i]), r_V(finger[i+1]))$ then
        - $b \leftarrow b.finger[i]$
        - fi
      - od

Lookup in Chord

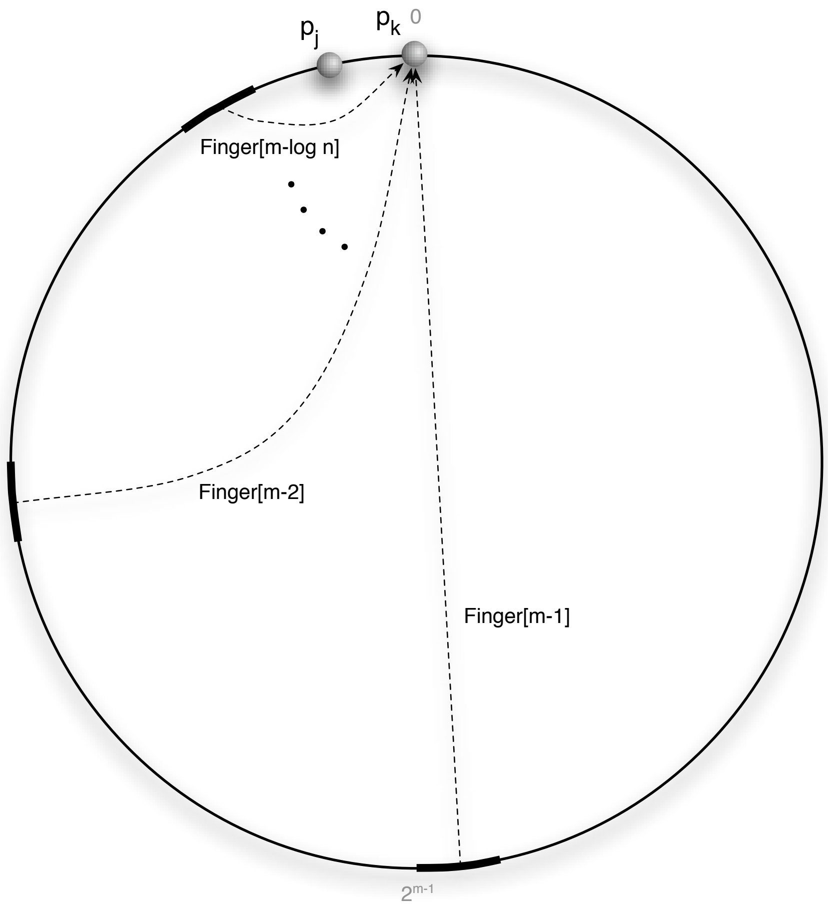
- Theorem
  - The Lookup in Chord needs O(log n) steps w.h.p.
- Proof:
  - Every hops at least halves the distance to the target
  - At the beginning the distance is at most
  - The minimum distance between is $2^m/n^c$ w.h.p.
  - Hence, the runtime is bounded by c log n w.h.p.





How Many Fingers?

- Lemma
  - The out-degree in Chord is O(log n) w.h.p.
  - The in-degree in Chord is $O(\log_2 n)$ w.h.p.
- Proof
  - The minimum distance between peers is $2^m/n^c$ w.h.p.
    - this implies that that the out-degree is O(log n) w.h.p.
  - The maximum distance between peers is $O(\log n\ 2^m/n)$ w.h.p.
    - the overall length of all line segments where peers can point to a peer following a maximum distance is $O(\log_2 n\ 2^m/n)$
    - in an area of size $w=O(\log_2 n)$ there are at most $O(\log_2 n)$ w.h.p.

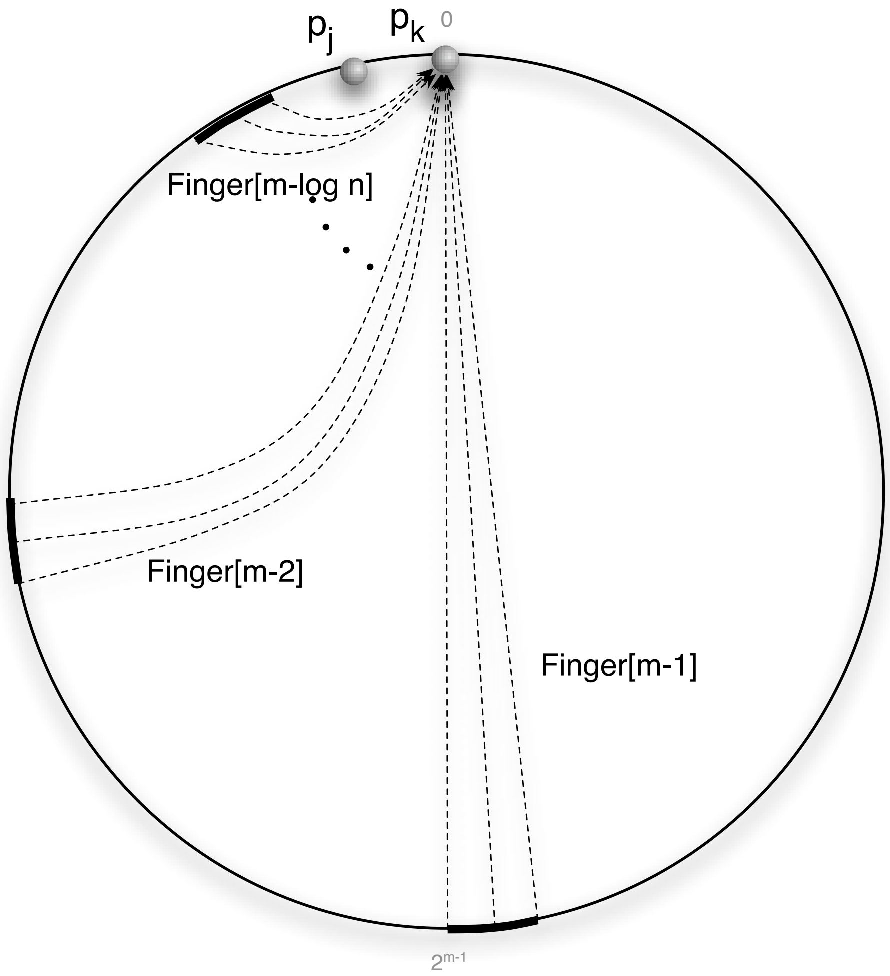


Inserting Peer

- Theorem
  - For integrating a new peer into Chord only $O(\log^2 n)$ messages are necessary.

Adding a Peer

- First find the target area in O(log n) steps
- The outgoing pointers are adopted from the predecessor and successor
  - the pointers of at most O(log n) neighbored peers must be adapted
- The in-degree of the new peer is $O(\log^2 n)$ w.h.p.
  - Lookup time for each of them
  - There are O(log n) groups of neighb ored peers
  - Hence, only O(log n) lookup steps with at most costs O (log n) must be used
  - Each update of has constant cost



Data Structure of Chord

- For each peer
  - successor link on the ring
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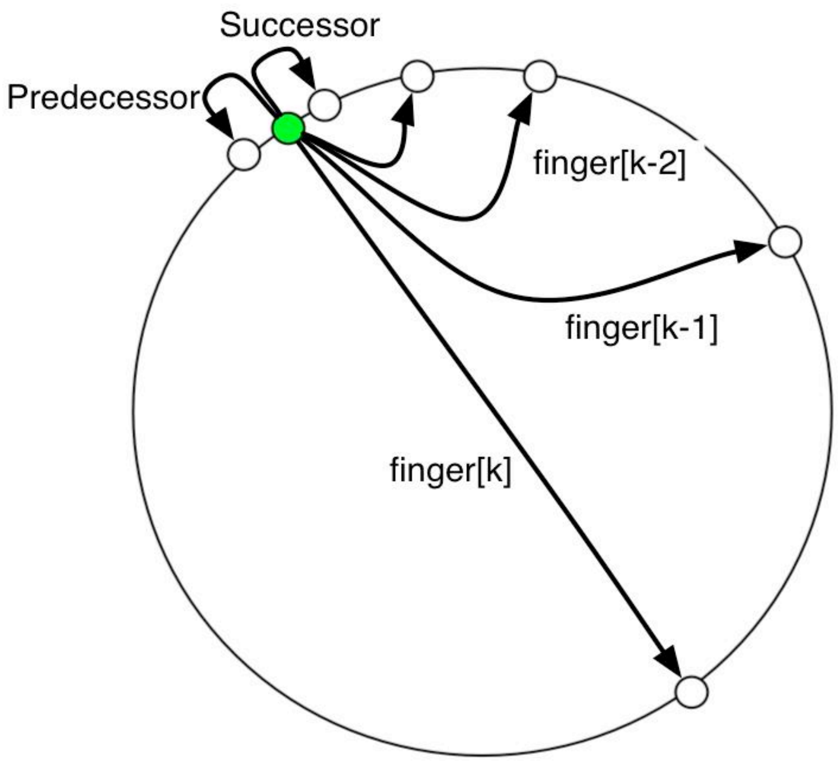
  - for all i ∈ {0,..,m-1}
    - Finger[i] := the peer following the value $r_V(b+2^i)$
- For small i the finger entries are the same
  - store only different entries
- Chord
  - needs O(log n) hops for lookup
  - needs O($\log^2$ n) messages for inserting and erasing of peers



Routing-Techniques for CHORD: DHash++

- Frank Dabek, Jinyang Li, Emil Sit, James Robertson, M. Frans Kaashoek, Robert Morris (MIT) „Designing a DHT for low latency and high throughput“, 2003
- Idea
  - Take CHORD
- Improve Routing using
  - Datenlayout
  - Recursion (instead of Iteration)
  - Next Neighbor-Election
  - Replication versus Coding of Data
  - Error correcting optimized lookup
- Modify transport protocol

Data Layout

- Distribute Data?
- Alternatives
  - Key location service
    - store only reference information
  - Distributed data storage
    - distribute files on peers
  - Distributed block-wise storage
    - either caching of data blacks
    - or block-wise storage of all data over the network

Recursive Versus Iterative Lookup

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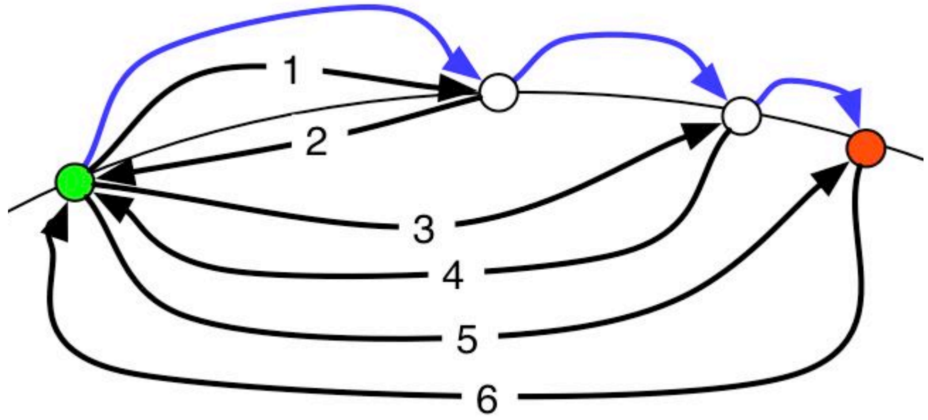
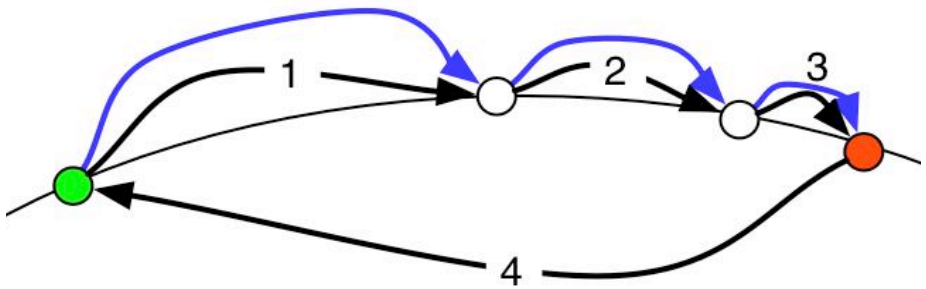
- Iterative lookup
  - Lookup peer performs search on his own
- Recursive lookup
  - Every peer forwards the lookup request
  - The target peer answers the lookup-initiator directly
- DHash++ choses recursive lookup
  - speedup by factor of 2





Recursive Versus Iterative Lookup

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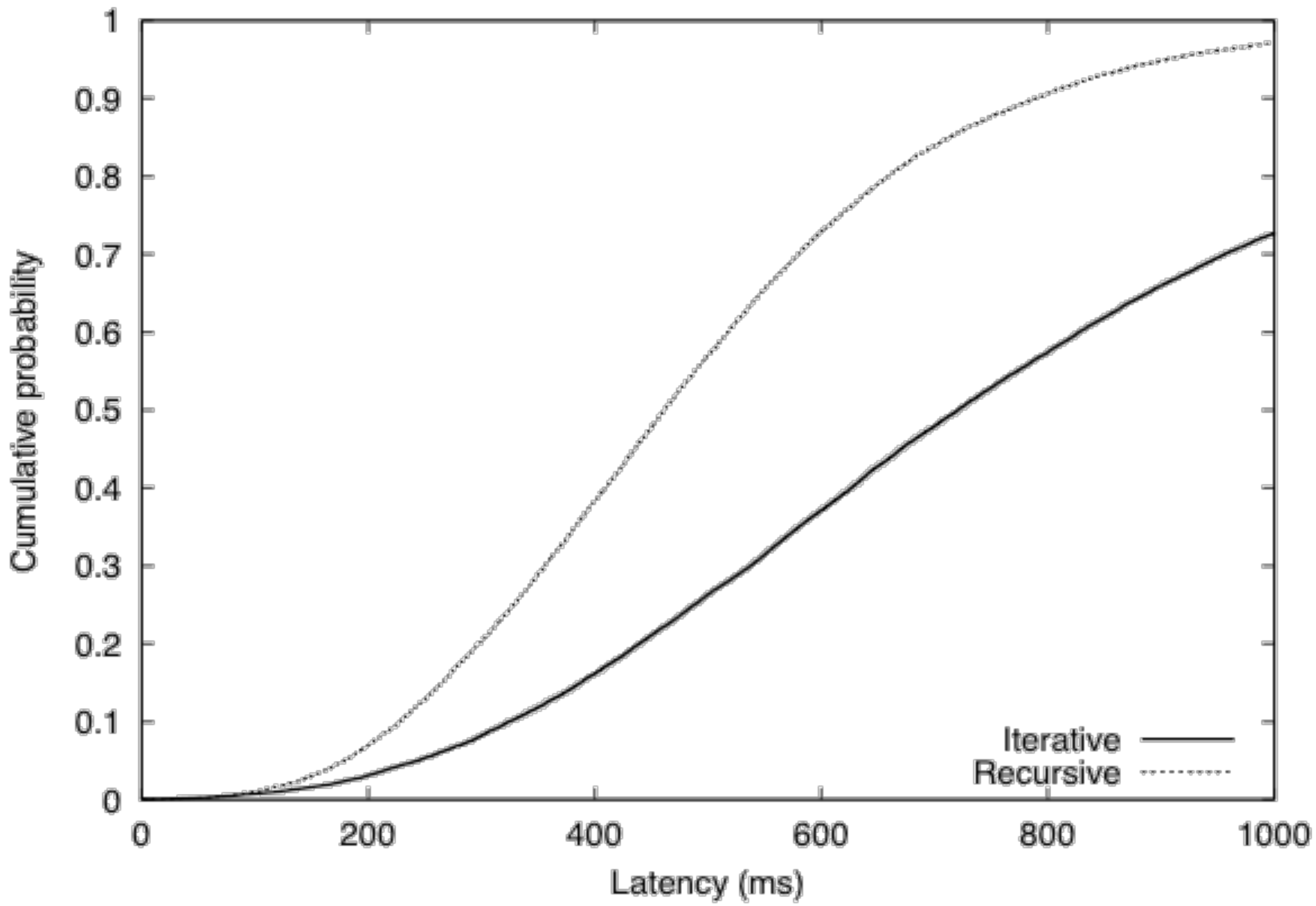
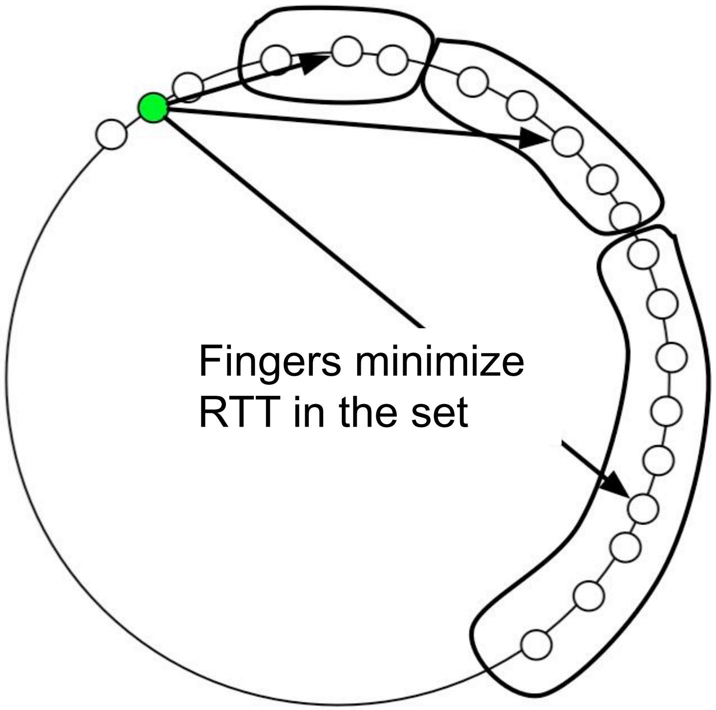


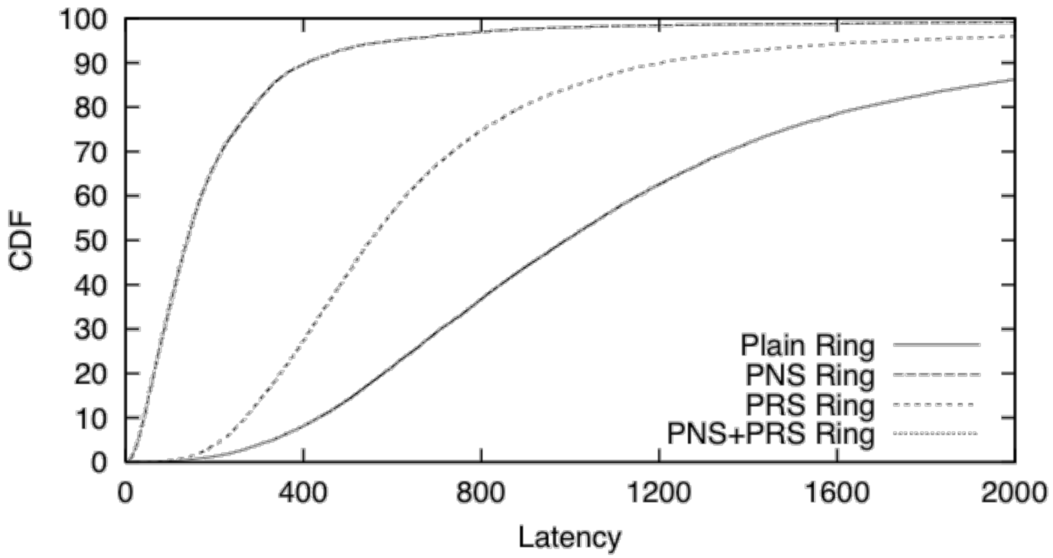
Next Neighbor Selection

- RTT: Round Trip Time
  - time to send a message and receive the acknowledgment
- Method of Gummadi, Gummadi, Grippe, Ratnasamy, Shenker, Stoica, 2003, „The impact of DHT routing geometry on resilience and proximity“
  - Proximity Neighbor Selection (PNS)
    - Optimize routing table (finger set) with respect to (RTT)
    - method of choice for DHASH++
  - Proximity Route Selection(PRS)
    - Do not optimize routing table choose nearest neighbor from routing table



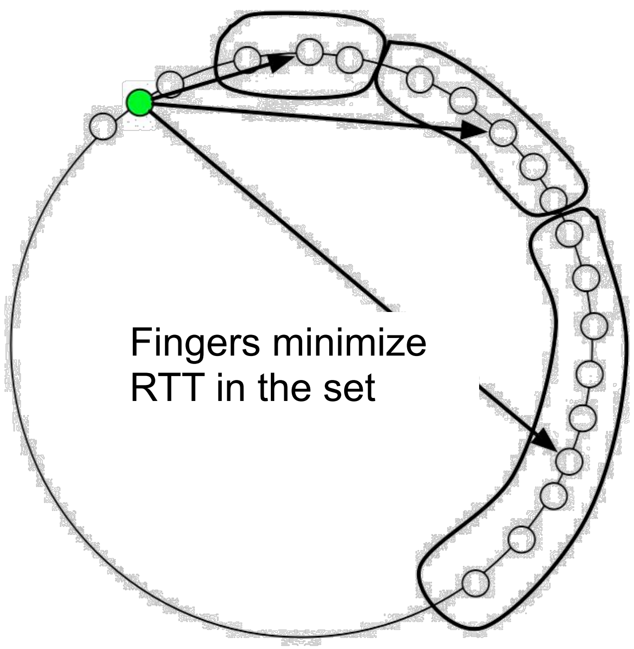
Next Neighbor Selection

- Gummadi, Gummadi, Grippe, Ratnasamy, Shenker, Stoica, 2003, „The impact of DHT routing geometry on resilience and proximity"
  - Proximity Neighbor Selection (PNS)
    - Optimize routing table (finger set) with respect to (RTT)
    - method of choice for DHASH++
  - Proximity Route Selection(PRS)
    - Do not optimize routing table choose nearest neighbor from routing table
- Simulation of PNS, PRS, and both
  - PNS as good as PNS+PRS
  - PNS outperforms PRS



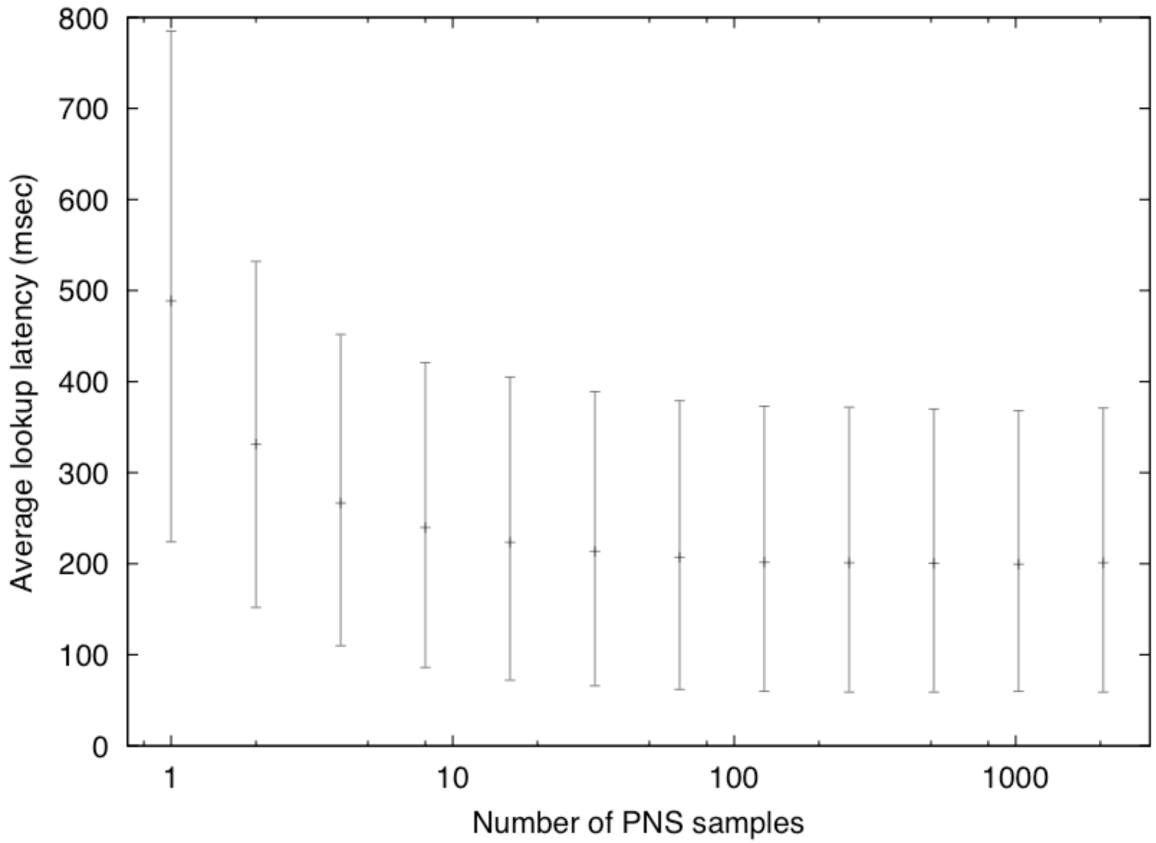
Next Neighbor Selection

- DHash++ uses (only) PNS
  - Proximity Neighbor Selection
- It does not search the whole interval for the best candidate
  - DHash++ chooses the best of 16 random samples (PNS-Sample)

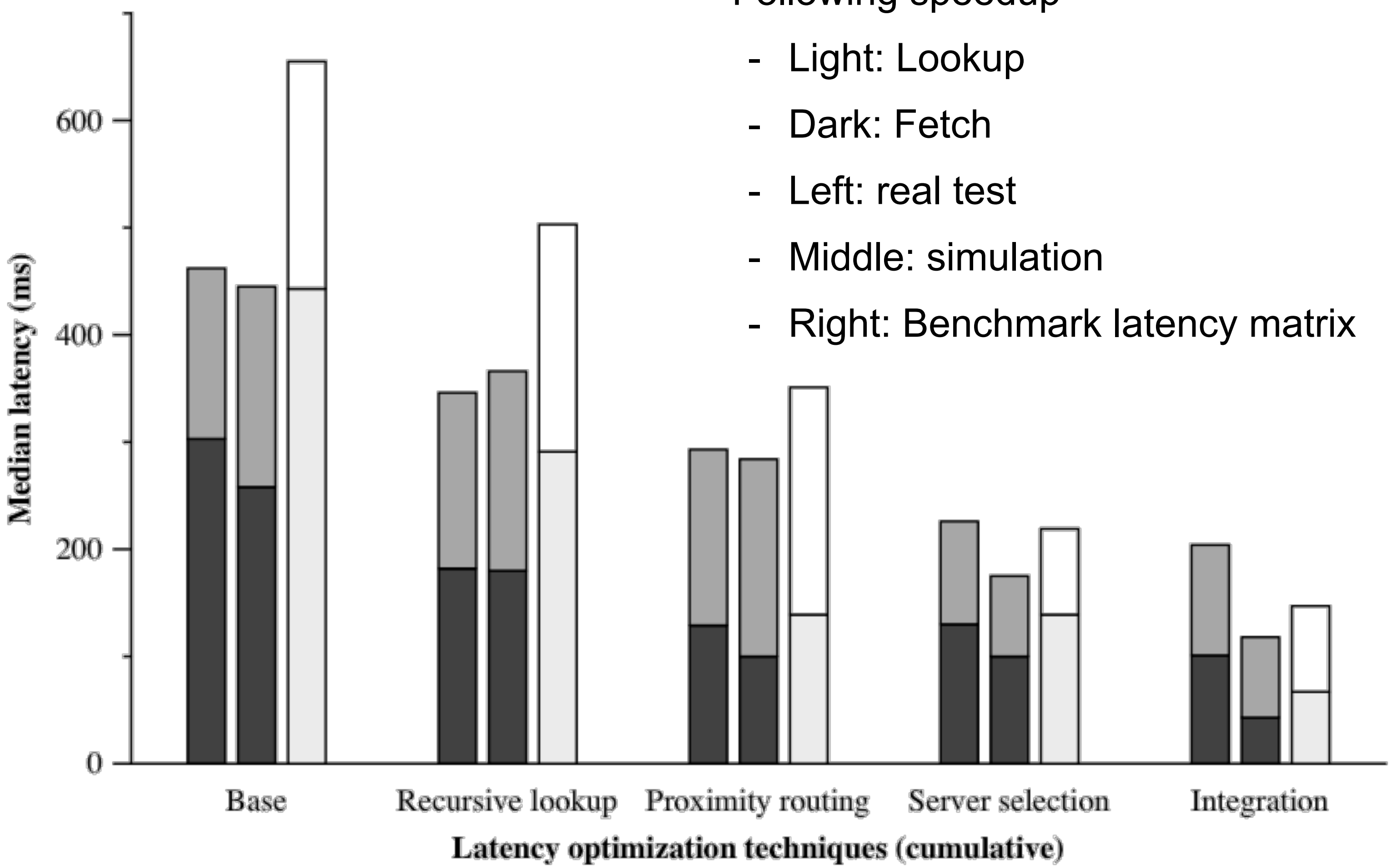


Next Neighbor Selection

- DHash++ uses (only) PNS
  - Proximity Neighbor Selection
- e (0.1,0.5,0.9)-percentile of such a PNS-Sampling

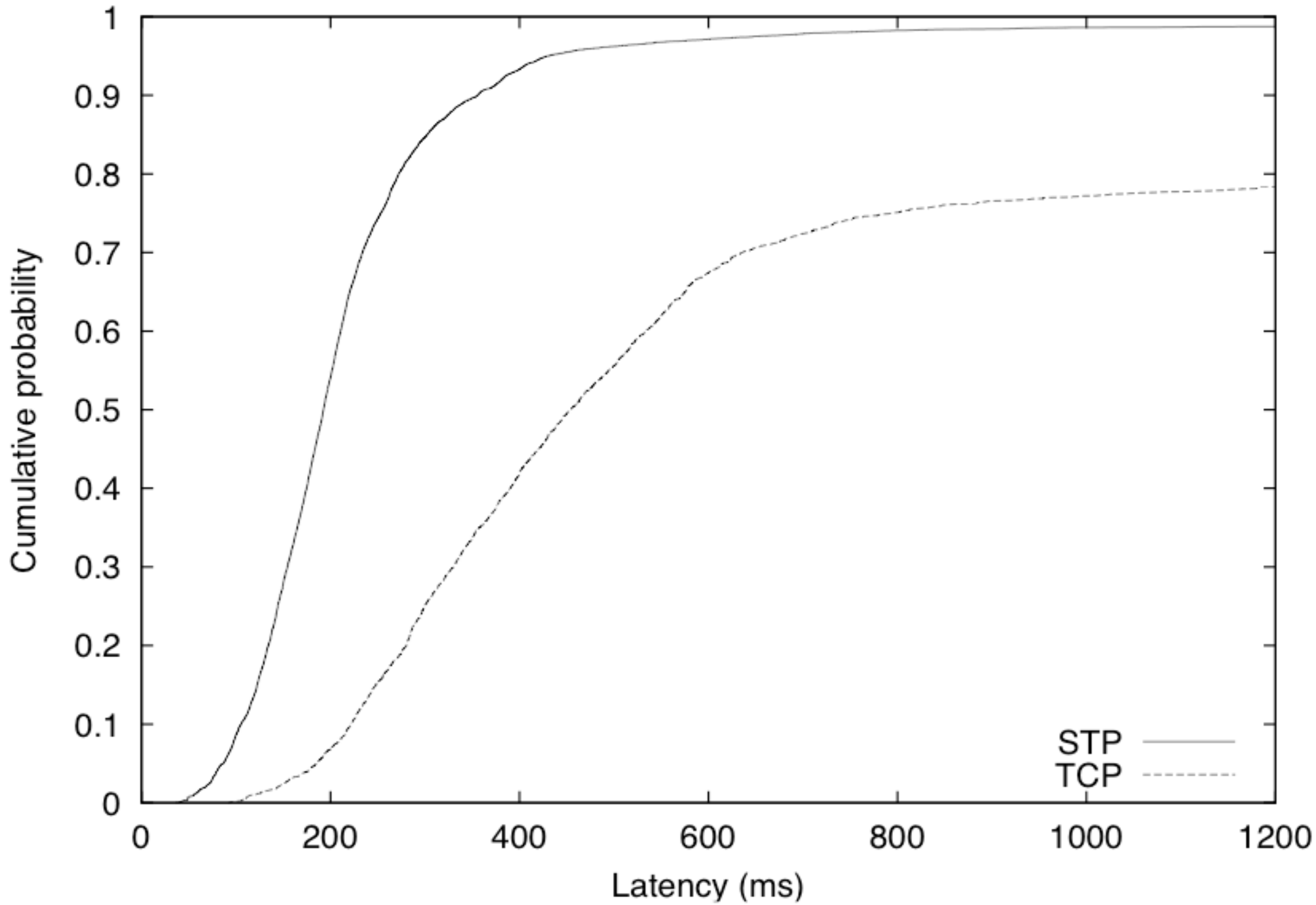


Cumulative Performance Win



- Following speedup
  - Light: Lookup
  - Dark: Fetch
  - Left: real test
  - Middle: simulation
  - Right: Benchmark latency matrix

Modified Transport Protocol



Discussion DHash++

- Combines a large quantity of techniques
  - for reducing the latecy of routing
  - for improving the reliability of data access
- Topics
  - latency optimized routing tables
  - redundant data encoding
  - improved lookup
  - transport layer
  - integration of components
- All these components can be applied to other networks
  - some of them were used before in others
  - e.g. data encoding in Oceanstore
- DHash++ is an example of one of the most advanced peer-to-peer networks

Peer-to-Peer Networks

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