CS644 Advanced Networks

Lecture 9

Intra Domain Routing

Andreas Terzis

Outline

- So far we have talked about E2E mechanisms
- Routing is the other big component of the network
  - Largest distributed system ever
- Two-level routing system
  - Inter-domain
  - Intra-domain
- Intra-Domain
  - Dynamic Routing
    - Revised ARPANET metric [AZ89]
  - Routing Architectures
    - Landmark [Tsu88]

Dynamic Routing in the Internet

- What is routing?
  - Distributed algorithm to calculate ***shortest*** path to all network destinations
- Benefits of routing
  - Dynamically circumvent failures
  - Remember Baran's paper
- How do we define shortest?
  - Each link has an associated metric
    - Can be static or dynamic

Original ARPANET routing algorithm

- Distributed version of Bellman-Ford (DV)
- Exchange table every 2/3 sec
- Link metric was equal to instantaneous queue length plus constant
- Results:
  - Persistent routing loops
  - Routing oscillations

SPF Algorithm

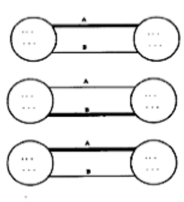
- Algorithm Overview
  - Routers periodically advertise adjacencies to *everyone*
  - Each router calculates shortest path using Dijkstra's algorithm
- Metric calculation
  - Average link delay over last 10 seconds
  - If new average crosses a threshold then update is generated
  - Each link has lower bound (bias)
    - Bias is function of link speed, prevents idle link from reporting zero delay

Limitations of Delay Metric

- Delay = Q_{delay} + T_{delay} + Pro_{pdelay}
- Low, medium load
  - Queuing delay is low -> Reported metric is good prediction of delay after traffic reroute
- High load
  - Queuing delay is high -> Metric does not correspond to delay after traffic is rerouted

Routing Oscillation

- No range on queuing delay
- All nodes adjust routes in response to delay metric updates
- Negative Effects
  - Oscillations
  - Unused capacity
  - Congestion
  - Increased routing traffic, CPU utilization

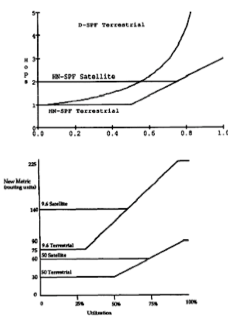


Revised Link Metric

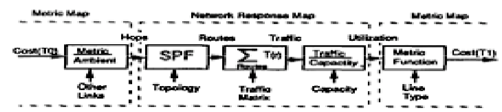
- Translate delay to link utilization (M/M/1)
- Take EWMA of calculated link utilization
- Normalize metric
- Limit the absolute change per update

Metric calculation example

- Transformations are parameterized based on link type
- Lower bound depends on link type
  - Satellite links have higher lower bound
    - Discourages use under low-link load
  - Metric is normalized on link bandwidth



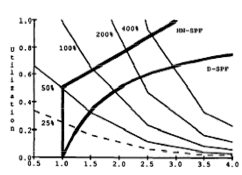
Details on Metric Calculation



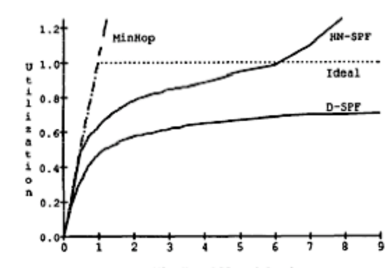
- Link Cost is input
- SPF calculates routes
- Traffic translates to link utilization
- Link utilization translates to new Link Costs
  - Equilibrium: New Cost equal to Old Cost

Stability

- HN-SPF is stable over larger area compared to D-SPF

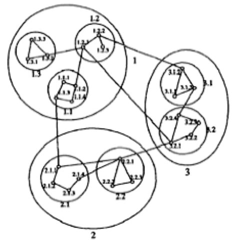


Utilization



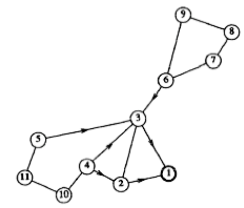
Area Hierarchy

- Group routers into *areas*
  - Each individual router is an area
  - Create a hierarchy of areas
- Pros and cons
  - + Reduced size of routing table
  - - Increased path
- Question:
  - How do you create the hierarchy?



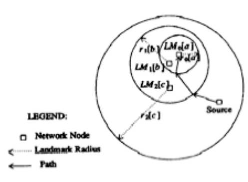
Landmark

- What is a landmark?
  - A router whose neighbor routers within a certain number of hops "know" about
    - Landmark "radius"



Hierarchy of Landmarks

- LM_i: Landmark at level i
- Every router is LM_0 with r_0
- Some routers are LM_1
  - $r_1 > r_0$
  - Reachable by LM_0 routers
- Stop at level H where $r_H > D$



Routing Table

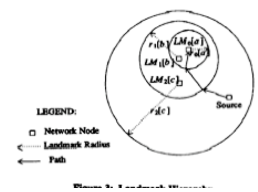
- Each router keeps
  - Next hop on the shortest path to each of the Landmarks it knows
  - Routers have full
- Result
  - Routers have full knowledge of immediate vicinity
  - Increasingly less information about *distant* locations

Addressing

- What is the address of a router?
  - Series of Landmark Ids: $LM_H, LM_{H-1}, \ldots LM_0$
  - Analogous to other hierarchical systems
  - Landmark at level i must be within radius of landmark at level i-1
  - Router might have multiple addresses

Routing

- Source routes first towards highest possible landmark
- Once packet enters radius of lower landmark it will follow more specific path
- Observations
  - Not shortest path
  - Path does not necessarily go through landmarks



Hierarchy Management Algorithm

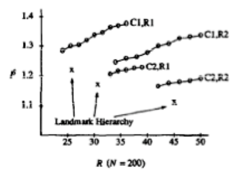
- Bottom-Up Approach
  - Each router advertises itself at distance r_0
  - If it hears from a Landmark at level 1 it grafts to the hierarchy
  - Otherwise do leader-election among peers at level 0
- Also required:
  - Algorithm to find path to Landmark
  - Use a variant of Distance Vector routing

Performance

- Compare against area hierarchy
- Metrics
  - Size of routing table
  - Ratio $R_L/R_{shortest}$
- Size of routing table
  - Area: $HN^{1/H}$
  - Landmark: $4N^{1/3}$ ($4N^{1/2}$)

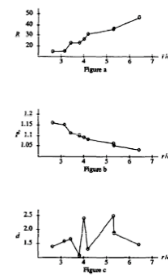
Routing Table Size

- Theoretical Results
  - Area: $HN^{1/H}$
  - Landmark: $4N^{1/3}$ ($4N^{1/2}$)
- Simulations



Landmark Routing Performance

- Effect of radius
  - Large radius: larger table, shorter paths
- Effect of number of Landmarks
  - More Landmarks at level i: shortest avg. distance to Landmark



Additional Issues

- Mapping between well known IDs and Landmark addresses
- Support for Administrative Boundaries