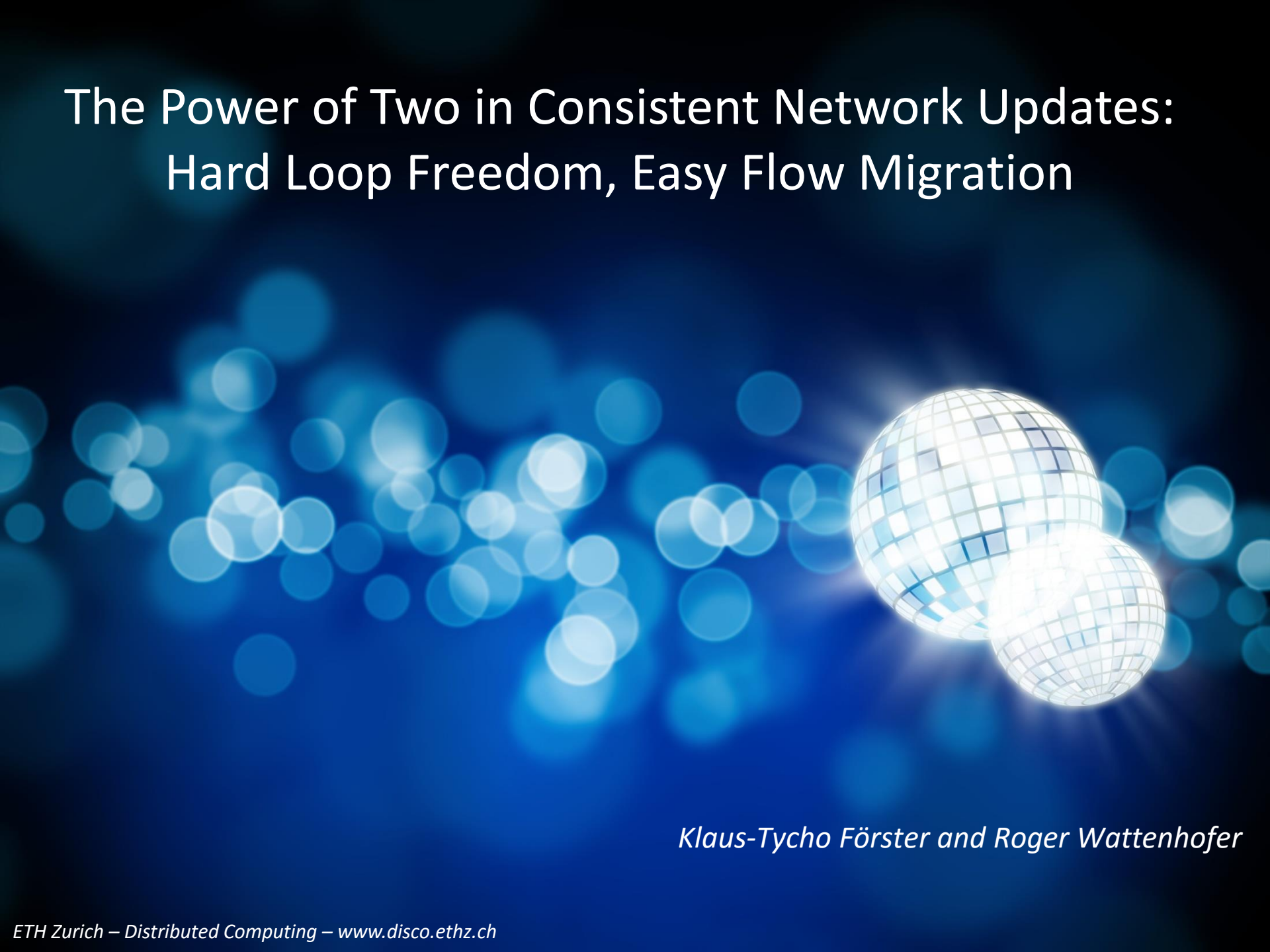
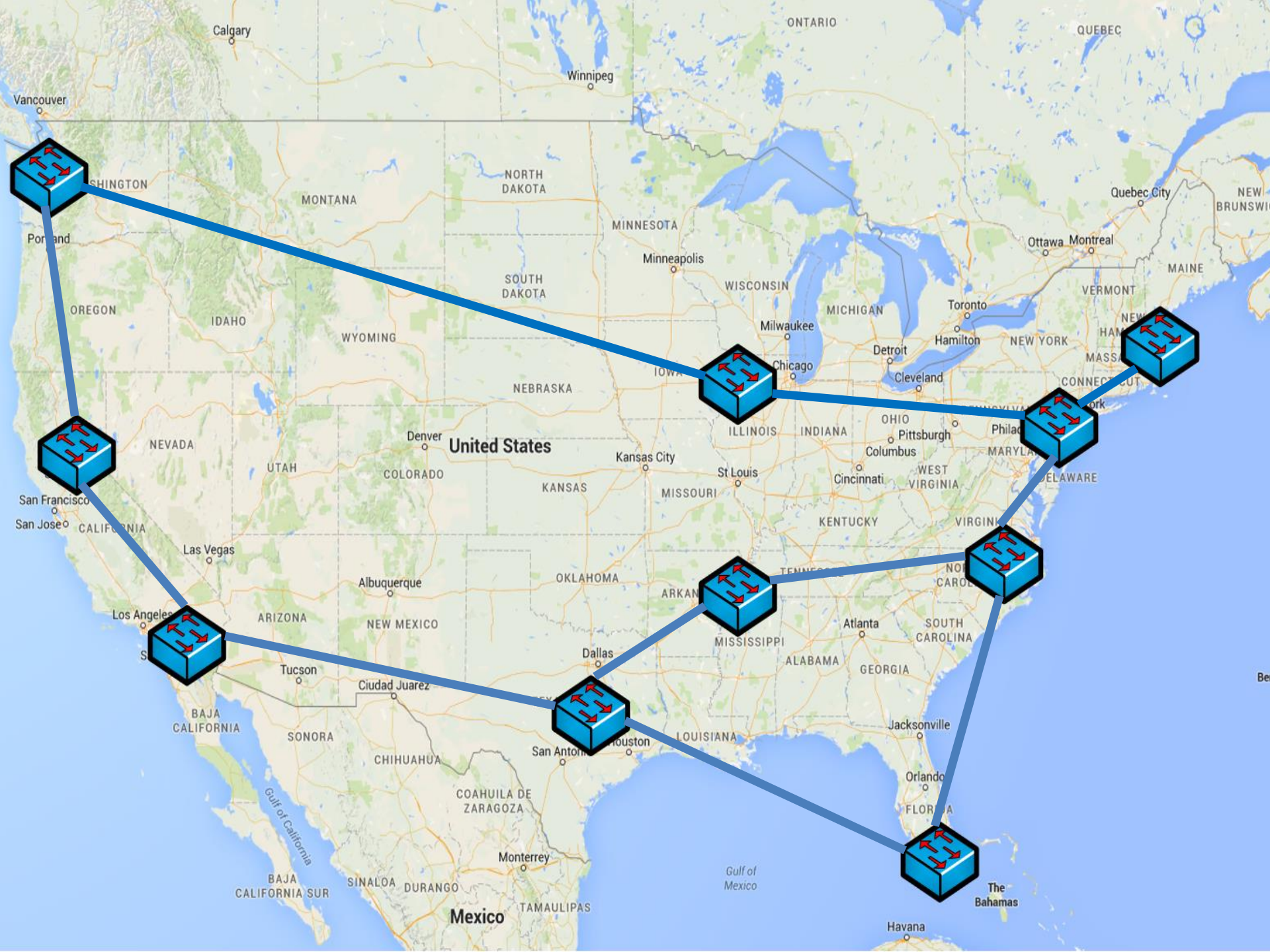
The Power of Two in Consistent Network Updates: Hard Loop Freedom, Easy Flow Migration



Klaus-Tycho Förster and Roger Wattenhofer

ETH Zurich – Distributed Computing – www.disco.ethz.ch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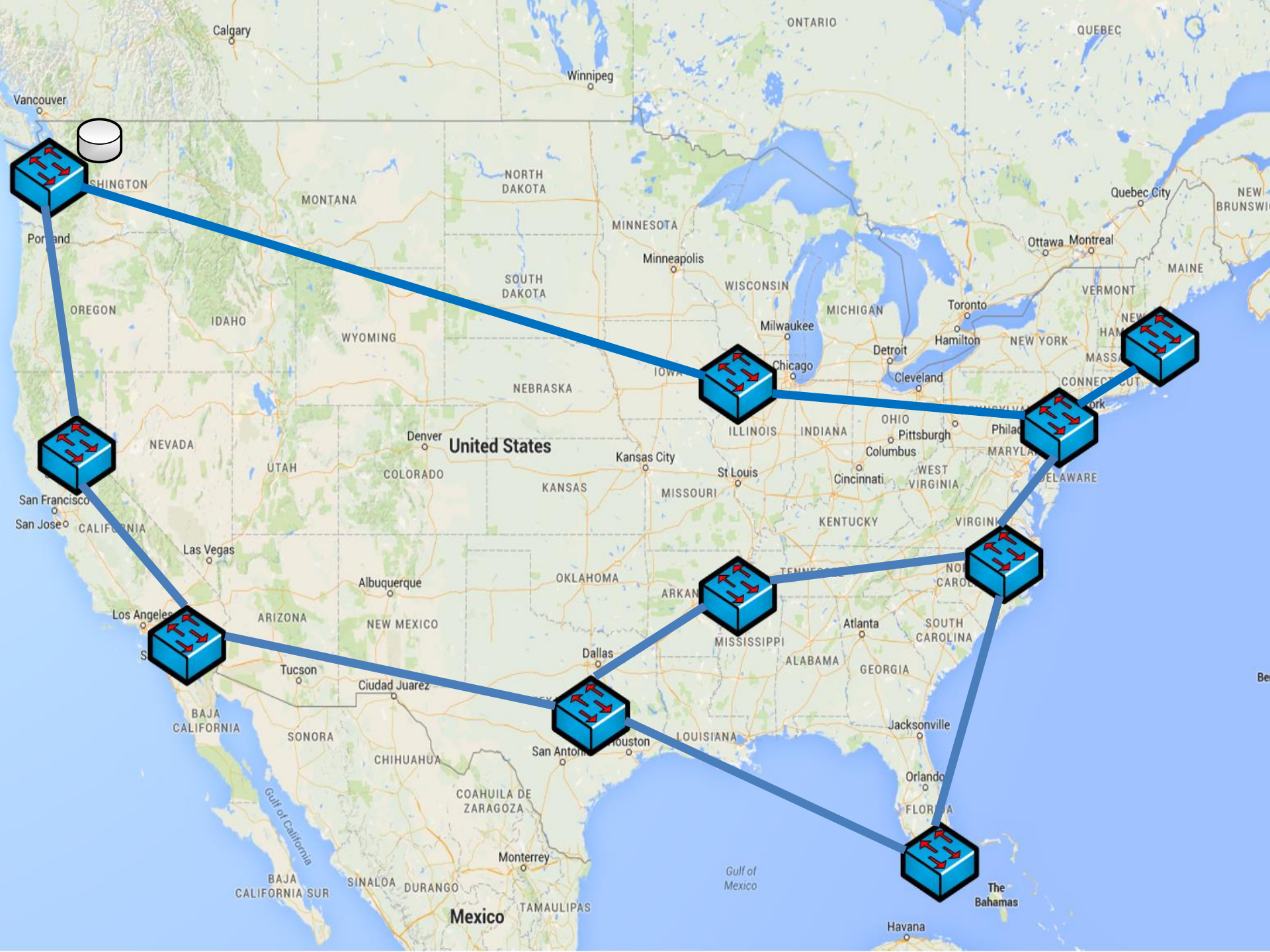
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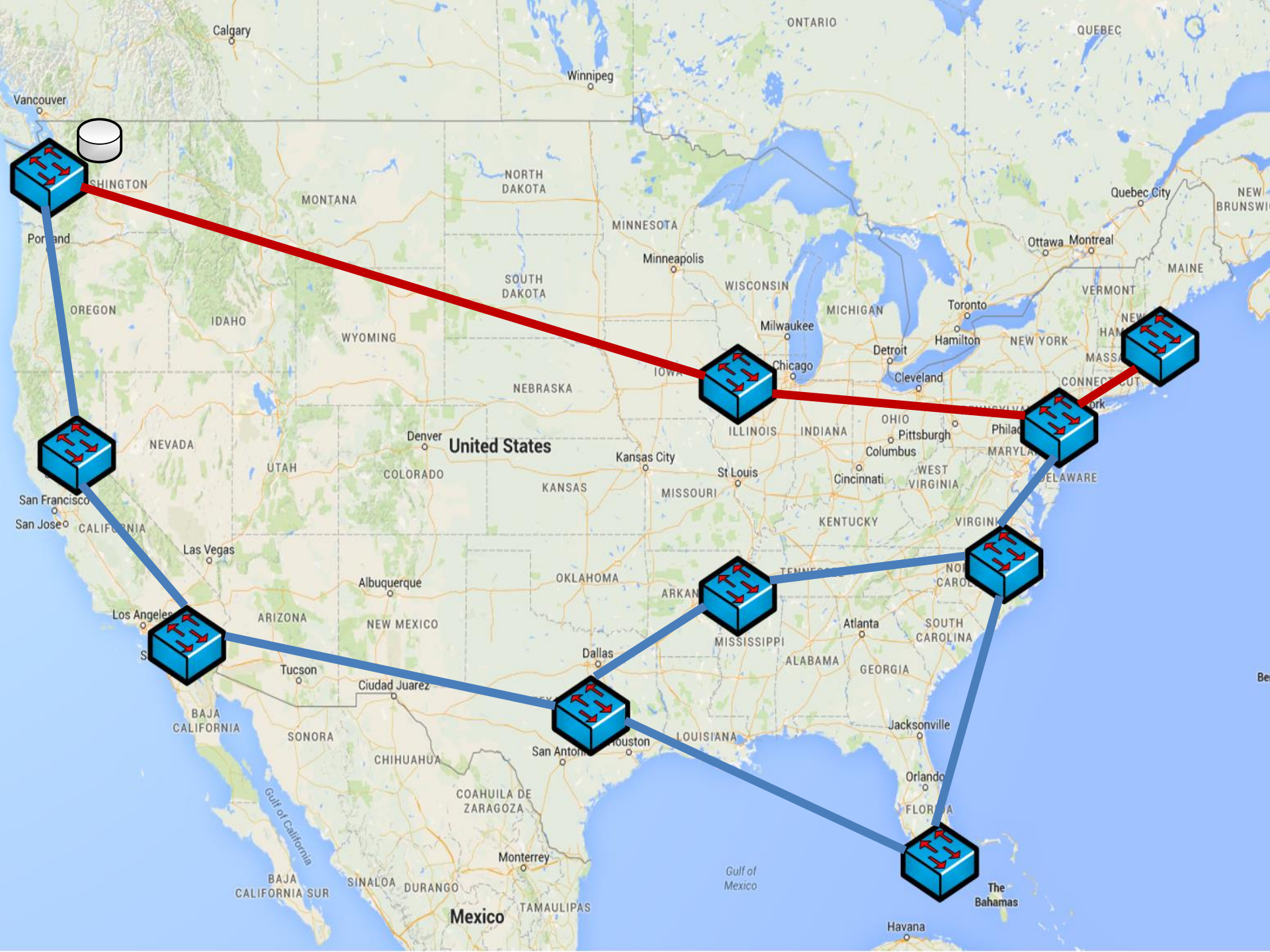
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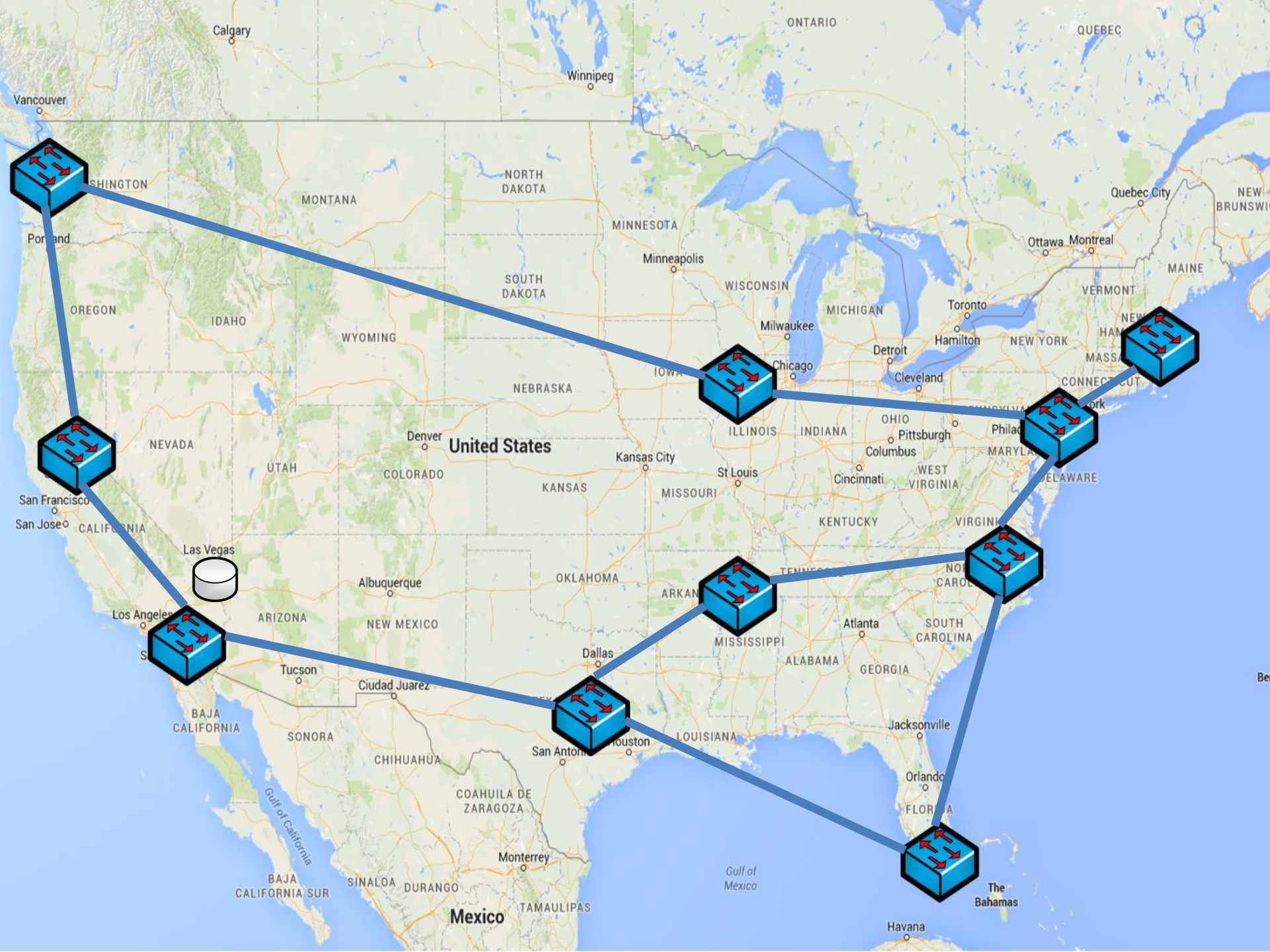
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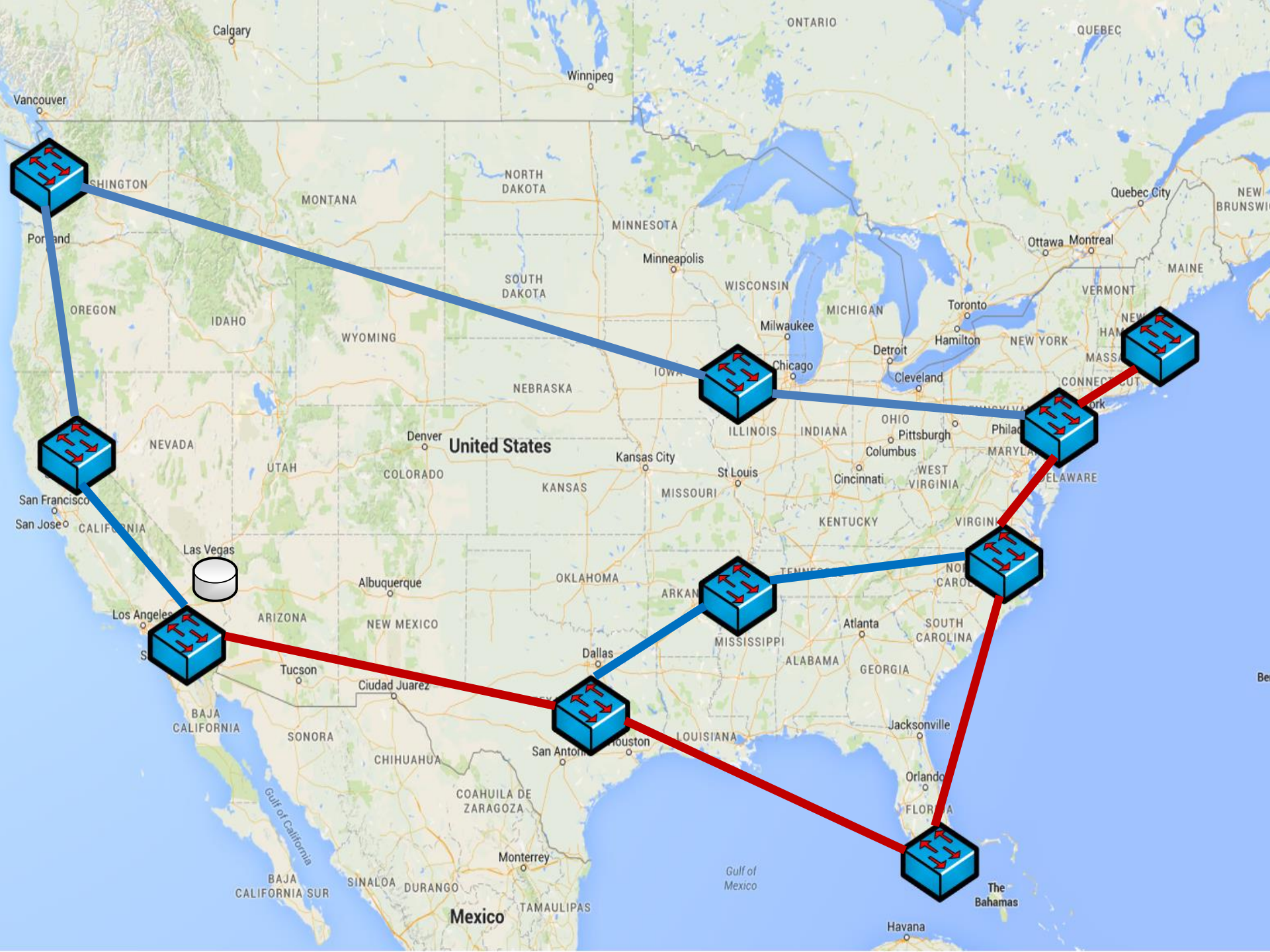
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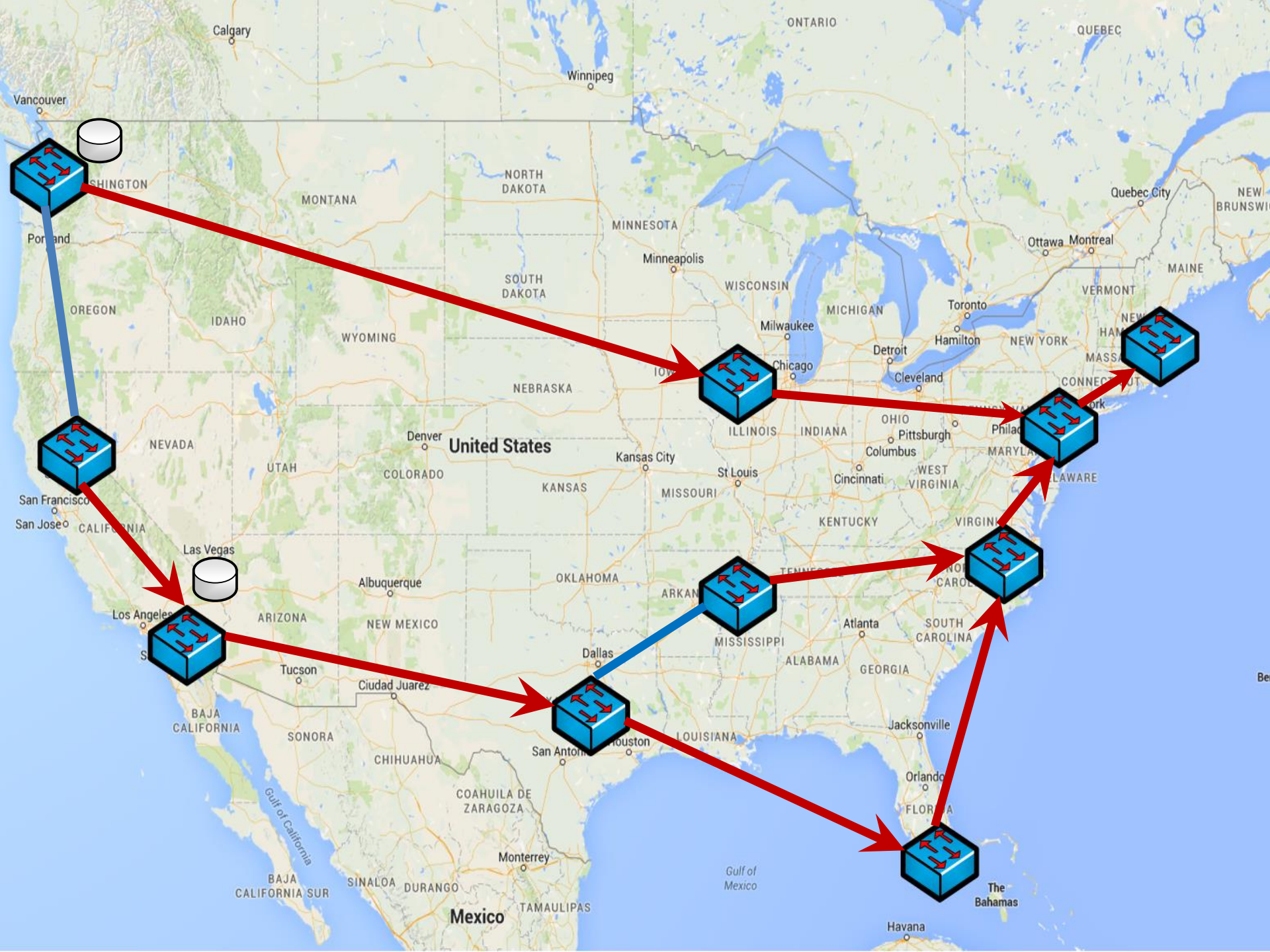
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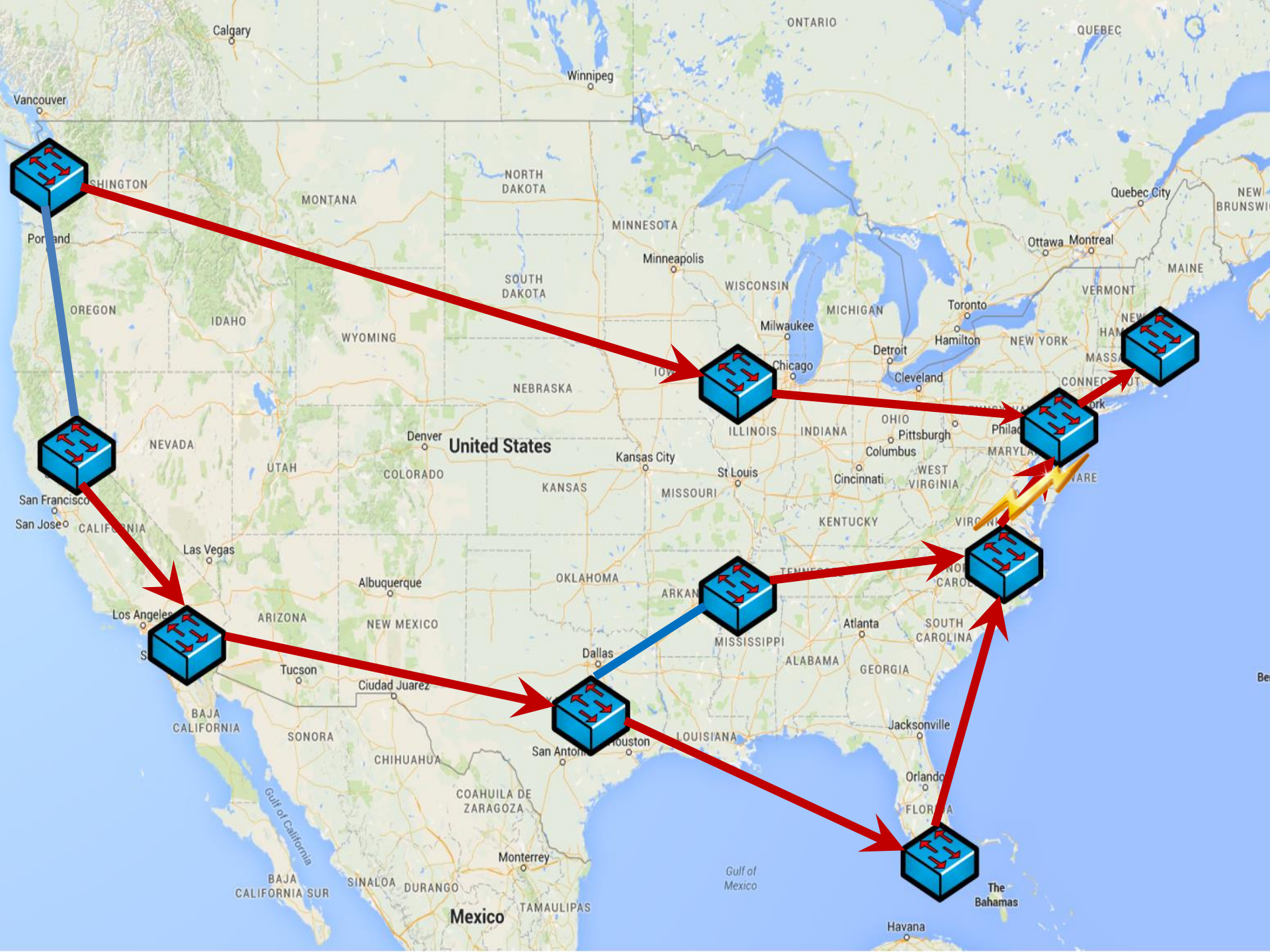
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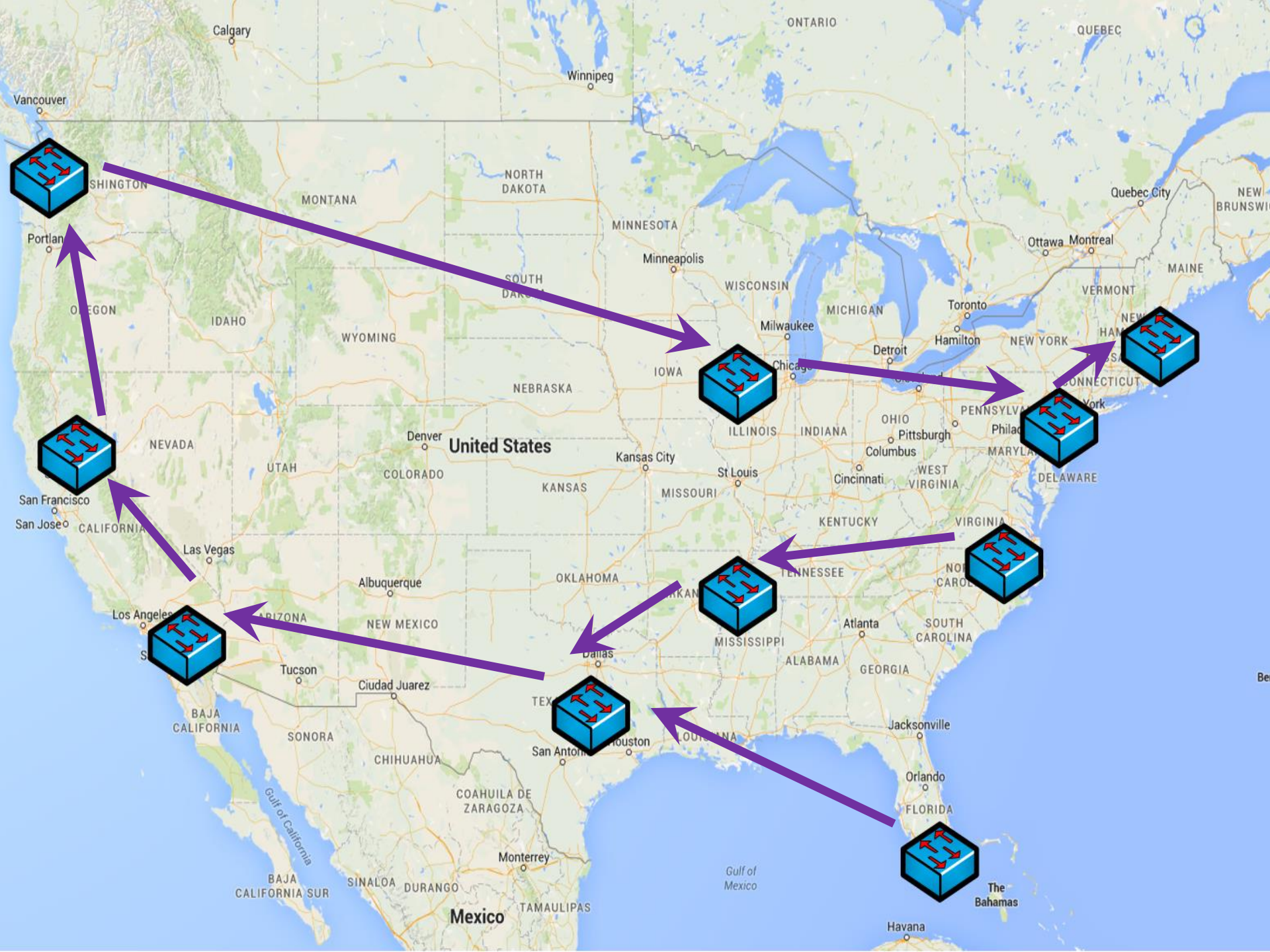
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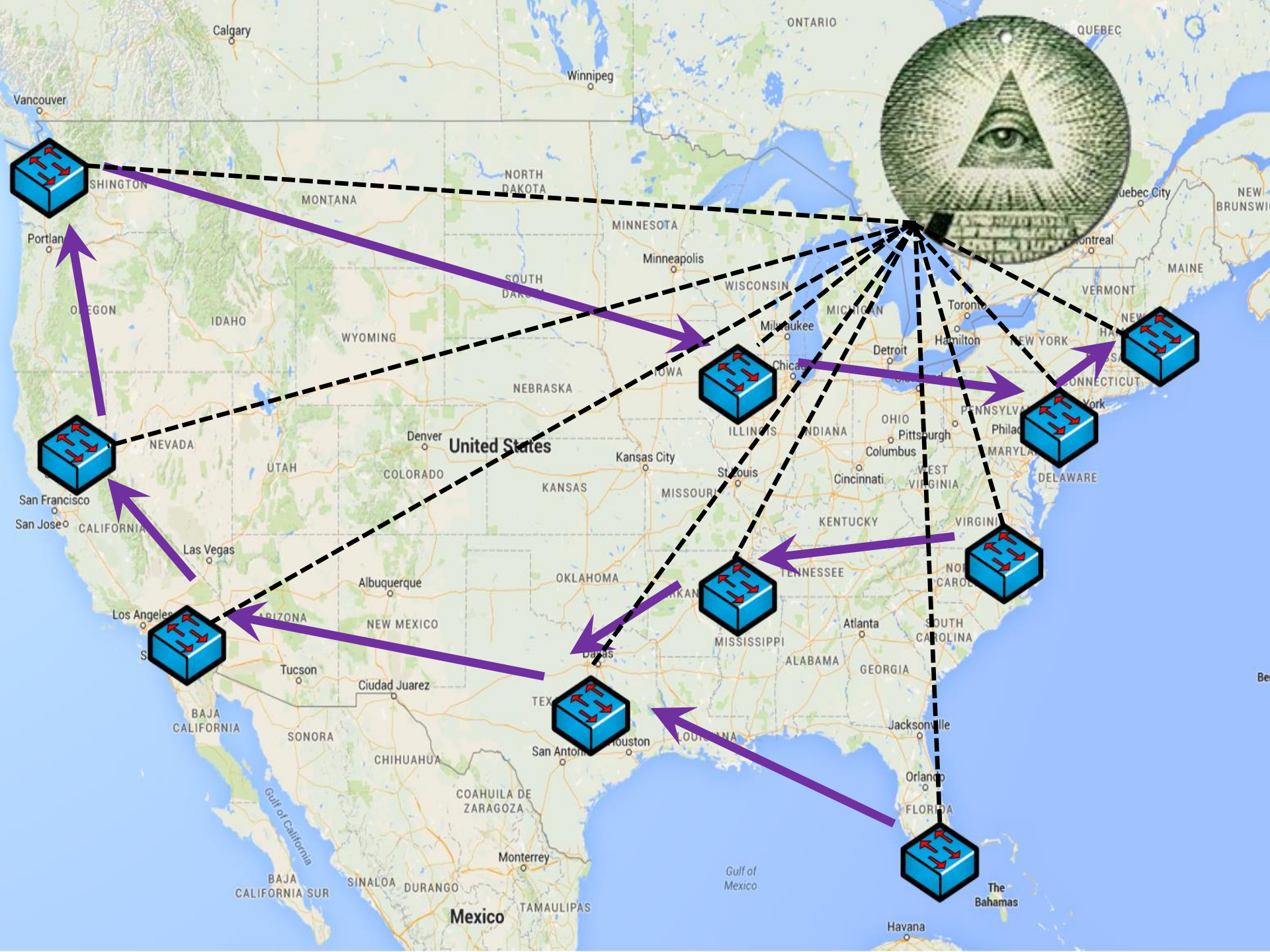
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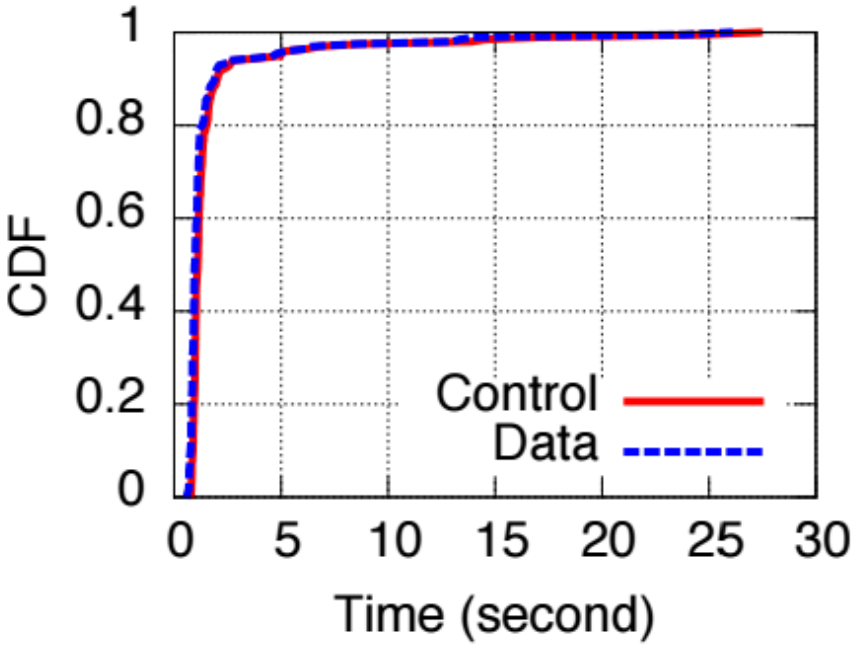
Appears in Practice



"*some switches can '**straggle**,' taking substantially **more time** than average (e.g., 10-**100x**) to apply an update*"
Jin et al., SIGCOMM 2014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“Tree Ordering”

“Tree Ordering”

"Tree Ordering"

“Tree Ordering”

Software-Defined Networking

Centralized controller updates networks rules for optimization

Controller (*control plane*) updates the switches/routers (*data plane*)

old network rules

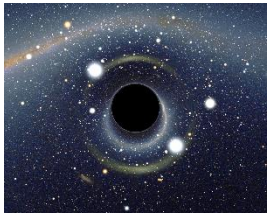
network updates

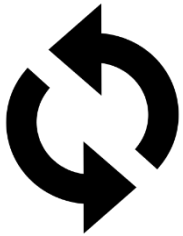
new network rules

old network rules

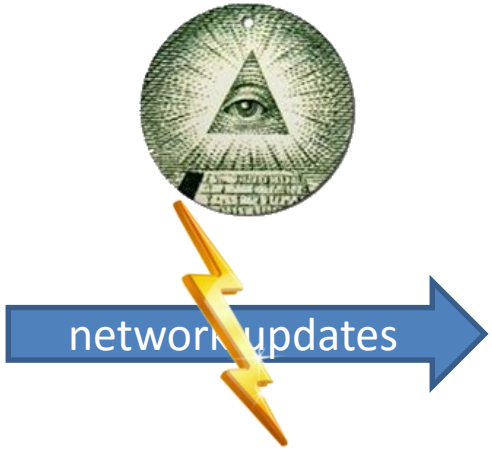
network updates

new network rules





old network rules

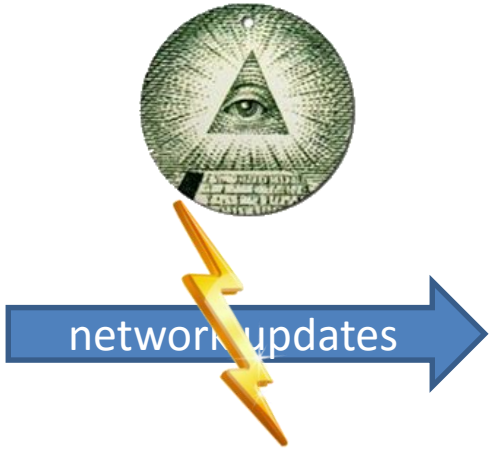


new network rules

possible solution: be fast!

e.g., B4 [Jain et al., 2013]

old network rules



new network rules

possible solution: be consistent!

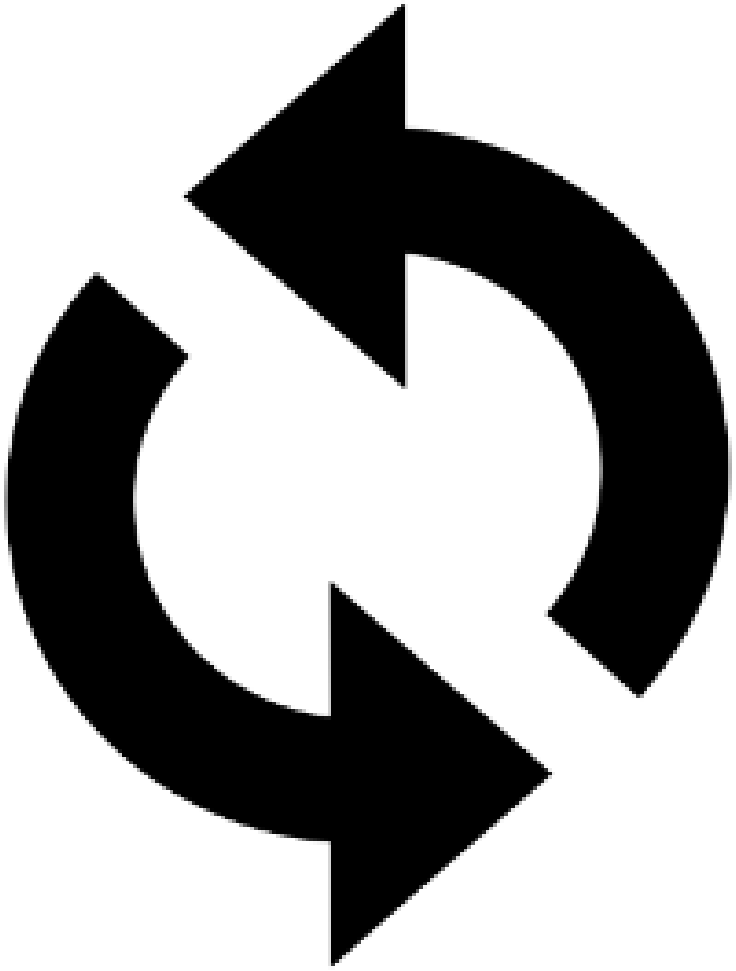
e.g.,

- per-router ordering [Vanbever et al., 2012]
- two phase commit [Reitblatt et al., 2012]
- SWAN [Hong et al., 2013]
- Dionysus [Jin et al., 2014]
- ….

old network rules

new network rules

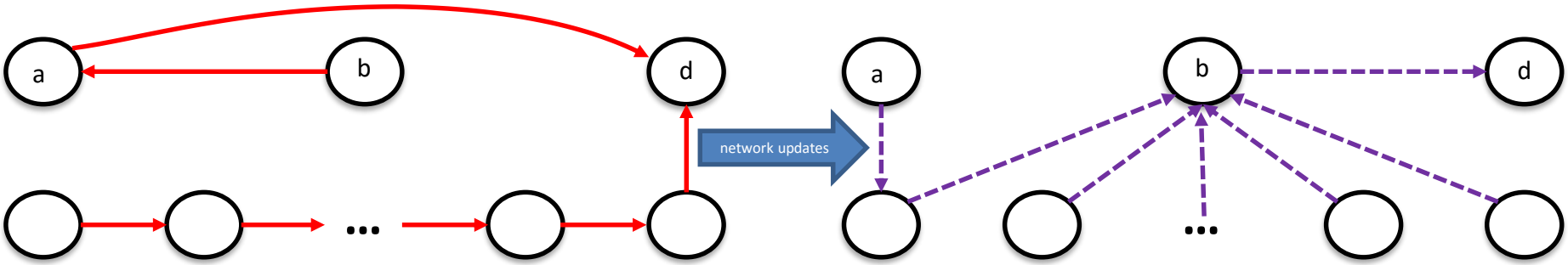
possible solution: be consistent!



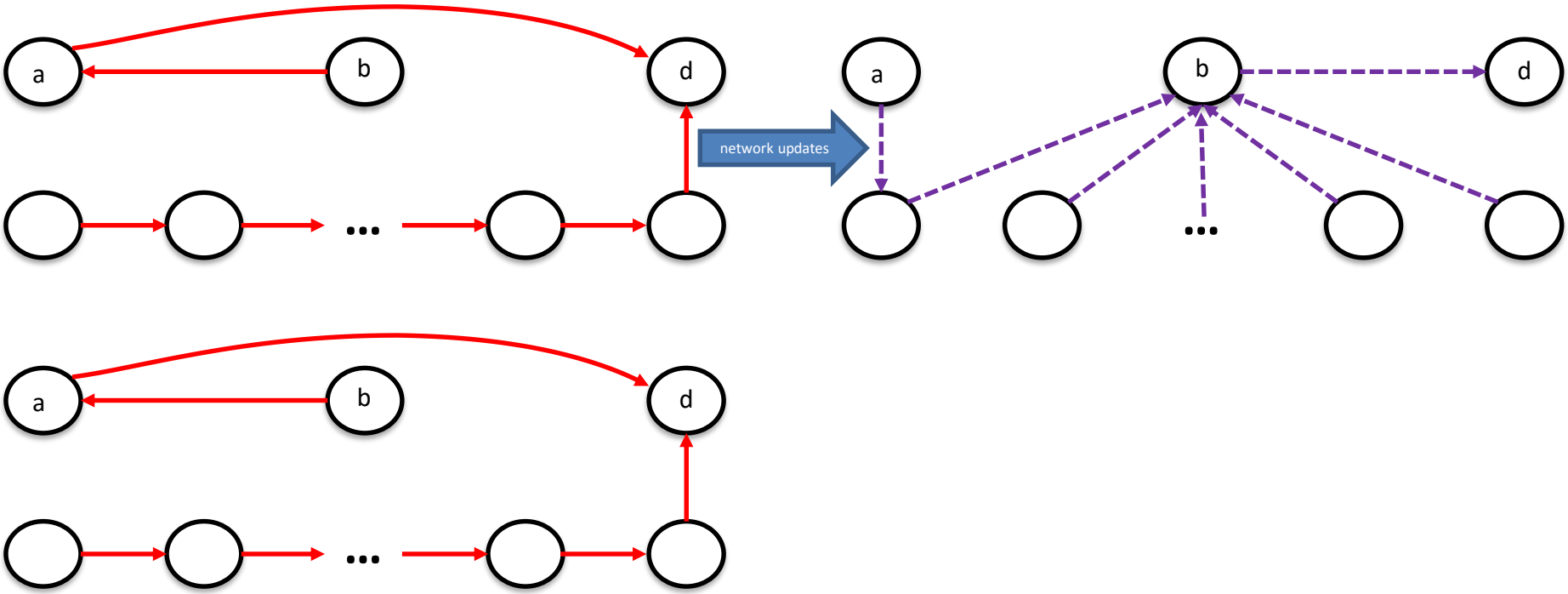
Dynamic Updates

Idea: Update as many edges as you can

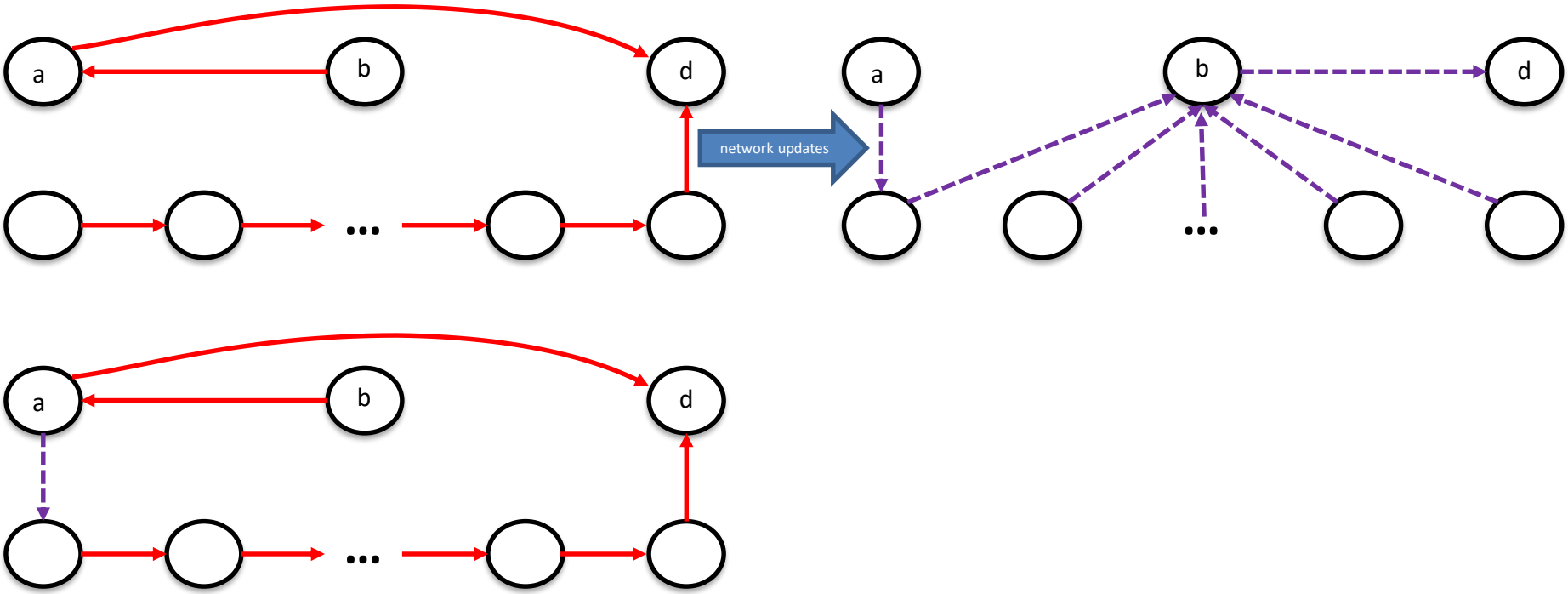
Dynamic Updates



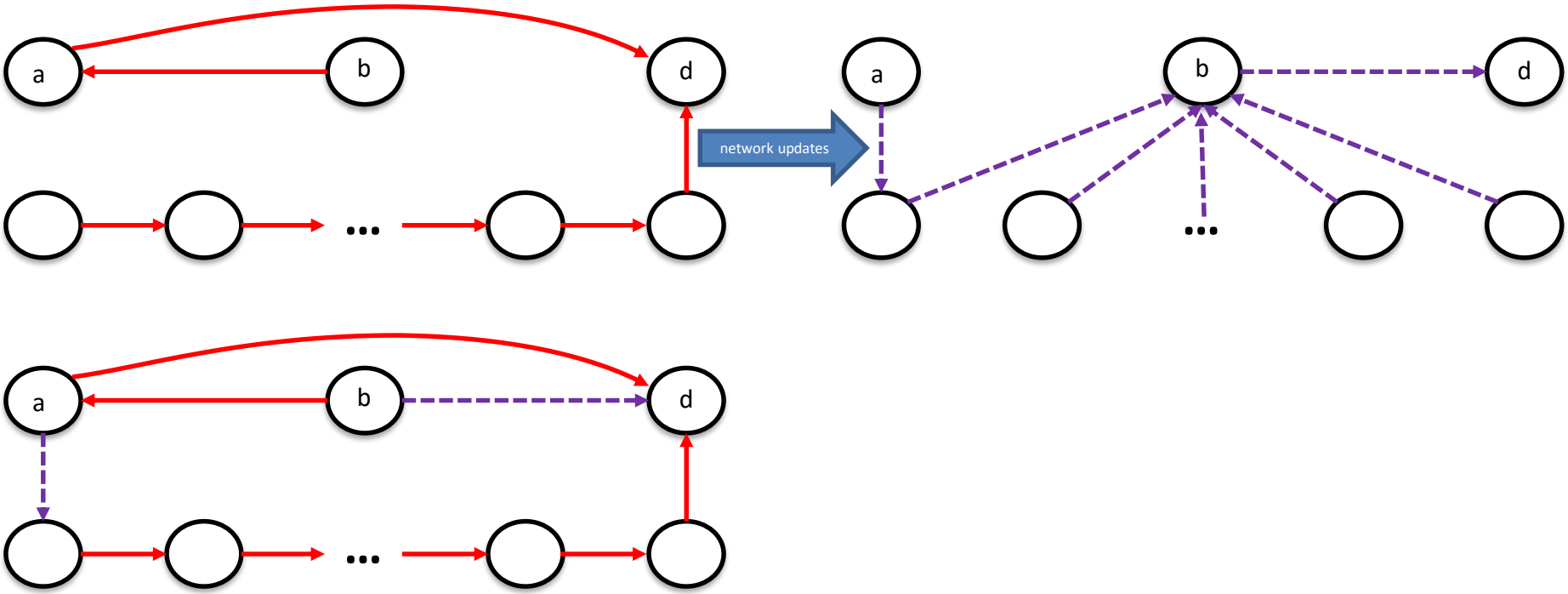
Dynamic Updates



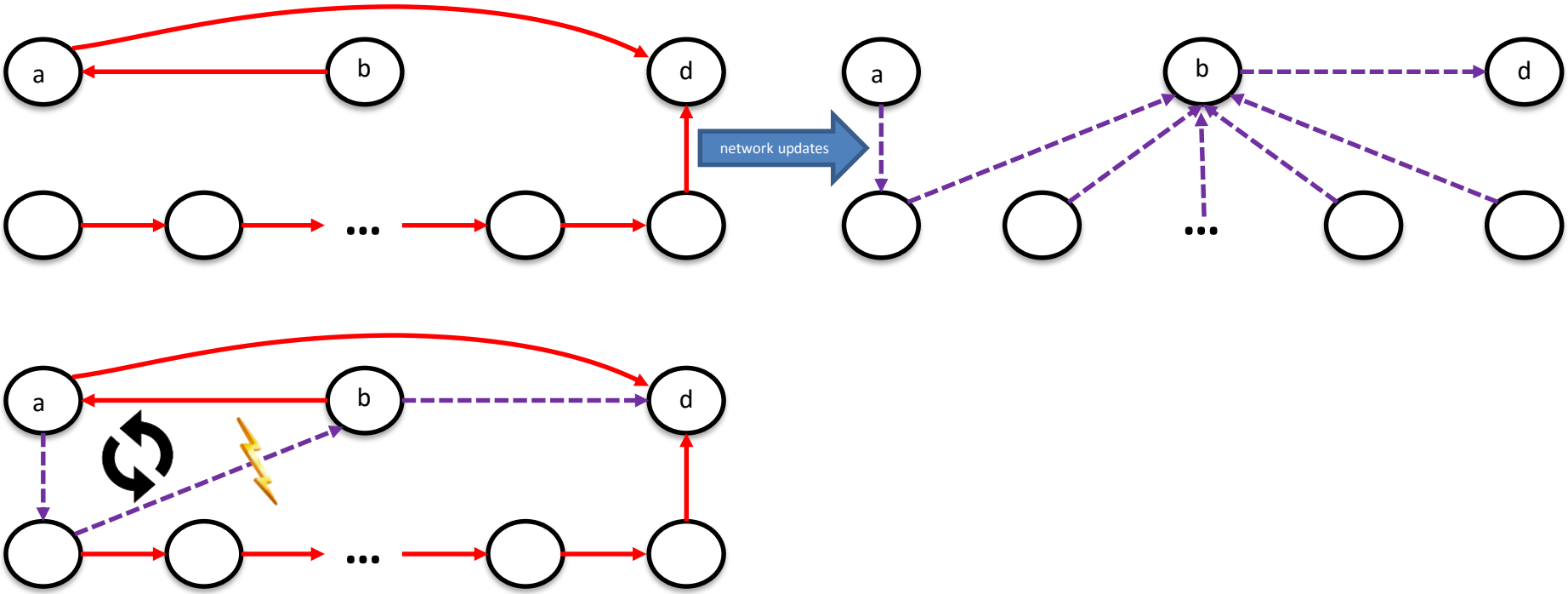
Dynamic Updates



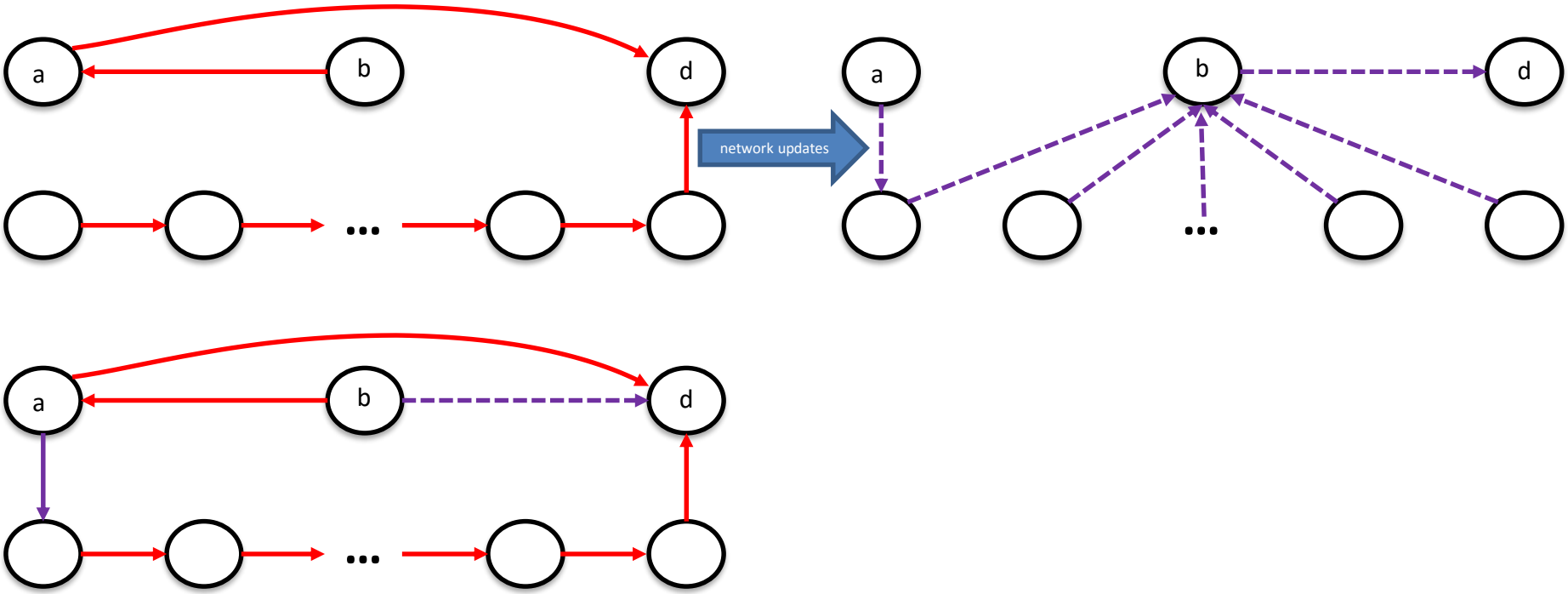
Dynamic Updates



Dynamic Updates

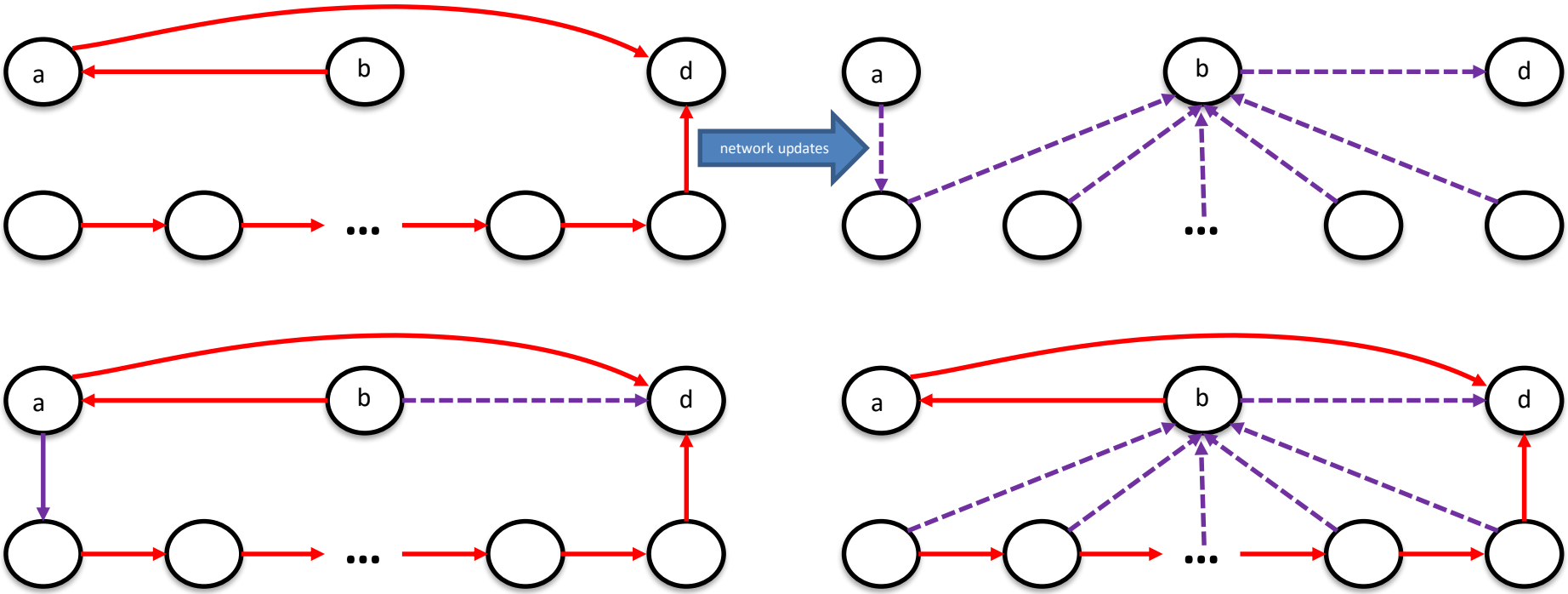


Dynamic Updates



greedy **maximum** update
a & b update → all others wait
2 nodes update

Dynamic Updates



greedy **maximum** update
a & b update → all others wait
2 nodes update

maximal update
a waits→ all others update
all but 1 update

Find maximal update?

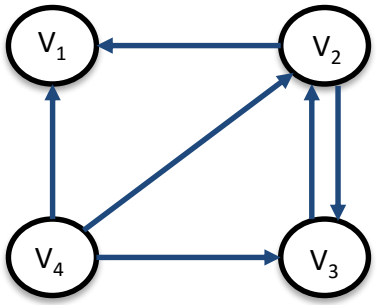
- Let’s go more general

Find maximal update?

- Let’s go more general
- Delete all cycles in a graph

Find maximal update?

- Let's go more general
- Delete all cycles in a graph



Find maximal update?

- Let’s go more general
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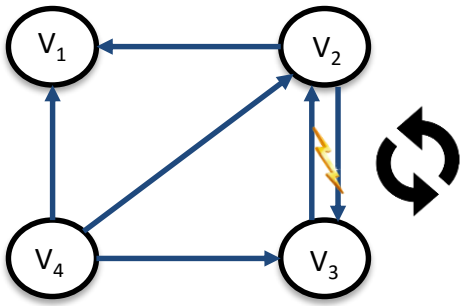
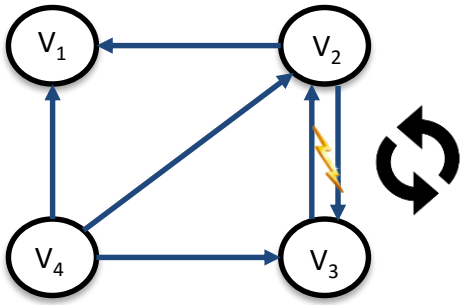


Find maximal update?

- Let's go more general
- Delete all cycles in a graph
- **NP-hard** to approximate
  - *Feedback Arc Set*



Find maximal update?

- Let's go more general
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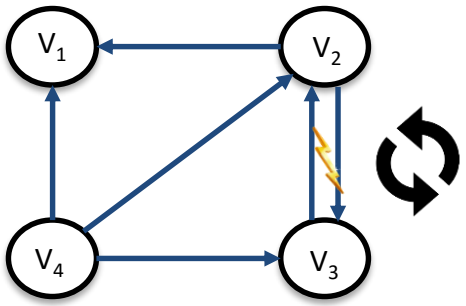
- And it's equivalent ☹



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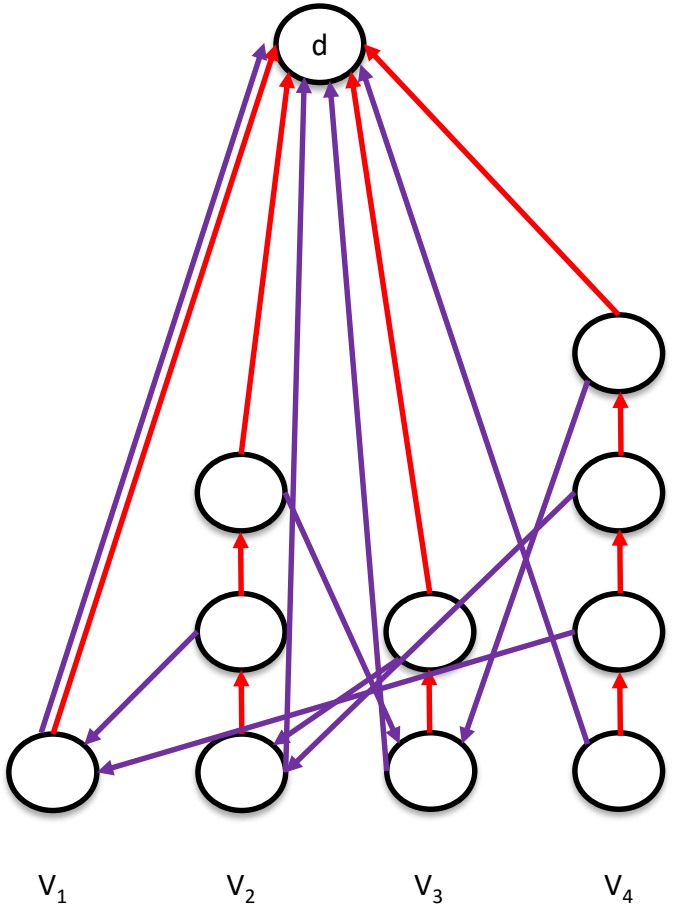

Find maximal update?

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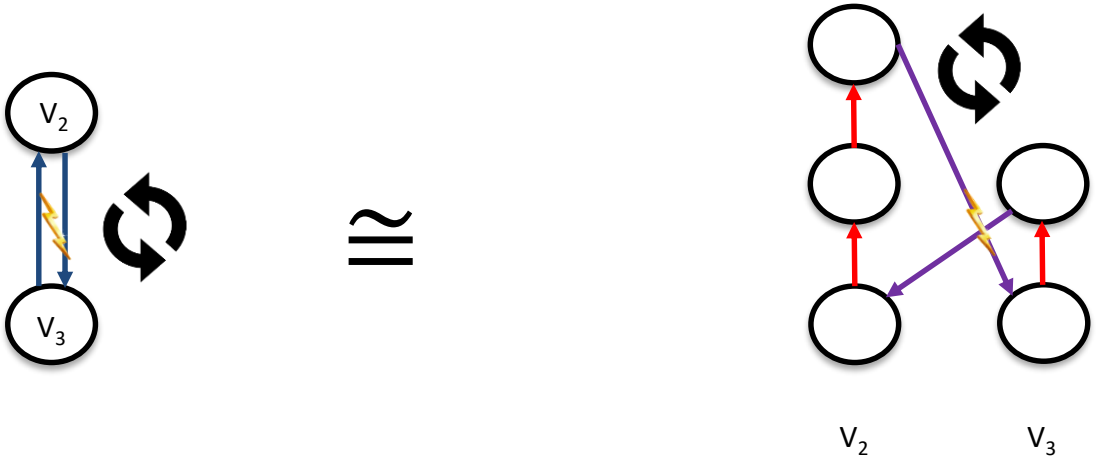

Dynamic Updates

Maximize #edges updated $\approx$ Feedback Arc Set

$\Rightarrow$ Approximate within $O(\log n \log\log n)$

Better approximation bound for Feedback Arc?

$\Rightarrow$ Implies better bound for #edges

Scheduling Updates

But how long until all edges updated?

Scheduling Updates

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- Ludwig et al. (2015): NP-hard for 3-schedule

Scheduling Updates

But how long until all edges updated?

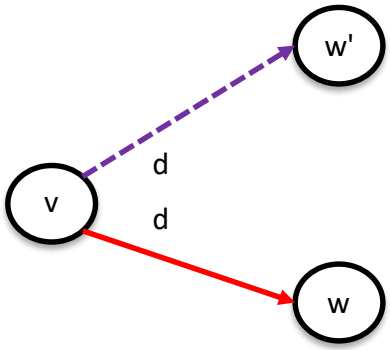
- Ludwig et al. (2015): NP-hard for 3-schedule

Our result (with 2 destinations)

- NP-hard for any sublinear schedule

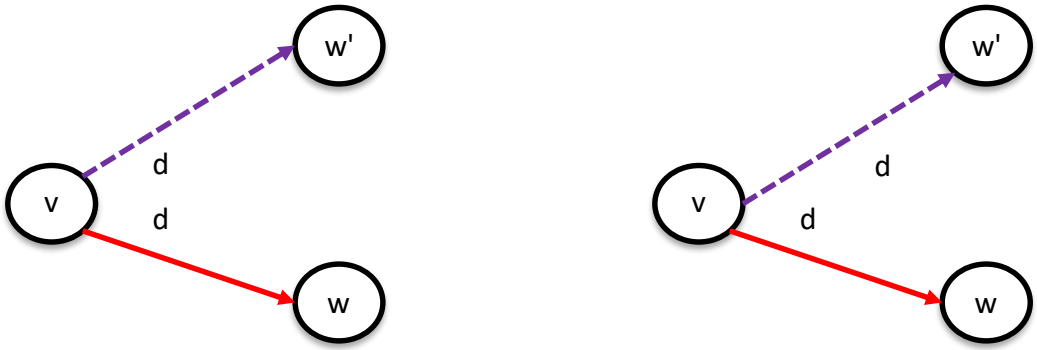
Scheduling Updates

Idea: Delay updates



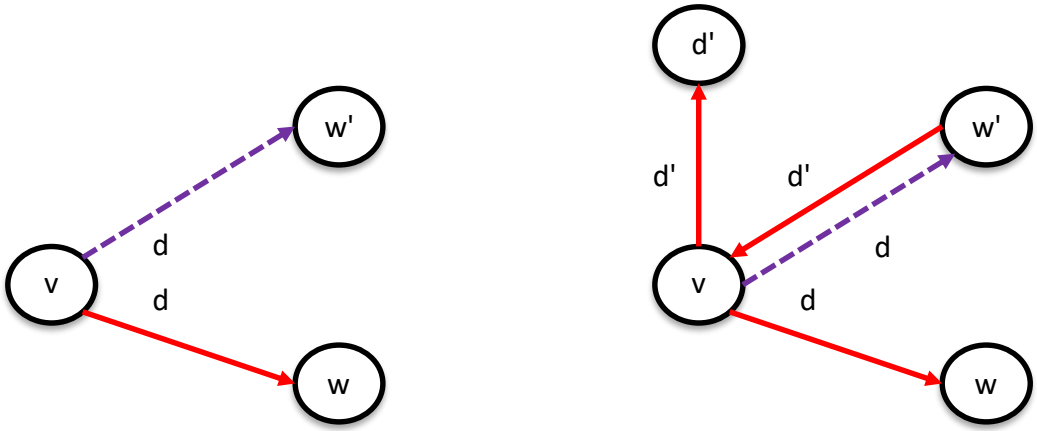
Scheduling Updates

Idea: Delay updates



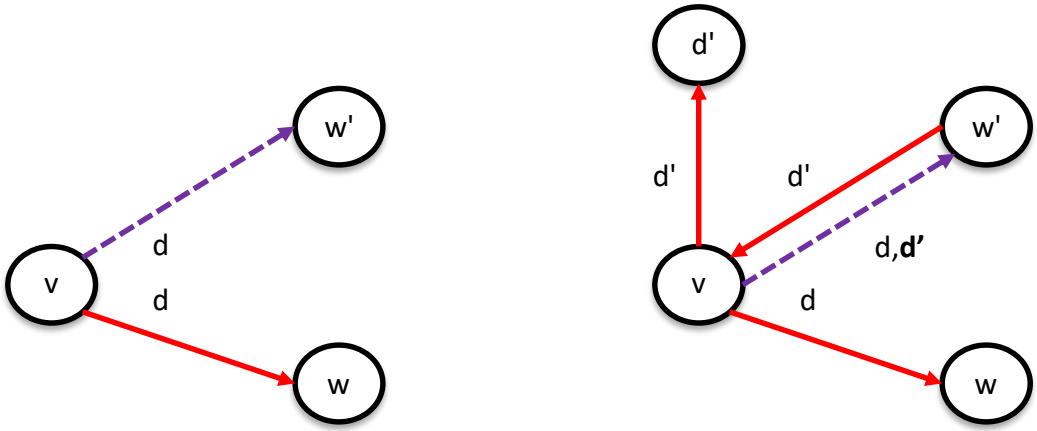
Scheduling Updates

Idea: Delay updates



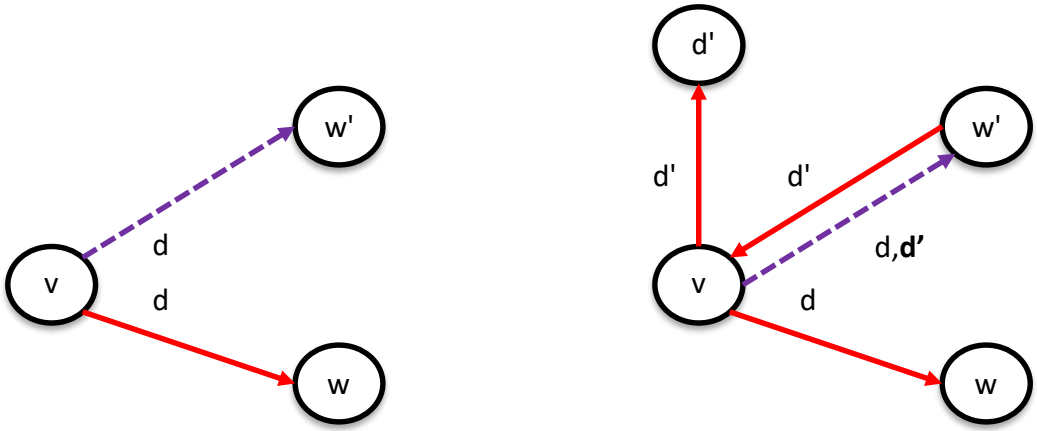
Scheduling Updates

Idea: Delay updates



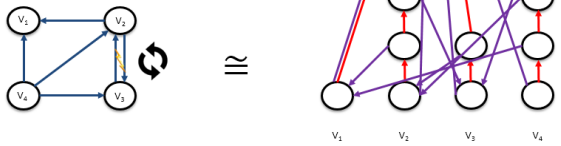
Scheduling Updates

Iterate over and over and over….

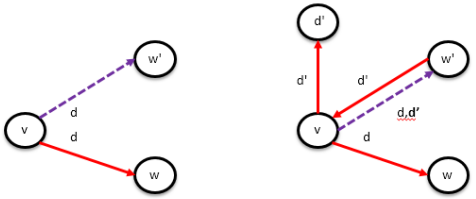


Loop Freedom Overview

- Maximize updated #edges per update
  - NP-hard

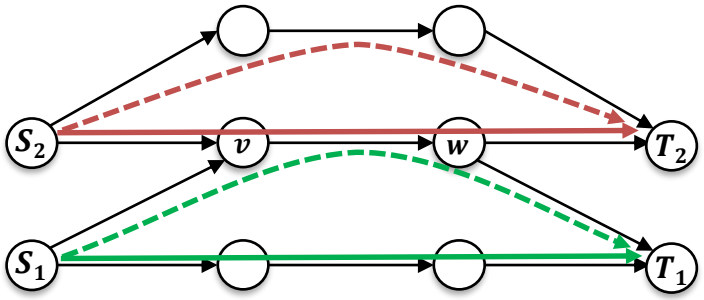


- Sublinear schedule checking for 2 destinations
  - NP-hard

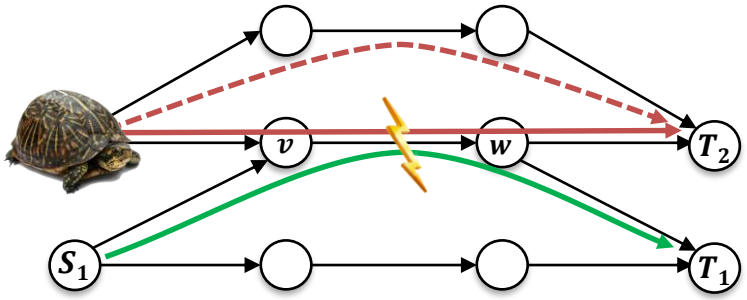



CONGESTION
AHEAD
NEXT 20
YEARS

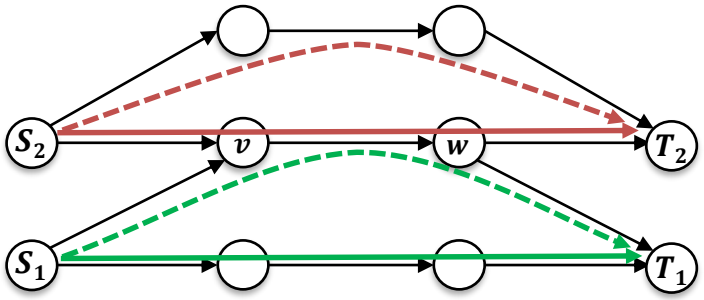
How to Move Flows?



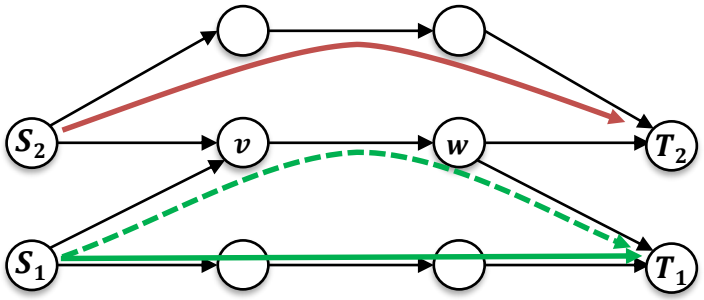
How to Move Flows?



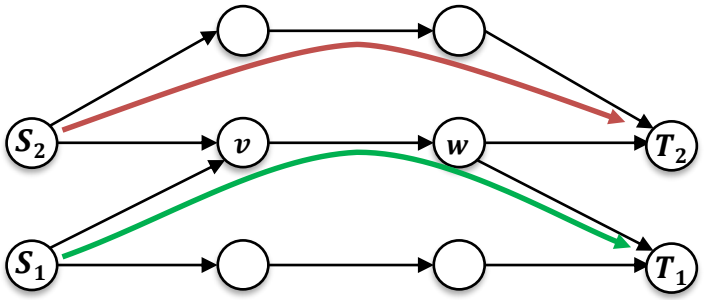
How to Move Flows?



How to Move Flows?



How to Move Flows?



How Hard in General w/o Splitting?

- Previous work: **Fastest** Migration is NP-hard

How Hard in General w/o Splitting?

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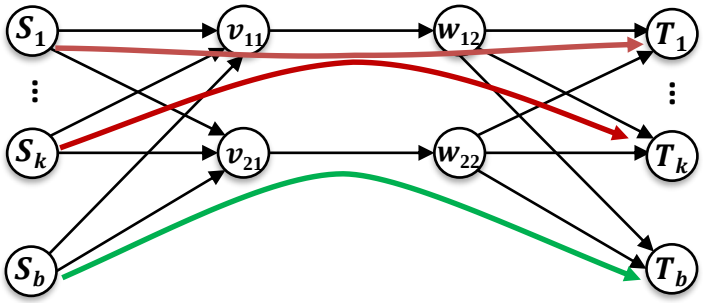
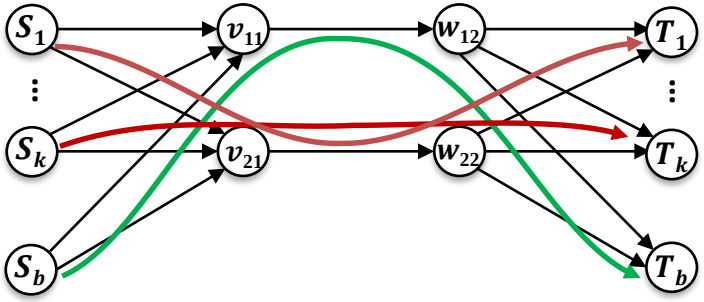
- Our work: **Deciding** is NP-hard

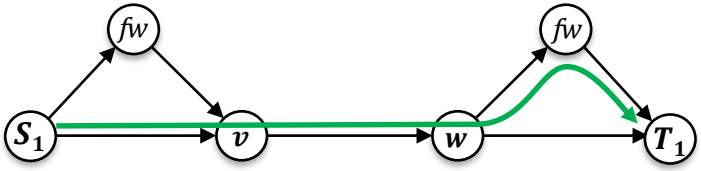
How Hard in General w/o Splitting?

- Previous work: **Fastest** Migration is NP-hard
- Our work: **Deciding** is NP-hard
  - Reduction from Partition

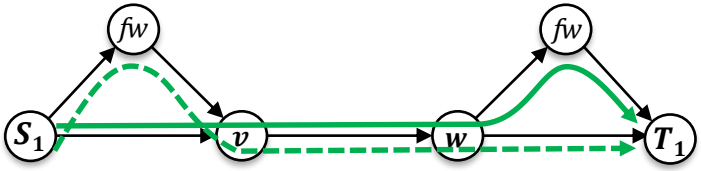




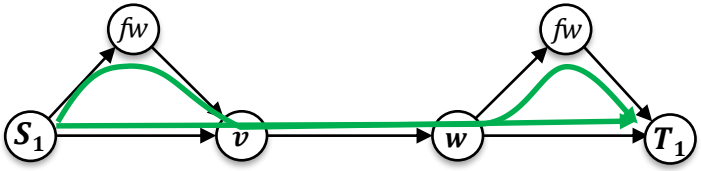
Issues with Splitting



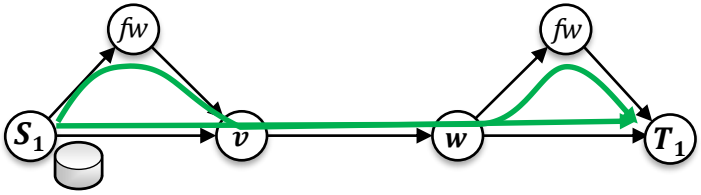
Issues with Splitting



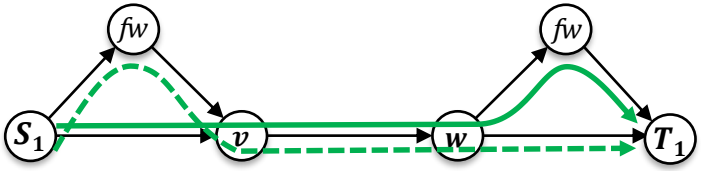
Issues with Splitting



Packets bypass Waypoints!



2-Splittable Flows



- Keep both flow paths at the same time
- Easy updates: Change allocations @sources

High-Level Algorithm Idea

- Establish new paths at size 0

High-Level Algorithm Idea

- Establish new paths at size 0
- Only if >0 for all paths can be obtained:
  - Consistent migration possible

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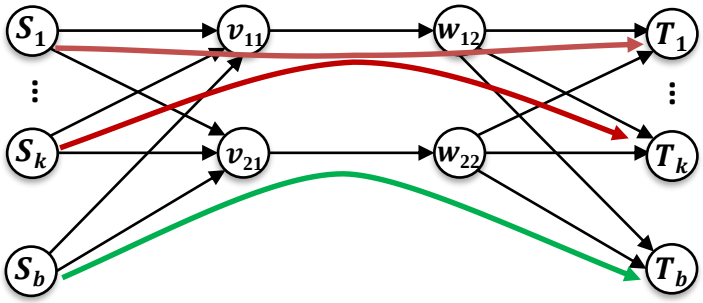
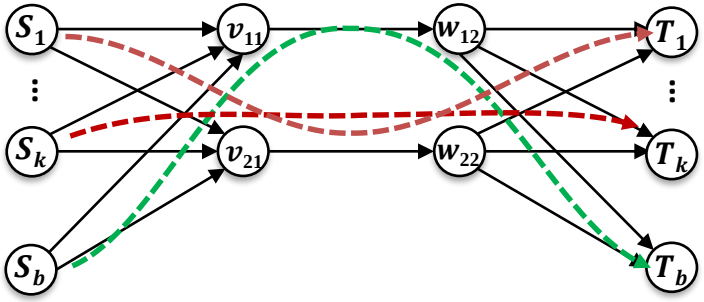
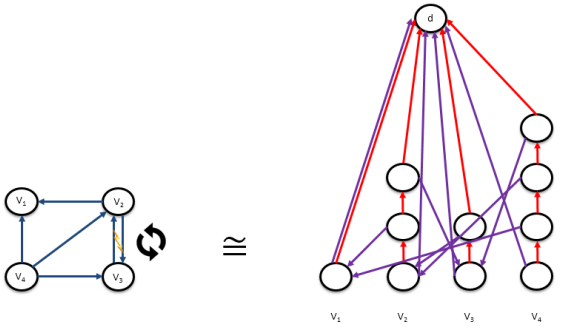
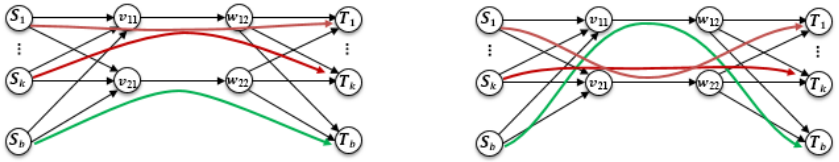




Summary


d
v1
v2
v3
v4


S1
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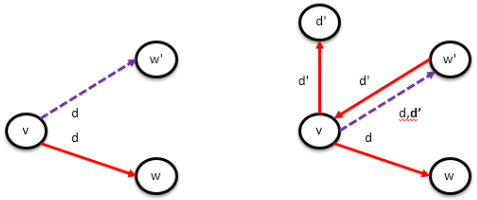
w12
w22
T1
Tk
Tb


w'
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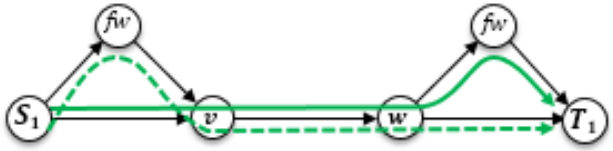
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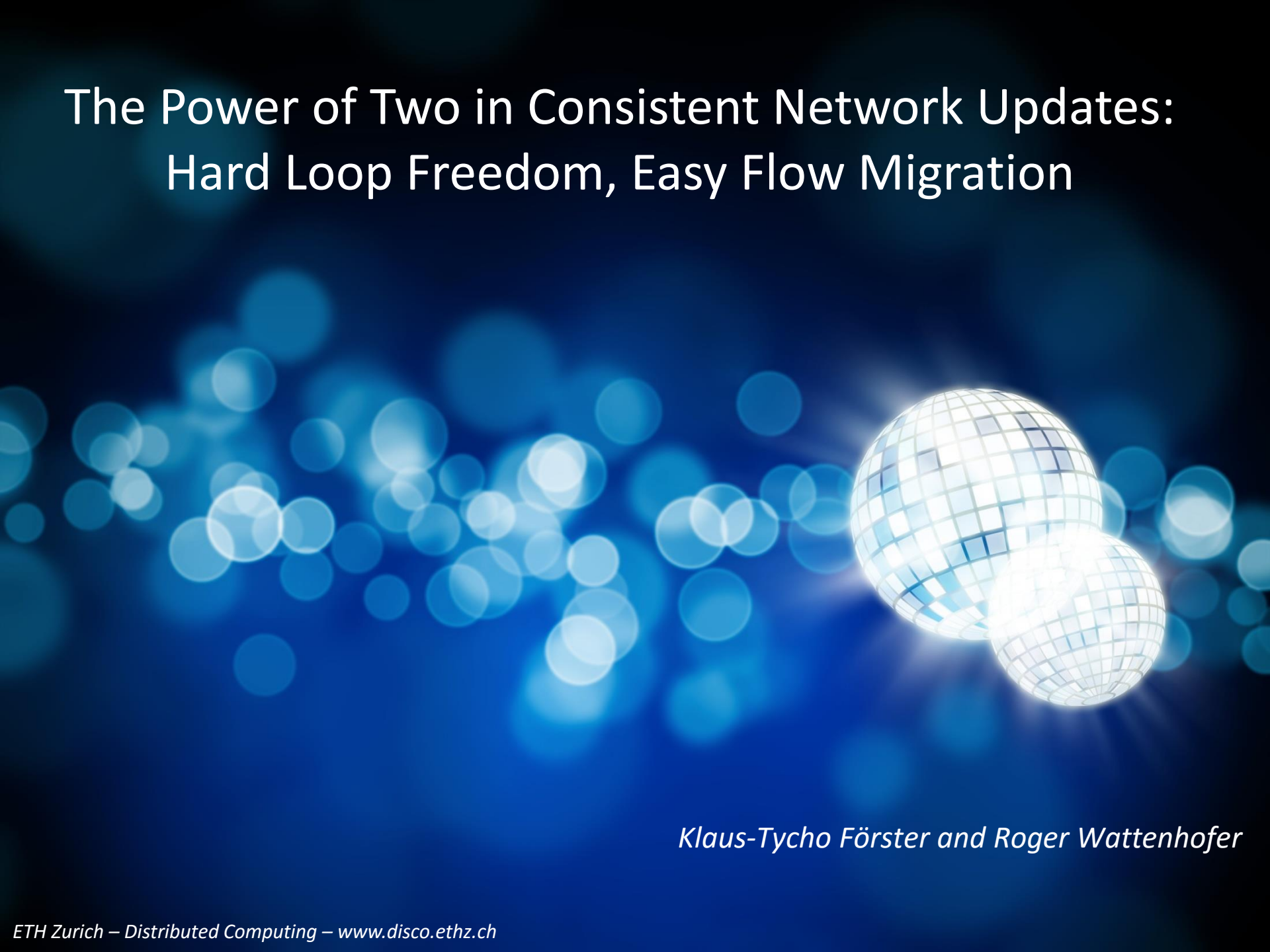
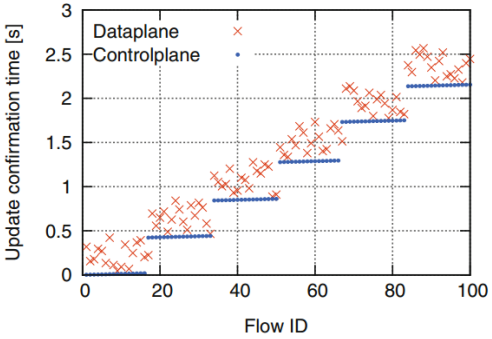
The Power of Two in Consistent Network Updates: Hard Loop Freedom, Easy Flow Migration



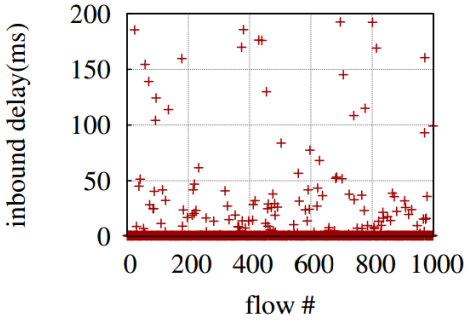
Klaus-Tycho Förster and Roger Wattenhofer

ETH Zurich – Distributed Computing – www.disco.ethz.ch

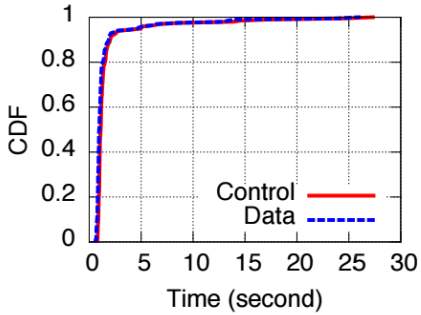
Appears in Practice



"*Data plane **updates may fall behind** the control plane acknowledgments and may be even **reordered**.*"
Kuzniar et al., PAM 2015



"*…the inbound latency is **quite variable** with a […] standard deviation of 31.34ms…*"
He et al., SOSR 2015



"*some switches can '**straggle**,' taking substantially **more time** than average (e.g., 10-**100x**) to apply an update*"
Jin et al., SIGCOMM 2014