The Impact of DHT Routing Geometry on Resilience and Proximity

Presented by Karthik Lakshminarayanan
at P2P Systems class
(Slides liberally borrowed from Krishna's SIGCOMM talk)

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Motivation

- New DHTs constantly proposed
  - CAN, Chord, Pastry, Tapestry, Viceroy, Kademlia, Skipnet, Symphony, Koorde, Apocrypha, Land, Bamboo, ORDI …
- Each is extensively analyzed but in isolation
- Each DHT has many algorithmic details making it difficult to compare

Goals:

a) *Separate fundamental design choices from algorithmic details*

b) *Understand their effect on reliability and efficiency*

Approach:Component-based analysis

- Break DHT design into independent components
- Analyze impact of each component choice separately
  - compare with black-box analysis:
    - benchmark each DHT implementation
    - rankings of existing DHTs vs. hints on better designs

Different components of analysis

- Two types of components
  - *Routing-level* : neighbor & route selection
  - *System-level* : caching, replication, querying policy etc.
- Separating "routing" and "system" level issues
  - Good to understand them in isolation
  - Cons of this approach?

Outline

- DHT Design
- Compare DHT Routing Geometries
- Geometry's impact on Resilience
- Geometry's impact on Proximity

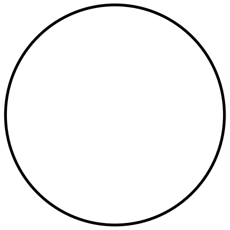
Three aspects of a DHT design

1) Geometry: a graph structure that inspires a DHT design
   - Tree, Hypercube, Ring, Butterfly, Debruijn

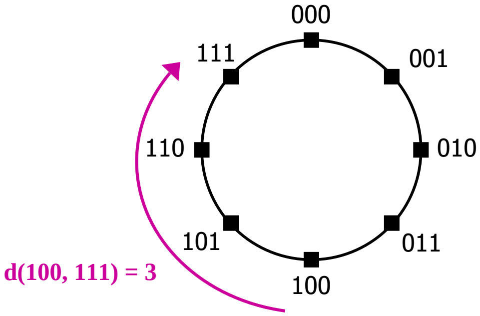
2) Distance function: captures a geometric structure
   - d(id1, id2) for any two node identifiers

3) Algorithm: rules for selecting neighbors and routes using the distance function

Chord DHT has Ring **Geometry**

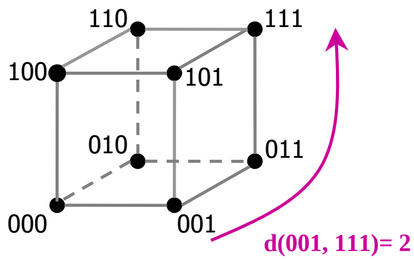


Chord **Distance** function captures Ring



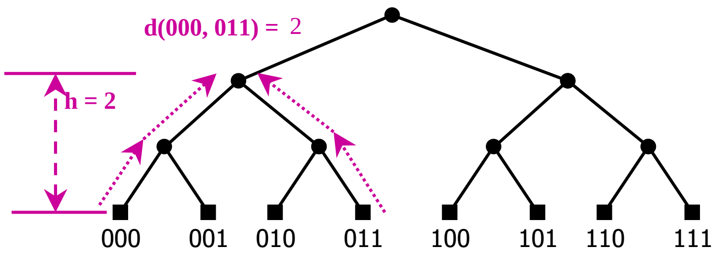
- Nodes are points on a clock-wise Ring
- **d(id1, id2) = length of clock-wise arc between ids = (id2 – id1) mod N**

CAN => Hypercube Geometry



- **d(id1, id2) = #differing bits between id1 and id2**
- Nodes are the corners of a hypercube

PRR => Tree



- Nodes are leaves in a binary tree
- **d(id1, id2) = height of smallest sub-tree with ids = logN – length of prefix_match(id1, id2)**

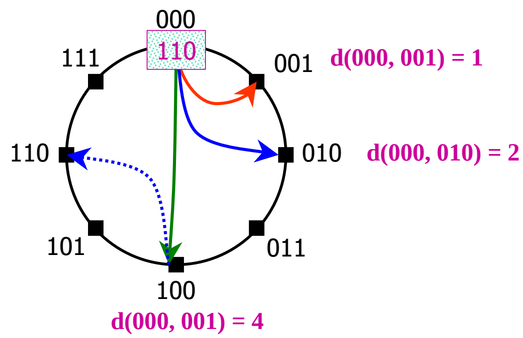
Geometry Vs Algorithm

- *Algorithm* : exact rules for selecting neighbors, routes
  - Chord, CAN, PRR, Tapestry, Pastry etc.
  - Inspired by geometric structures like Ring, Hyper-cube, Tree
- *Geometry* : an algorithm's underlying structure
  - *Distance* function is the formal representation of Geometry
  - Chord, Symphony => Ring
  - Many algorithms can have same geometry

Is the notion of Geometry clear?

- Notion of geometry is vague (as the authors admit)
- It is really a distance function on an ID-space
  - Hypercube is a special case of XOR!
- Possible formal definitions?

Chord Neighbor and Route selection Algorithms



- Neighbor selection: $\mathbf{i}^{th}$ neighbor at $\mathbf{2}^{i}$ distance
- Route selection: pick neighbor closest to destination

Geometry => Flexibility => Performance

- Geometry captures *flexibility* in selecting algorithms
- Flexibility is important for routing performance
  - Flexibility in selecting routes leads to shorter, reliable paths
  - Flexibility in selecting neighbors leads to shorter paths

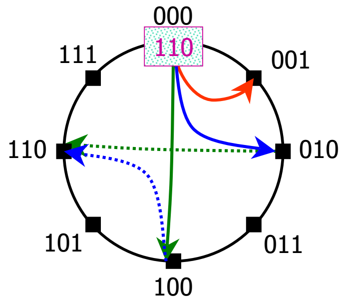
Outline

- Routing Geometry
- Comparing DHT Geometries
- Geometry’s impact on Resilience
- Geometry’s impact on Proximity

Geometries considered

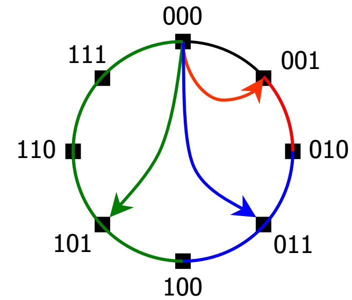
Geometry	**Algorithm**
Ring	Chord, Symphony
Hypercube	CAN
Tree	PRR
Hybrid = Tree + Ring	Tapestry, Pastry
XOR d(id1, id2) = id1 XOR id2	Kademlia

Route selection flexibility allowed by Ring Geometry



- Chord algorithm picks neighbor closest to destination
- A different algorithm picks the best of alternate paths

Neighbor selection flexibility allowed by Ring Geometry

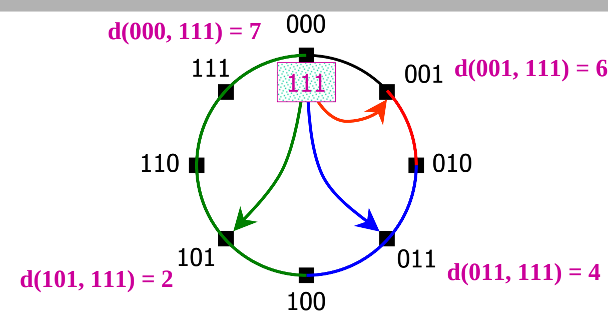


- Chord algorithm picks **i^th^** neighbor at **2^i^** distance
- A different algorithm picks $\mathbf{i^{th}}$ neighbor from $\mathbf{[2^i, 2^{i+1})}$

Metrics for flexibility

- **FNS**: Flexibility in Neighbor Selection
  = number of node choices for a neighbor
- **FRS**: Flexibility in Route Selection
  = avg. number of next-hop choices for all destinations
- Constraints for neighbors and routes
  - select neighbors to have paths of **O(logN)**
  - select routes so that each hop is closer to destination

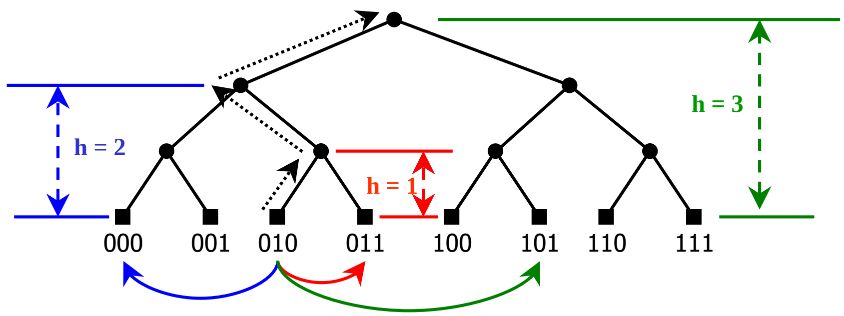
Flexibility of Ring



- **logN** neighbors at exponential distances
- **FNS = $\mathbf{2^{i-1}}$** for $\mathbf{i^{th}}$ neighbor
- Route along the circle in clock-wise direction

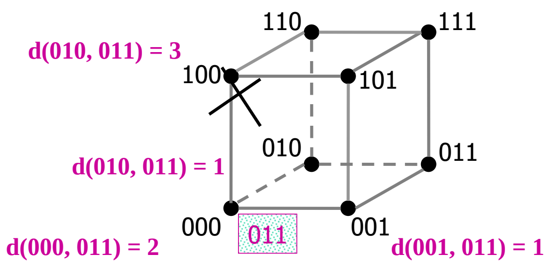
$$\mathbf{FRS} = \sum_{\forall J} \mathbf{\log(\, d(000, J)\,)/N \approx \log N}$$

Flexibility for Tree



- **logN** neighbors in sub-trees of varying heights
- **FNS = 2^{i-1}** for **i^{th}** neighbor of a node
- Route to a smaller sub-tree with destination;**FRS=1**

Flexibility for Hypercube



- Routing to next hop fixes one bit
- **FRS =Avg. (#bits destination differs in)=logN/2**
- **logN** neighbors differing in exactly one bit; **FNS=1**

Summary of flexibility analysis

Flexibility	Ordering of Geometries
Neighbors (FNS)	**Hypercube << Tree, XOR, Ring, Hybrid** (1) (2^{i-1})
Routes (FRS)	**Tree << XOR, Hybrid < Hypercube < Ring** (1) (logN/2) (logN/2) (logN)

How relevant is flexibility for DHT routing performance?

Outline

- Routing Geometry
- Comparing DHT Geometries
- Geometry's impact on Resilience
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Static Resilience

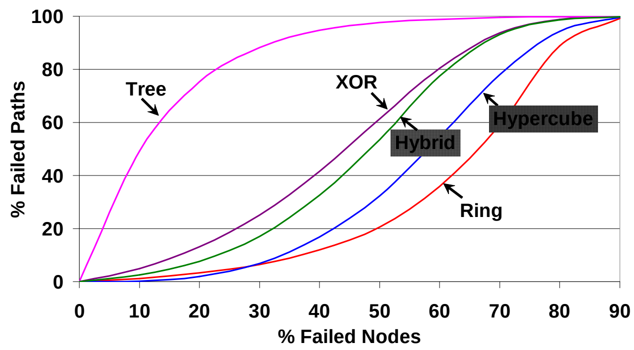
Two aspects of robust routing

- Dynamic Recovery : how quickly routing state is recovered after failures
- Static Resilience : how well the network routes before recovery finishes
  - captures how quickly recovery algorithms need to work
  - depends on FRS

Evaluation:

- Fail a fraction of nodes, without recovering any state
- Metric: **% Paths Failed**

Does flexibility affect Static Resilience?



Tree << XOR ≈ Hybrid < Hypercube < Ring

Static Resilience: Summary

- Tree << XOR ≈ Hybrid < Hypercube < Ring
  - What about trees with 2 neighbors?
- Addition of sequential neighbors helps resilience, but increases stretch
- Sequential neighbors offer more benefit, again at the cost of increased stretch

Flexibility in Route Selection matters for Static Resilience

Outline

- Routing Geometry
- Comparing flexibility of DHT Geometries
- Geometry's impact on Resilience
- Geometry's impact on Proximity
  - Overlay Path Latency
  - Local Convergence

Analysis of *Overlay Path Latency*

- Goal: Minimize end-to-end overlay path latency
- Both FNS and FRS can reduce latency
  - Tree has FNS, Hypercube has FRS, Ring & XOR have both

Evaluation:

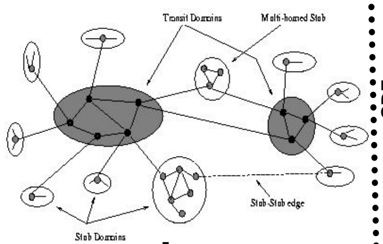
- Using Internet latency distributions

Problems with existing Network Models

- How to assign edge latencies to network topologies?
  - topology models: GT-ITM, Power-law, Mercator, Rocketfuel
  - no edge latency models, even for measured topologies
- Solution : A model using *only* latency distribution seen by a typical node

Simulations using latency distribution *only*

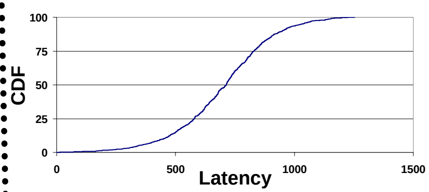
1) Topology, Edge Latencies



Simulate

Simulated Overlay Path Latency Distribution ≈

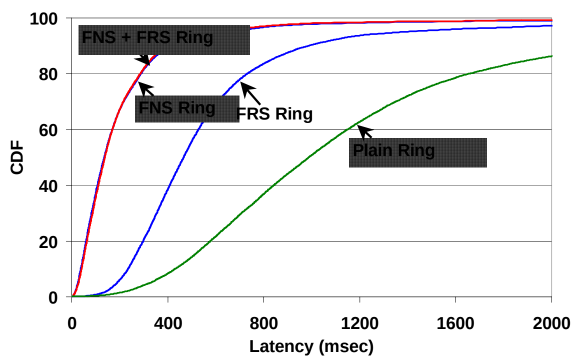
2) Latency Distribution



Compute

Computed Overlay Path Latency Distribution

Which is more useful: FNS or FRS?



Plain << FRS << FNS ≈ FNS+FRS

Neighbor Selection is much better than Route Selection

Proximity results: Summary

- Using neighbor selection is much better than using route selection flexibility
- Performance of FNS/FRS is independent of geometry beyond its support for neighbor selection
- In absolute terms, proximity techniques perform well (stretch of <2)

Local convergence: Summary

- Flexibility in neighbor selection helps much better than that in route selection
- Relevance of FRS depends on whether FNS restricted to a k-random sample closely approximates ideal FNS

Limitations

- Notion of geometry is vague (as the authors admit) – it is really a distance function on an ID-space
  - Hypercube is a special case of XOR!
- Not considered other factors that might matter
  - algorithmic details, symmetry in routing table entries
- Metrics under consideration can bias results – eg. In ring, do not distinguish between OPT and slightly sub-optimal paths