Simulating Disaster Scenarios and Geographically-Correlated Resilient Overlay Networks

Heuristics for Location-based Routing

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Challenges

- **Goal:** Improve data delivery ratio/speed during geographically-correlated network failures (earthquakes)
- No control over and limited knowledge about routing infrastructure
- But can gather location information
- **Claim:** Resilient Overlay Networks can help establish more reliable connections between end-hosts with limited topology knowledge

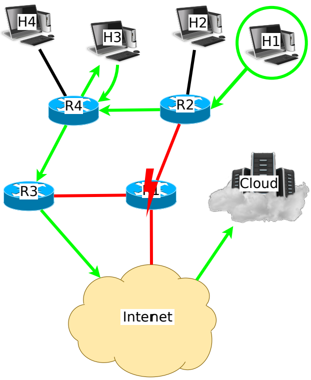

Figure: H1 routes around failed R1 using H3 as an overlay.

Exploiting Location Information

- Contact overlay nodes outside of local region to avoid failures
- Choose overlay nodes from diverse regions not previously attempted
- Failure likely along path to server or in local area
- Choose node outside local region to avoid overlapping paths
- Choose path avoiding as much of the direct path as possible
- Overlay node may use similar route to sensor

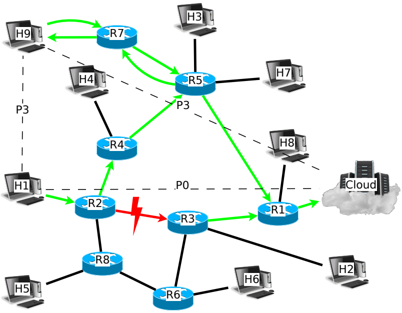

Figure: Sensors try to contact nodes outside of the local area and not along the straight-line path to the server.

Orthogonal Distant Path Heuristic

Algorithm 1:

begin

```
/* Sensor, server, and overlay
nodes are a, b, c respectively
*/
```

$idealDist = |0.5 \cdot dist(a, b)|$
$perpDist = |\sin(angA) \cdot dist(a, c)|$
if $angA > \frac{\pi}{2}$ **or** $angA + angC < \frac{\pi}{2}$ **or** $perpDist > dist(a, b)$ **then**
$likelihood = 0$
else
$likelihood = 0.5 \cdot ((1.0 - (||perpDist| - |idealDist||/idealDist)^2) + (1.0 - (|\frac{\pi}{2} - angC|/\frac{\pi}{2})^2))$

end

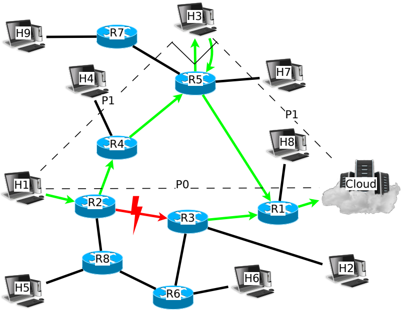

Figure: The intuition of this heuristic is to avoid the straight path, without diverging from it too much. It strikes a middle ground by choosing a path at an ideal angle of 45°, which makes the angle at the top orthogonal, hence the name.

New Region Heuristic

Algorithm 2:

begin
  if $peer.region \in regionsAttempted$
  then $likelihood = 0$
  else $likelihood = 1.0$
end

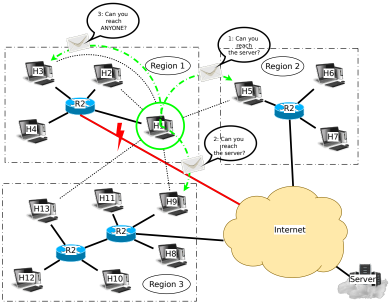

Figure: The intuition of this heuristic is to avoid regions that have been previously attempted unsuccessfully. We assume that no further attempts to contact such a region will succeed.

New Angle Path Heuristic

Algorithm 3:

begin

$angle = Angle(overlay, server)$
for $(path \in pathsAttempted)$
do if $angle = \pi$ **or** $angle = 0$ **then**
$likelihood = 0$
else if $angle < \pi$ **then**
$likelihood = \cos(angle - \frac{\pi}{4})$
else if $angle > \pi$ **then** $likelihood = \cos(2 \cdot ((2\pi - angle) - \frac{\pi}{4})/3)$
$likelihood = likelihood \cdot pastLikelihood$

end

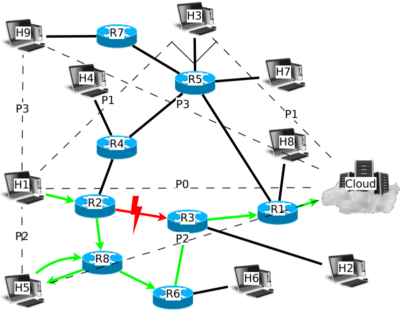

Figure: This heuristic attempts paths along new angles different from the ones previously attempted.

Distance-Dependent Path Heuristic

Algorithm 4:

---

begin

/* minDist = some reasonably small number */

idealDist $= 0.5 \cdot dist(sensor, server)$

dist $= dist(sensor, overlay)$ **if** *dist* $<= minDist$ **then** *likelihood* $= 0$

else if *minDist* $<$ *dist* $<$ *idealDist* **then** *likelihood* $= dist^2/idealDist^2$

else if *dist* $>=$ *idealDist* **then** *likelihood* $= idealDist/dist$

end

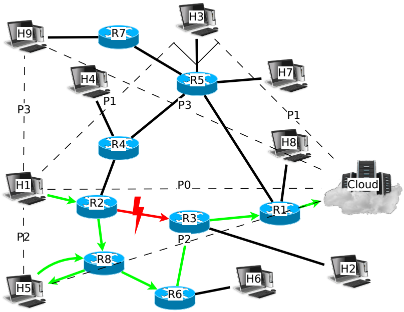

Figure: This heuristic attempts paths that use overlay nodes at an ideal distance from the sensor. This ideal distance is chosen as a radius that reaches half-way to the server.

Furthest First Path Heuristic

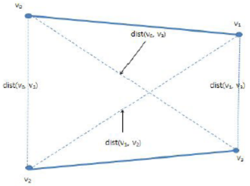

Figure: Definition of path similarity presented in W. Sun, “A Method for Overlay Network Latency Estimation from Previous Observation”, ICN-2013.

$geo\_similarity(v_0, v_1, v_2, v_3) =$
$\min[dist(v_0, v_2) + dist(v_1, v_3), dist(v_0, v_3) + dist(v_1, v_2)]$

When considering one server,

$geo\_similarity(v_0, v_1, v_2, v_3) =$
$dist(v_0, v_2) = geo(v_0, v_2)$

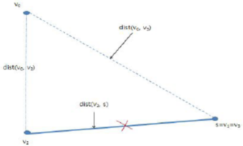

Figure: Thus, this heuristic considers overlay peers located further away to be more likely candidates.

begin

/* minDistance = some constant small number */

if $dist(a, b) < minDistance$ **then** $likelihood = 0$

else $likelihood = (dist(a, b) - minDistance)/dist(a, b)$

end

Closest First Path Heuristic

Algorithm 5:

begin
  `/* maxDistance = some constant large number */`
  if $dist(a, b) > maxDistance$ **then** $likelihood = 0$
  else $likelihood = (maxDistance - dist(a, b))/maxDistance$
end

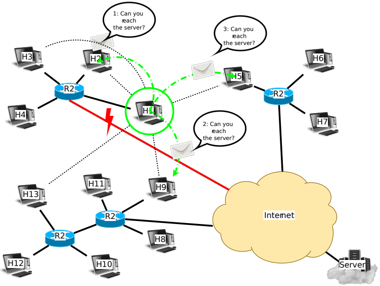

Figure: The intuition of this heuristic is to contact nearby overlay nodes that have found a path out of the local region. We found, however, that this approach does not always work well in practice, likely due to the path similarity inherent with nearby nodes.

Simulation Environment

- Compared heuristics with baseline Random
- ns-3 simulation environment
- 10 seconds simulation time
  - $>$10s $\rightarrow$ data not as useful for early warning
  - Most damage done (earthquake over)
  - Routes start to recover
- Nodes retry every *timeout* seconds (up to 20 times)
- $timeout = 500ms$: East $\rightarrow$ West RTT $\approx$200-300ms
- Nodes/links in disaster region fail uniformly with probability $p = 0.1, 0.2, 0.3, 0.4, 0.5$
- All overlay nodes in region (one incident link) report to server during disaster
- Server chosen randomly from 10 highest-degree nodes outside disaster
- Each combination of parameters repeated 100 times with different RNG seeds
- BRITE topology generator (10,000 nodes, 50 AS'es, top-down Barabasi/Waxman model, 25 regions)

Results

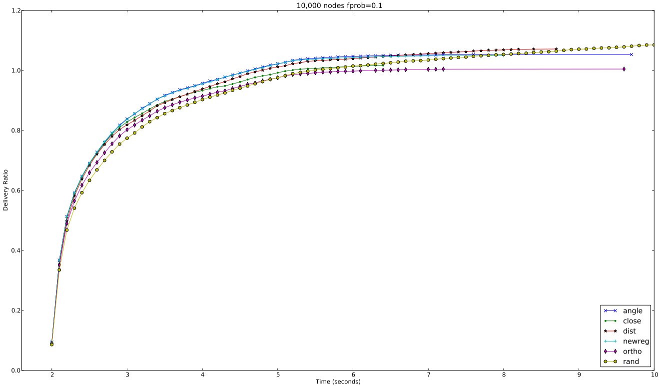

Figure: Delivery ratio of the various heuristics for a failure probability of 0.1. One can notice the way the heuristics sometimes overcome another's delivery ratio as time evolves and different paths are considered. NOTE: due to some necessarily aggressive data cleaning, the delivery ratio is exaggerated and skewed.

Results

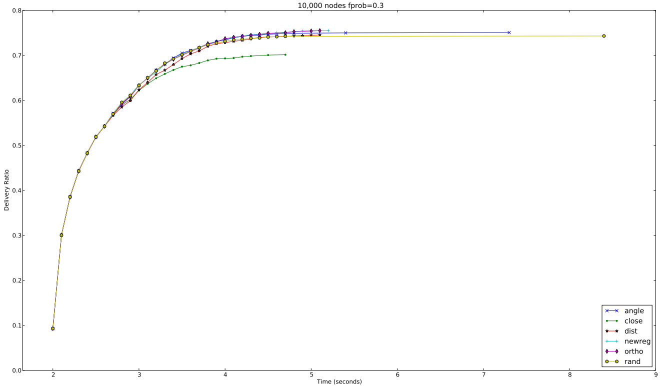

Figure: Delivery ratio for a failure probability of 0.3. Note that the more restrictive heuristics stop finding alternative connections before those that pick from more diverse areas, such as Random and New Angle. This pattern, as well as the relatively poor performance of Nearest Neighbor, grows proportionally to the failure probability.