Optimal Standby Virtual Routers Selection for Node Failures in a Virtual Network Environment

Xuan Liu and Deep Medhi

Network Research Lab (NeTReL)
University of Missouri – Kansas City

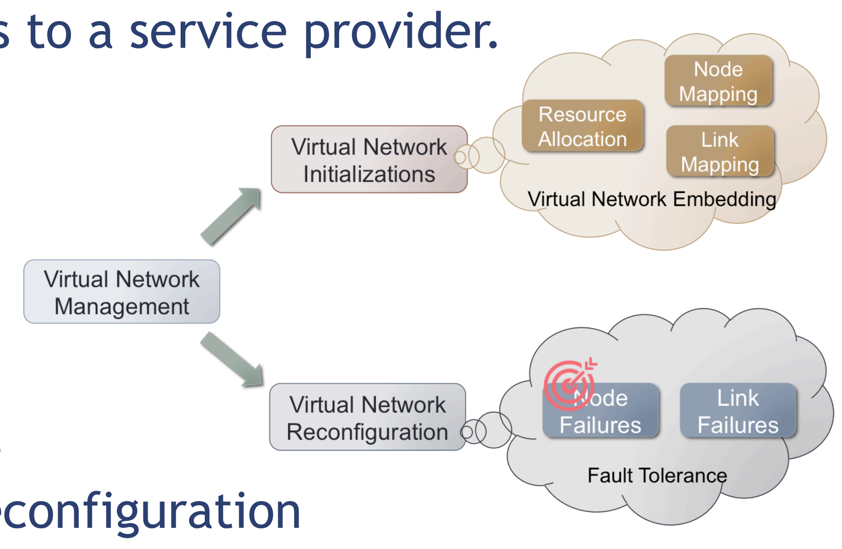
21th GENI Conference, Oct. 21-23, 2014

Introduction

Network virtualization allows flexibility to configure virtual networks in a dynamic manner. In such a setting, to provide resilient services to virtual networks, we consider the situation where the substrate network provider wants to have standby virtual routers ready to serve the virtual networks in the event of a failure. Such a failure can affect one or more virtual routers in multiple virtual networks. The goal of our work is to make the optimal selection of standby virtual routers so that virtual networks can be dynamically reconfigured back to their original topologies after a failure. We present an optimization formulation and a preliminary implementation on GENI testbed by applying the idea behind the model.

Dynamic Reconfiguration Scheme For Virtual Networks

- Substrate network providers are capable to provide standby virtual routers (S-VRs) when leasing virtual networks to a service provider.
- Requirements to the reconfiguration
  - Conservation
    - Topological structure
    - Bandwidth requirement
  - Fast restoration
  - Focus on the core node failures
- Software-defined management for reconfiguration
  - Autonomic Management
  - Central Controller



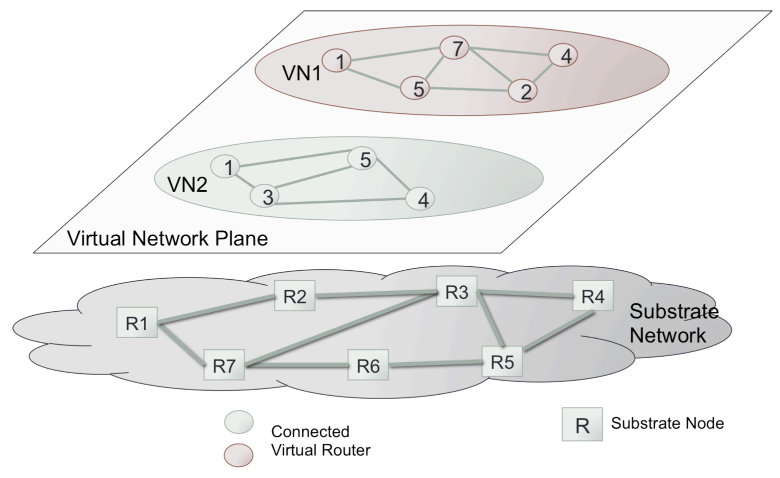


Fig. 1: Virtual Networks over the Substrate Network

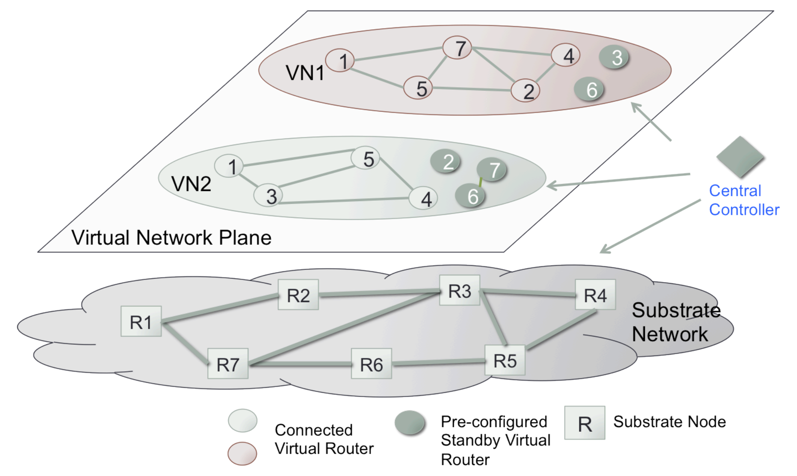


Fig. 2: Dynamic Reconfiguration Scheme for Virtual Network Environment

Our Goal: Optimal S-VR Selection Model

- Selects an optimal S-VR to restore single-VR failure for one or more VNs
  - The S-VR has optimal geographical location
  - Minimizing the maximum residual bandwidth utilization on the substrate nodes.
  - Subject to several main constraints
    - The VN topological structure does not change
    - The substrate node hosting the S-VR should have enough capacity

Assumptions

- Within a virtual network, any two virtual routers, including the standby virtual routers, are not hosted on the same substrate node.
- One substrate node failure at a time
- For each virtual network, at most one virtual router failure at a time

Type of Node Failures

- Independent Virtual Router Failure
  - Caused by software failures within the virtual nodes
  - Does not affect other virtual nodes in current or other virtual networks
- Dependent Virtual Router Failure
  - Caused by a failure occurring at a substrate node
  - Multiple virtual networks may get affected

Acknowledgement

This work has been supported by NSF Grant Nos. 0916505 and 1217736.

Optimization Model

Constraints

- Only a reserved S-VR can be used to restore a VR failure.

$$u_i^{j,f} \le \delta_i^j (1-\beta_i^j), \quad \forall i \in \mathcal{R}, \forall f \in \mathcal{F}^j, \forall j \in \mathcal{G}, i \neq f \qquad (1)$$

- For any VR failure in a VN, only one S-VR can be selected

$$\sum_{i\in\mathcal{R}} \delta_i^j \cdot u_i^{j,f} = 1, \forall f \in \mathcal{F}^j, \forall j \in \mathcal{G} \qquad (2)$$

- An S-VR can restore at most one VR failure in a VN

$$\sum_{f\in\mathcal{F}^j} \delta_i^j \cdot u_i^{j,f} \le 1, \forall i \in \mathcal{R}, \forall j \in \mathcal{G} \qquad (3)$$

- The number of S-VRs selected from the same substrate node cannot exceed a predetermined limit h_i.

$$\sum_{f\in\mathcal{F}^j} \sum_{j\in\mathcal{G}} \delta_i^j u_i^{j,f} \le h_i, \forall i \in \mathcal{R} \qquad (4)$$

- Virtual Interfaces on an S-VR can be enabled only when this S-VR is selected.

$$\gamma_{i,m,k}^{j,f} \cdot v_{i,m,k}^{j,f} \le u_i^{j,f}, \quad \forall f \in \mathcal{F}^j, \forall i,k \in \mathcal{R}, \forall j \in \mathcal{G}, \forall m \in \mathcal{M}_i^j, i \neq k \neq f \qquad (5)$$

- Conservation of VN topological Structures

$$\sum_{m\in\mathcal{M}_i^j} \sum_{k\in\mathcal{R}} e_{f,k}^j \cdot \delta_i^j \cdot \gamma_{i,m,k}^{j,f} \cdot v_{i,m,k}^{j,f} = \sum_{k\in\mathcal{R}} \delta_i^j \cdot u_i^{j,f} \cdot \beta_f^j \cdot e_{f,k}^j \quad \forall j \in \mathcal{G}, \forall f \in \mathcal{F}^j, \forall i \in \mathcal{R}, i \neq k \neq f \qquad (6)$$

- Conservation of Virtual Link Bandwidth Requirement

$$\sum_{m\in\mathcal{M}_i^j} \sum_{k\in\mathcal{R}} \delta_i^j \cdot \gamma_{i,m,k}^{j,f} \cdot c_{i,m,k}^{j,f} \cdot v_{i,m,k}^{j,f} \le \sum_{p\in\mathcal{P}_i} \delta_i^j \cdot b_{i,p} \cdot u_i^{j,f}, \quad \forall j \in \mathcal{G}, \forall f \in \mathcal{F}^j, \forall i \in \mathcal{R}, i \neq k \neq f, \qquad (7)$$

- Only select the S-VR when there is a path from its host to its neighbors' host on the substrate network.

$$\sum_{q\in\mathcal{Q}_{(ik)}} x_q^{(jfik)} = \sum_{m\in\mathcal{M}_i^j} \gamma_{i,m,k}^{j,f} \cdot c_{i,m,k}^{j,f} \cdot \delta_i^j \cdot u_i^{j,f}, \quad \forall j \in \mathcal{G}, \forall f \in \mathcal{F}^j, \forall i,k \in \mathcal{R}, i \neq k \neq f \qquad (9)$$

$$\sum_{(j,f,i,k)} \sum_{q\in\mathcal{Q}_{ik}} \Delta_{q,l}^{(jfik)} \cdot x_q^{(jfik)} \le b_l, \quad \forall l \in \mathcal{L}, i \neq k \neq f \qquad (10)$$

- Residual bandwidth utilization balancing on the substrate nodes.

$$\sum_{j\in\mathcal{G}} \sum_{f\in\mathcal{F}} \delta_i^j \cdot u_i^{j,f} \cdot \Big(\sum_{k\in\mathcal{R}} \sum_{m\in\mathcal{M}_i^j} \gamma_{i,m,k}^{j,f} \cdot c_{i,m,k}^{j,f}\Big) \le \sum_{p\in\mathcal{P}_i} b_{i,p} \cdot t, \quad \forall i \in \mathcal{R}, i \neq k \neq f \qquad (8)$$

- Objective Function

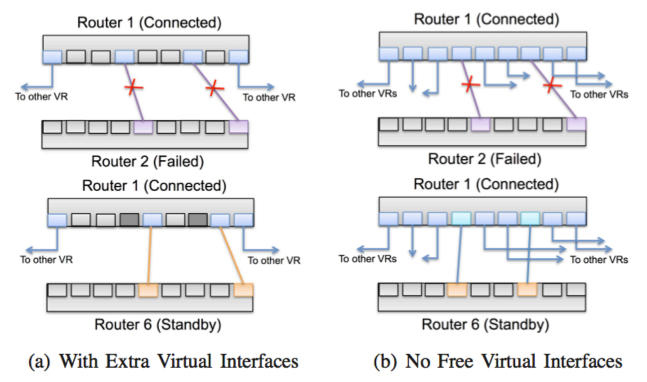
Weight for minimum cost selection (MCS) objective; Type-I Cost; Type-II Cost

$$\min\{\lambda \cdot [\sum_{j\in\mathcal{G}} \sum_{f\in\mathcal{F}^j} \sum_{i\in\mathcal{R}} \sum_{m\in\mathcal{M}_i^j} \sum_{k\in\mathcal{R}} (w_{\theta 1} \cdot \eta_{i,m,k}^{j,f} + w_{\theta 2} \cdot \sigma_{i,m,k}^{j,f}) \cdot \delta_{i,j} \cdot \gamma_{i,m,k}^{j,f} \cdot v_{i,m,k}^{j,f}] + \pi \cdot t\}, i \neq k \neq f \qquad (11)$$

Weight for residual bandwidth balancing (RBB) objective

Symbols	Description (all non-negative)
λ, π	Indicates the proportion for sub-objectives
w_θ	Primary weight parameters used in (11): $w_\theta = \langle w_{\theta 1}, w_{\theta 2} \rangle$
w_b	Secondary weights in (13): $w_b = \langle w_{b1}, w_{b2} \rangle$
w_a	Third level weights in (13): $w_a = \langle w_{a1}, w_{a2} \rangle$

- Cost Functions
  - Type-I: Interface Operations



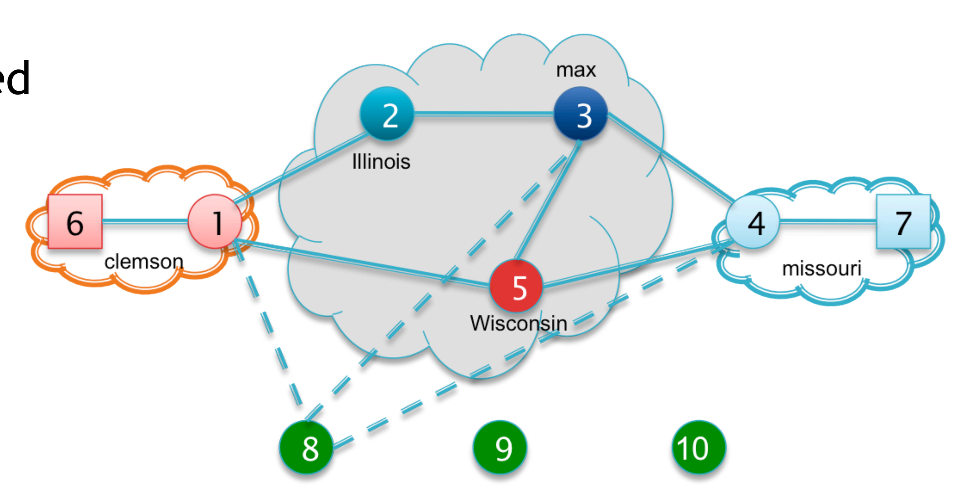
$$\eta_{i,m,k}^{j,f} = 2 \cdot (s^- + s^+) + \tau_i^{j,f} \cdot l \quad \forall m \in \mathcal{M}_i^j, \forall k \in \mathcal{R}, i \neq k \neq f \qquad (12)$$

  - Type-II: Connectivity Cost

$$\sigma_{i,m,k}^{j,f} = w_{b1} \cdot (w_{a1} \cdot d_{i,f} + w_{a2} \cdot d_{i,k}) + w_{b2} \cdot rtt_{i,k}, \quad \forall j \in \mathcal{G}, \forall m \in \mathcal{M}_i^j, i \neq k \neq f \qquad (13)$$

Preliminary Implementation on GENI

- Topology
  - Seven Sites on GENI testbed
  - One virtual network
  - Three core virtual routers
  - Three S-VR virtual routers
  - One VR failure



- Selection Metrics
  - Geographical location
  - VM load on each VR's host.

SVR	Site	Latitude	Longitude	Dist (mile)	VM Load
8	Wisconsin	43.075	-89.41	0	6%
9	Stanford	37.430	-122.17	1760.078	14%
10	UtahDDC	40.751	-111.89	1164.032	4%