Internet Coordinate Systems
Tutorial

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Outline

- Motivation
  - Problem statement
  - General Approach
- Techniques
  - Global Network Positioning (GNP)
  - Practical Internet Coordinates (PIC)
  - Lighthouses
  - PCA-based techniques (Virtual Landmark and ICS)
- Conclusions
- Open Issues
Motivation

What’s the closest server to a client in Brazil?

Source: planet-lab.org

Network Latency (RTT)

- server1 -> 120 ms
- server2 -> 130 ms
- ...
- ...
Motivation

- Network round-trip-time = network distance
  - E.g. ping measurements
- Issue
  - Client needs ‘N’ measurements to select the closest server
  - Update list of network distances (overhead)
- How do we solve this problem?
Internet Coordinate System

Difference between coordinates $\approx$ network distance

Source: planet-lab.org
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Problem Statement

Problem statement (graph embedding into a vector space):

- Find a scalable mapping $\alpha : H \rightarrow V^k$, such that $d(h_i,h_j) \approx D(v_i,v_j)$, where:
  - $H$ is the original space (Internet graph)
  - $V$ is the target vector space of dimensionality $K$
  - Example: $H = \{h_1,h_2,h_3\}; V = \{v_1,v_2,v_3\}; d(h_1,h_2) \approx D(v_1,v_2)$
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General Approach

• Steps:
  1) Select a subset of hosts for ‘reference points’ (RP)
     • Create the origin of the coordinate system
  2) Measure round-trip-time (distance) between RPs
  3) Calculate coordinates for each RP
  4) Measure RTT between host and RPs
  5) Calculate coordinates for the host
• Different proposed techniques for steps 1,3 and 5
• Reference points = landmarks, lighthouses, beacons
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Global Network Positioning (GNP)

- Pioneering work: T.S.E. Ng, H. Zhang [ACM IMW’01, INFOCOM’02]
- Landmark coordinates

1) Landmark Selection (fixed set)
2) ‘L’ landmarks measure mutual network RTT/distance (ping)
3) Landmarks computes coordinates by minimizing the overall error between the measured and the estimated distances

Multi-dimensional global minimisation problem

minimise: error(d_{ij}, D_{ij})
Global Network Positioning (GNP)

- Host coordinates

1) Host measures its network distances (RTT) to the ‘L’ landmarks
2) Host computes its own coordinate relative to the Landmarks
3) Multi-dimensional global minimisation problem
   \[ \text{minimise: } \text{error}(d_{ij}, D_{ij}) \]
Global Network Positioning (GNP)

• Issues:
  • Landmark selection
    • Fixed set
    • Landmark failures and overload
    • What’s the optimal selection?

• Technique (Simplex downhill)
  • Unique coordinates are not guaranteed
  • Depends on the starting point of the algorithm
Lighthouses

- Pias, M. et al [IPTPS’03]
- Host selects random reference points (lighthouses)
- Coordinates computed through linear transformations
Lighthouses coordinates

Derive a distance matrix $D = \begin{bmatrix} 0 & d_{12} & d_{13} \\ 0 & 0 & d_{23} \\ 0 & 0 & 0 \end{bmatrix}$

Computes an orthogonal basis using QR decomposition: $D = Q \cdot R$

$Q$ is the orthogonal basis that creates the coordinate system

Each lighthouse is assigned a column vector of $Q$
Host coordinates

1) Host measures its network distances to the ‘L’ lighthouses
2) Distances of the host are projected onto the orthogonal basis
3) Host coordinates $H = Q \cdot B$, where $B$ is the matrix with RTTs between the host and lighthouses
Lighthouses

3-D coordinates based on RTTs of 'research sites' in North America
1) Any host with computed coordinates can serve as a landmark
2) Host measures RTTs to other ‘L’ landmarks
3) Host computes its own coordinate relative to the Landmarks
4) Multi-dimensional global minimisation problem
   minimise: $\text{error}(d_{ij}, D_{ij})$
Practical Internet Coordinates (PIC)

- PIC was tested in Pastry (Structured P2P system):
  - Each node maintains a routing table with distances to closest nodes
  - Without coordinates: a joining node measures 297 RTT distances in a p2p system of 20,000 nodes
  - Using coordinates: joining node measures 32 RTTs

- Selection strategy
  - Random: pick landmarks randomly
  - Closest: pick landmarks ‘closest’ to the host
  - Hybrid: pick landmarks as in random and others as in closest
PCA-based techniques (Virtual Landmarks and ICS)

- Tang, L, Crovella, M. [ACM IMC’03]: “Virtual Landmarks”
- Lim, H, Hou, J.C, Choi, C-H [ACM IMC’03]: “ICS”

1) Larger number of landmarks/beacons (m) - high dimensionality
2) Derive a landmark distance matrix m x m
3) Use Principal Component Analysis to derive an optimal basis
Optimal basis through Singular Value Decomposition: $D = U \cdot W \cdot V^T$

- Where columns of $U$ are the principal components and form an orthogonal basis
- $U$ has ‘$m$’ columns (components)
- Use the first ‘$k$’ principal components that allow ‘good’ projections
PCA-based techniques (Virtual Landmarks and ICS)

- Host Coordinates
  - Linear projections on the first ‘k’ principal components
  - \( H_i = U^T \cdot d_i \)
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Conclusions

- Techniques explored:
  - Minimisation of error functions: GNP and PIC
  - Linear matrix transformation: Lighthouses, Virtual Landmarks and ICS

- Applications
  - Closest server selection (e.g. distributed network games)
  - Network-aware construction of peer-to-peer systems
  - Routing in mobile ad-hoc networks
  - Network distance estimation

- Internet Coordinate System is promising but …
Open Issues/Future work

• Landmark placement
• How many dimensions do we need to create an “Internet Coordinate System”?
  • Some of the research suggested 6-9 dimensions
  • However, different datasets give different values
• Routing policies x dimensionality x error
• Future work
  • Visualisation tools (network topology/dynamics)
  • Refine the Usable Coordinate System (UCS) on PlanetLab
BACKUP Slides
Motivation

What’s the closest server to a client in Brazil?

Source: planet-lab.org

Geographical distances

server1 -> 4500 miles
server2 -> 6000 miles
...

Source: planet-lab.org
Motivation

• Difficulties:
  • Geographical distance $\neq$ network distance
    • Routing policies/connectivity
    • GPS is not wide available
  • Client needs ‘N’ distances to select the closest server
Practical Internet Coordinates (PIC)

Source: Costa, M. et al [ICDCS '04]

Thanks to Manuel Costa (MSR)
Distortion vs. Dimensionality

![Graph showing distortion vs. dimensionality](image)
Distortion vs. Dimensionality

All Sites – Distortion Comparisons with Different Dimensionalities for Techniques

- Lipschitz plain
- Lipschitz scaled
- Virtual Landmarks
- ICS
- Lighthouses
- Vivaldi
Triangle Inequality

North America Research (NAR)

Distortion

No. nodes

0% TIV

8.63% TIV

13.38% TIV

18.77% TIV