Five Nines of Southbound Reliability in Software-Defined Networks

Francisco J. Ros
Pedro M. Ruiz
University of Murcia
The Problem

- Enables programmability
- Facilitates innovation

- Resiliency?
  Challenge for network operators

Control plane

Controller

centralized control

Southbound protocol

Data plane

Oops! No control

forwarding
Our Objective

• Communication between any node and (at least) one controller guaranteed with high probability
• At least five 9’s reliability in the Southbound interface
  – How many controllers?
  – Where?
  – What controllers per node?

How guarantee that $u,v,w,x$ can connect to $z$ with $P>0.99999$?

$p \equiv$ operational probability
Fault Tolerant Controller Placement

**Formulation**

\[
\min \sum_{i \in F} \psi_i y_i + \sum_{j \in N} \sum_{i \in F} \omega_{ij} x_{ij}
\]

subject to:

- \( \sum_{i \in F} x_{ij} > 0, \ \forall j \in N \)
- \( x_{ij} \leq y_i, \ \forall j \in N, \forall i \in F \)
- \( R(G, j, I_j) \geq \beta \), \ \forall j \in N

\( x_{ij}, y_i \in \{0, 1\} \)

**Algorithm heuristic**

**Algorithm 1: Heuristic algorithm for FTCP.**

Input: Graph \( G \), nodes \( N \), facilities \( F \), reliability threshold \( \beta < 1 \), incentive parameter \( \tau > 1 \)

1. \( S_i \leftarrow \sum_{j \in \mathcal{N}(i)} D_{ji}, \forall i \in F \)
2. foreach \( j \in N \) do
   3. \( I_j \leftarrow 0; \ \hat{R}_{prev} \leftarrow 0; \)
   4. \( rank \leftarrow [i \in F] \) in reverse order of \( S_i \)
   5. foreach \( i \in rank \) do
      6. \( I_j \leftarrow I_j \cup \{i\} \)
      7. Build \( G' \) from \( G \) and \( I_j \)
      8. \( f \leftarrow \max_{\text{flow}} (G', j_0, i) \)
      9. \( \text{remove\_edge}(G', u, v), \forall (u, v) : f(u, v) = 0 \)
      10. \( \Pi_{j_0,i} \leftarrow \lambda \) disjoint paths in \( G' \)
      11. \( \hat{R} \leftarrow 1 - \prod_{v \in \Pi_{j_0,i}} (1 - \prod_{\pi(v, u) \in \Pi_{j_0,i}} p_{u,v}) \)
      12. if \( \hat{R} > \hat{R}_{prev} \) then
          13. if \( \hat{R} \geq \beta \) then
              14. \( I_j \leftarrow \{k \in I : (\exists \pi \in \Pi_{j_0,k} : k \in \pi)\} \)
              15. break
          16. \( \hat{R}_{prev} \leftarrow \hat{R} \)
      17. \( S_i \leftarrow \tau S_i, \forall i \in I_j \)

**Evaluation**

randomized

**The Internet Topology Zoo**

124 WANs

**high complexity**
Results

- **How many controllers?**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Median</th>
<th>75-pctl</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>10</td>
<td>8.2</td>
<td>7</td>
</tr>
</tbody>
</table>

- It depends, more on topology than size
- In 75% of networks with certain degree of redundancy, ≤10 controllers provide five 9’s
Results

• Where?

Sprint
  Usually in central facilities with high connectivity
  In facilities with poor connectivity if necessary

BtNorthAmerica
Results

• **Controllers per node?**

![Graphs showing distribution of controllers per node and network size.]

- Avg ≈ 2, Max = 3
- R > five 9’s for most nodes

<table>
<thead>
<tr>
<th>Ř</th>
<th>5 9’s</th>
<th>6 9’s</th>
<th>7 9’s</th>
<th>≥ 8 9’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>2.26%</td>
<td>44.38%</td>
<td>47.15%</td>
<td>6.21%</td>
</tr>
</tbody>
</table>
Conclusion and Ongoing Work

If

deploy the appropriate number of controllers
place them wisely
nodes connect to the right subset of controllers

Then

data and control planes attached with high
likelihood in many network topologies
Thank you

Francisco J. Ros
http://masimum.inf.um.es
fjros@um.es