On Quantifying Performance Enhancement of Distributed SDN Architecture

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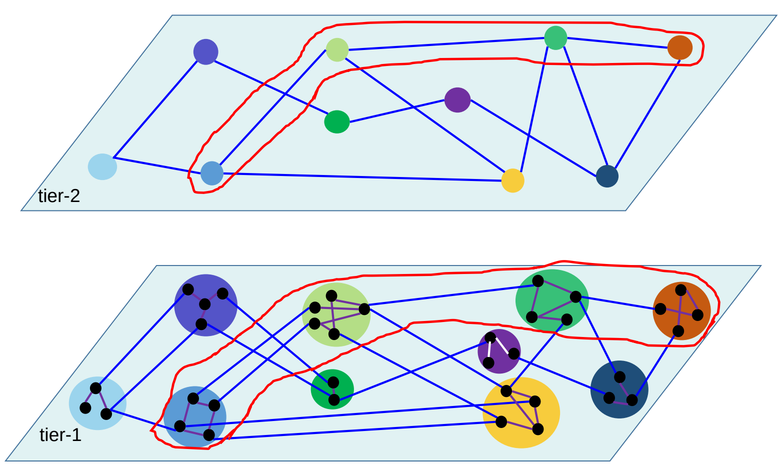
Summary & Problem Statement

Goal: Quantify performance enhancement by SDN
Performance Metric: APL: the average length of the shortest path between two arbitrary nodes in the network under different synchronization levels
Performance Bounds:
Upper bound: complete control plane syncs;
Somewhere in the middle: partial syncs;
Lower Bound: no syncs among any domains;

Network Model

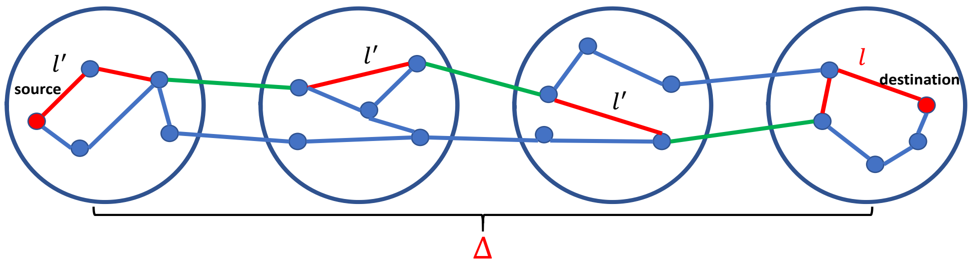
Y: RV of # domains that the shortest path between two arbitrary nodes traverses
$h_Y(y)$: PMF of RV Y



Tier-1: domains whose topology is decided by degree distribution extracted from real network
Tier-2: each domain is abstracted as a single node and two domains are joined by a link in domain-wise topology if there are physical connections

No Inter-domain Syncs

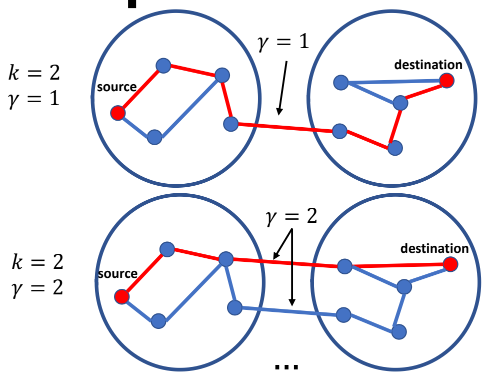
APL between 2 arbitrary nodes when there is no inter-domain syncs



- $l \simeq \ln(n/z_1)/\ln(z_2/z_1)+1$ — l: APL between two arbitrary nodes within one domain
- $\Delta \simeq \ln(m/z_1')/\ln(z_2'/z_1')+2$ — Δ: avg. # domains on a domain-wise route
- $l' \simeq \begin{cases} \frac{n-\gamma}{n}\left(\frac{\ln(\frac{n+1-\gamma}{\gamma})}{\ln(z_2/z_1)}+1\right) & \text{for } \gamma \le (n+1)/2, \\ \frac{n-\gamma}{n} & \text{for } \gamma > (n+1)/2. \end{cases}$
- $\gamma = n(1-(1-1/n)^{\beta})$ — γ: # gateway nodes in one domain
- $L_{\mathrm{BGP}} \simeq (l'+1)(\Delta-1)+l$ — L_{BGP}: APL under BGP

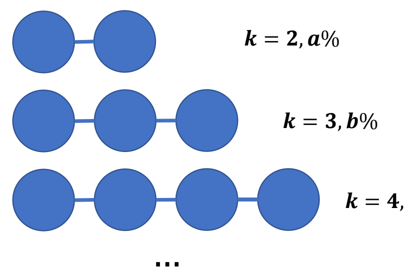
n: # nodes in one domain
z_i: avg. # vertices i hops away from an arbitrary node
z_i': corresponding z_i in domain-wise network
l': average distance between an ordinary node and its nearest gateway node

Complete Inter-domain Syncs



APL between two arbitrary nodes in two synced domains

Domains connected in a bus topology: the routes between any pair of nodes are on a domain-wise path as follows



Distribution of the shortest APL of domain-wise routes

- $f_{D_1}(d) = \Pr(D_1 = d) = z_d/n, d = 0,1,2,\ldots$
- $f_{D_k}(d) = \begin{cases} (1-F_U(d-1))^{\beta^{k-1}} - (1-F_U(d))^{\beta^{k-1}} & d \ge k, \\ 1-(F_U(d))^{\beta^{k-1}} & d = k-1. \end{cases}$
- $L_k := \mathbb{E}[U]$
- $L^* = \sum_{y=2}^{m} L_y h_Y(y)$

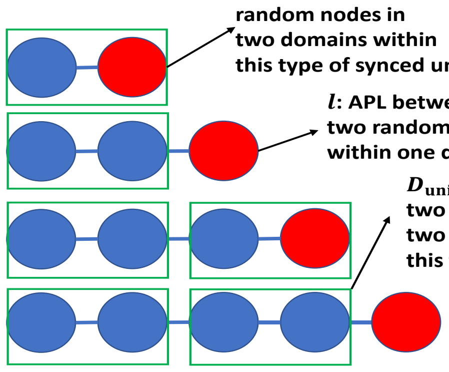
L_k: mean of RV D_k
L^*: APL under complete inter-domain synchronizations

$f_{D_1}(d)$: distance distribution in one domain
$f_{D_k}(d)$: joint distance distribution between two random nodes in two terminal domains of k domains connected in a bus topology
$F_U(d)$: CDF of $f_{D_k}(d)$
U: RV of distance between two random nodes in two terminal domains of k domains connected in a bus topology

Theorem 1. *$L_k < L_{k+1}$ under the 2-tier network model.*

Partial Inter-domain Syncs

How SDN-assisted inter-domain routing works?
(1) The domain-wise path is jointly constructed by each controller in these domains like BGP;
(2) The SDN controller in the current domain follows the instruction from the previous domain(s); if no such instruction exists, go to (3);
(3) The SDN controller in the current domain selects a path starting from the ingress node to the closest egress node

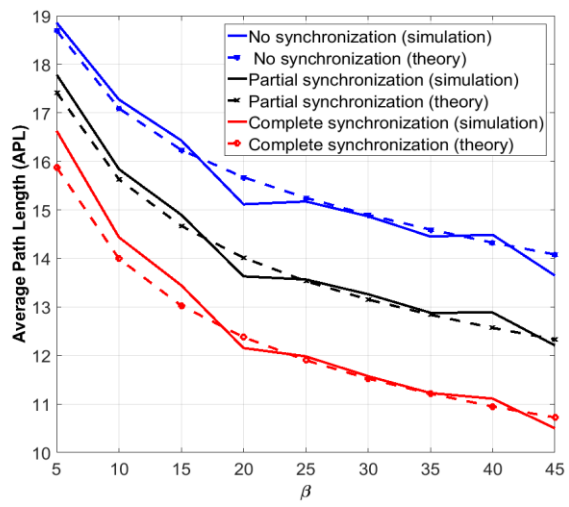


L_2: APL between two random nodes in two domains within this type of synced unit
l: APL between two random nodes within one domain
D_{unit}: APL between two random nodes in two domains within this type of synced unit

- $L_k^{\mathrm{SDN}} = \begin{cases} (\frac{k}{2}-1)L_{\mathrm{unit}} + L_2 + \frac{k}{2} - 1 & k \text{ is even}, \\ \frac{k-1}{2}L_{\mathrm{unit}} + l + \frac{k-1}{2} & k \text{ is odd}. \end{cases}$
- $L_{\mathrm{SDN}} = \sum_{y=2}^{m} L_y^{\mathrm{SDN}} h_Y(y)$

L_k^{SDN}: APL in a bus topology with k domains
L_{unit}: APL in step (3)
L_{SDN}: APL under the simple scheme

Evaluations



- Intra-domain topology collected from the Rocketfuel Project
- Simulation results confirm the validity of analytical framework
- A basic SDN-based strategy can Reduce the gap to optimal value by Around 50%

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