Network Updates

Part 3, Chapter 6

Roger Wattenhofer

Overview

- Software-Defined Networking
- Loop-Free Updates
- Consistent Updates
- Bandwidth
  - Maximization
  - Fairness
  - Updates

Network Updates

- The Internet: Designed for selfish participants
  - Often inefficient (low utilization of links), but robust

- But what happens if the WAN is controlled by a single entity?
  - Examples: Microsoft & Amazon & Google …
  - They spend hundreds of millions of dollars per year

Software-Defined Networking

- Possible solution: **S**oftware-**D**efined **N**etworking (**SDN**s)

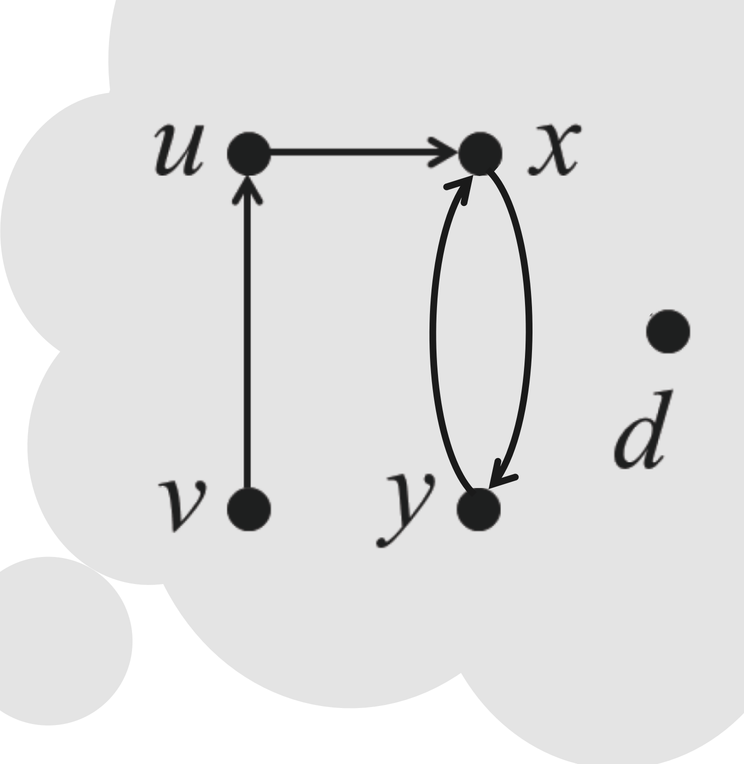
- General Idea: Separate data & control plane in a network
- Centralized controller updates networks rules for optimization
  - Controller (*control plane*) updates the switches/routers (*data plane*)

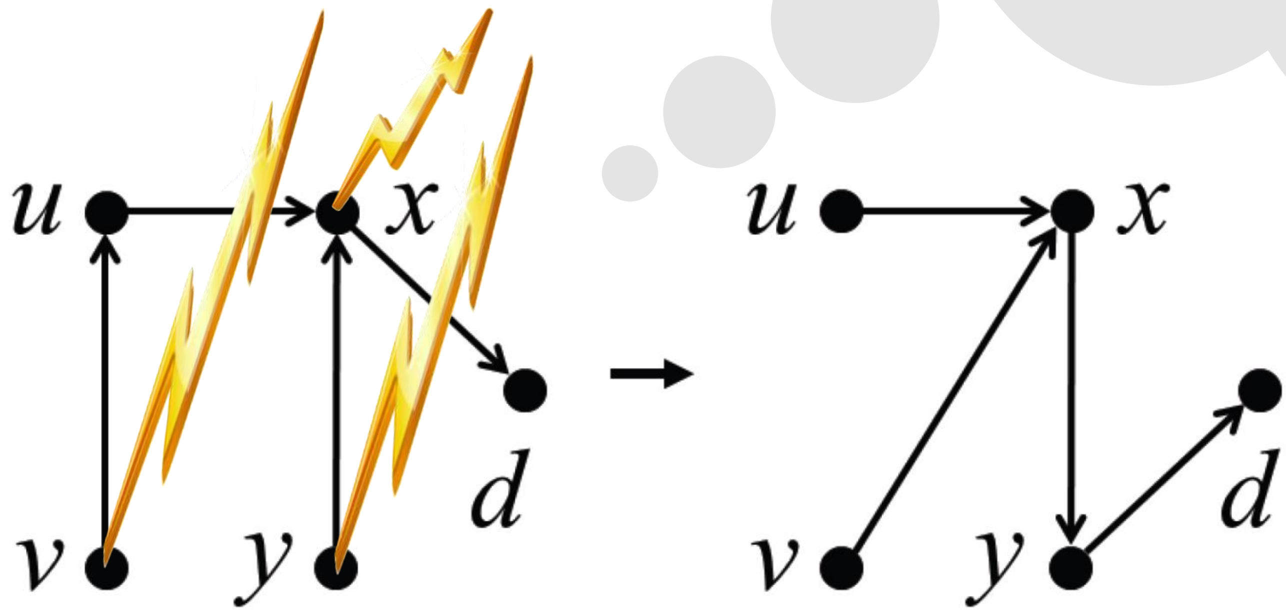
Virtual Services ⟷ Controller ⟷ Physical Network

- Centralized controller implemented with replication, e.g. Paxos

Example

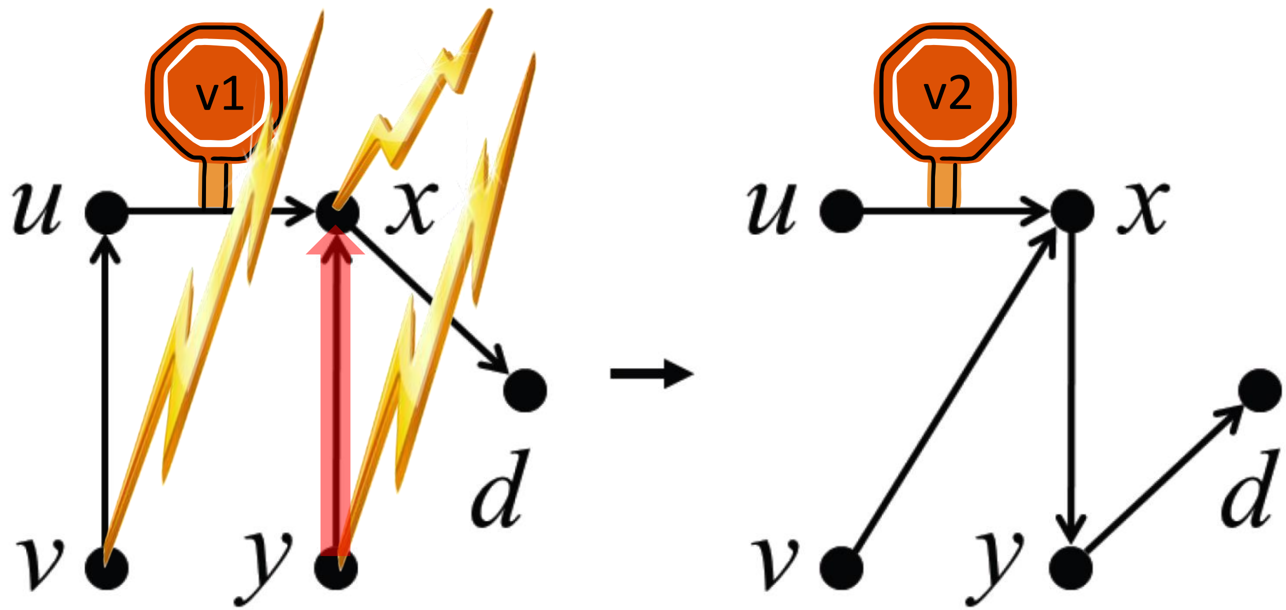
SDN Controller





Example

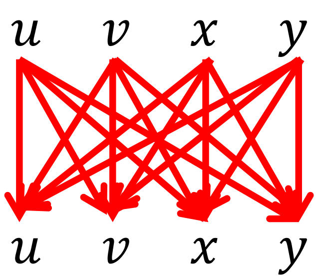
SDN Controller



Dependencies

Version Numbers 

“Better” Solution



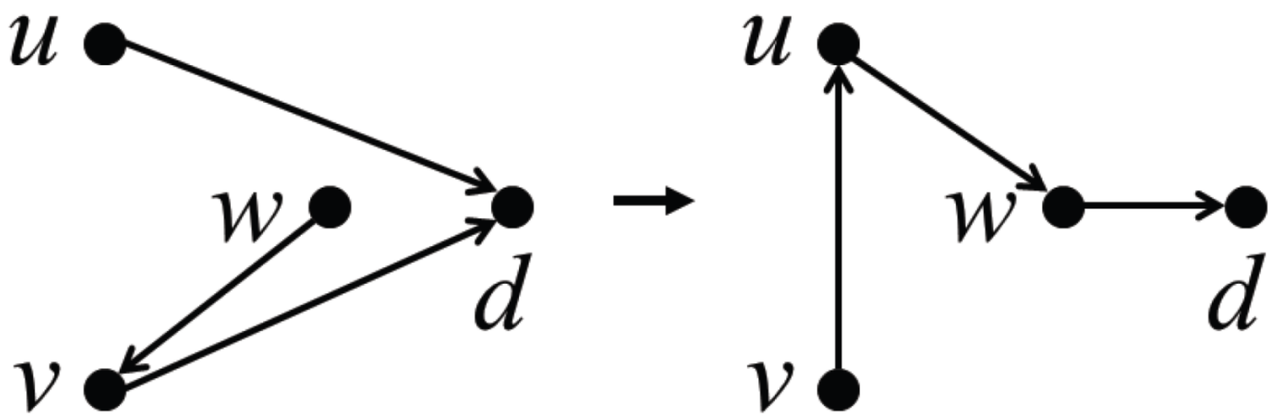
+ stronger packet coherence

– version number in packets

– switches need to store both versions

Minimum SDN Updates?

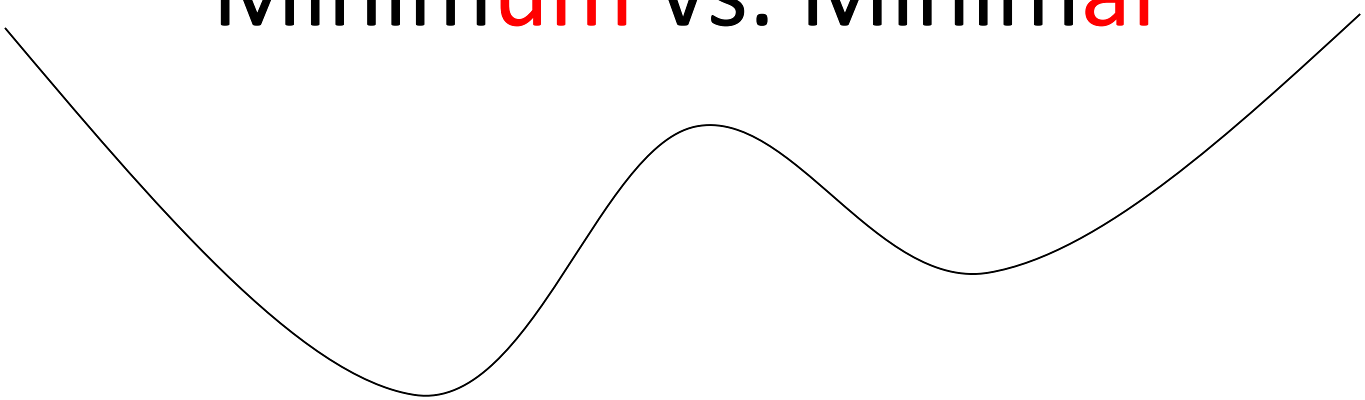
Minimum Updates: Another Example



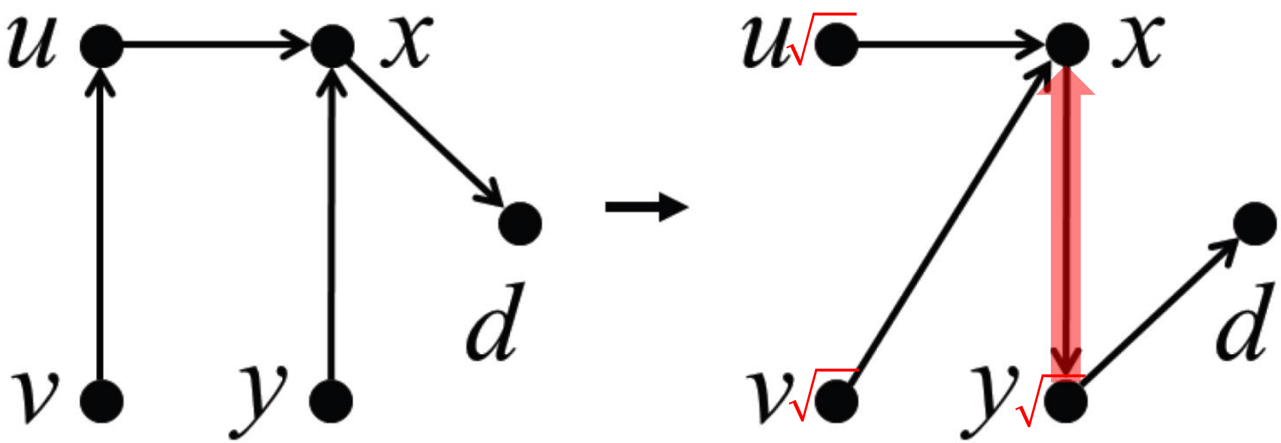
$w \downarrow u$ *or* $w \downarrow v$

No node can improve without hurting another node

Minimum vs. Minimal



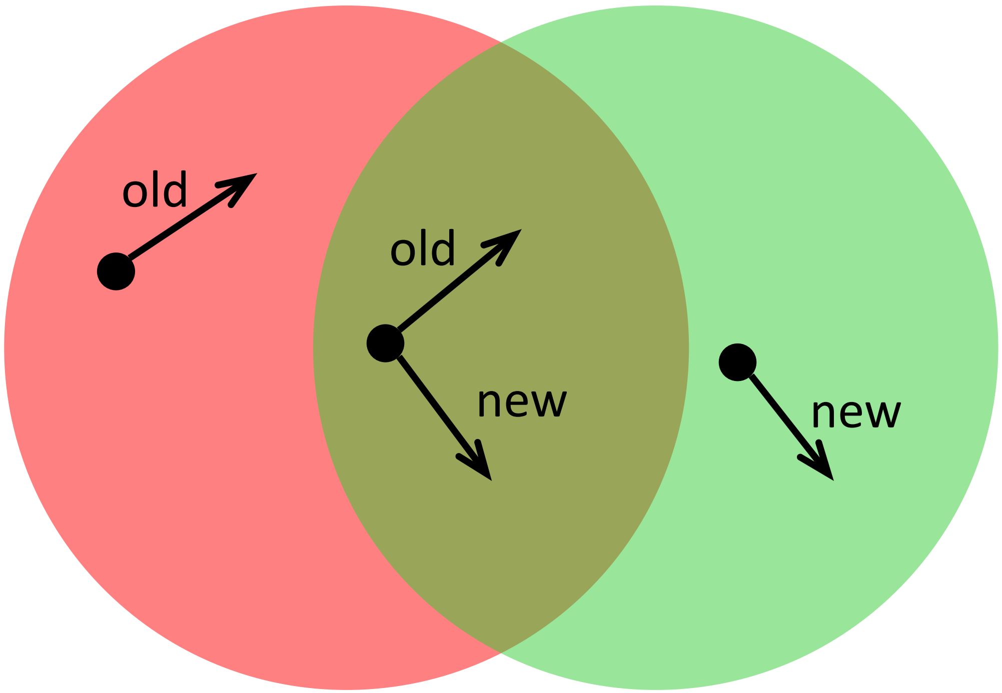
Minimal Dependency Forest



Next: An algorithm to compute minimal dependency forest.

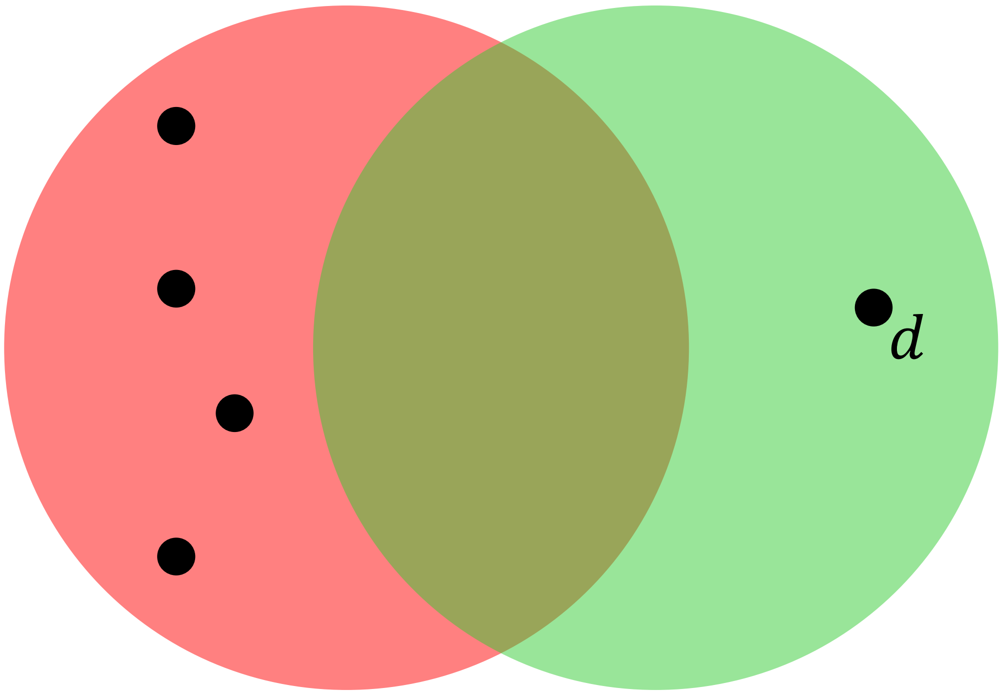
Algorithm for Minimal Dependency Forest

- Each node in one of three states: old, new, and limbo (both old *and* new)



Algorithm for Minimal Dependency Forest

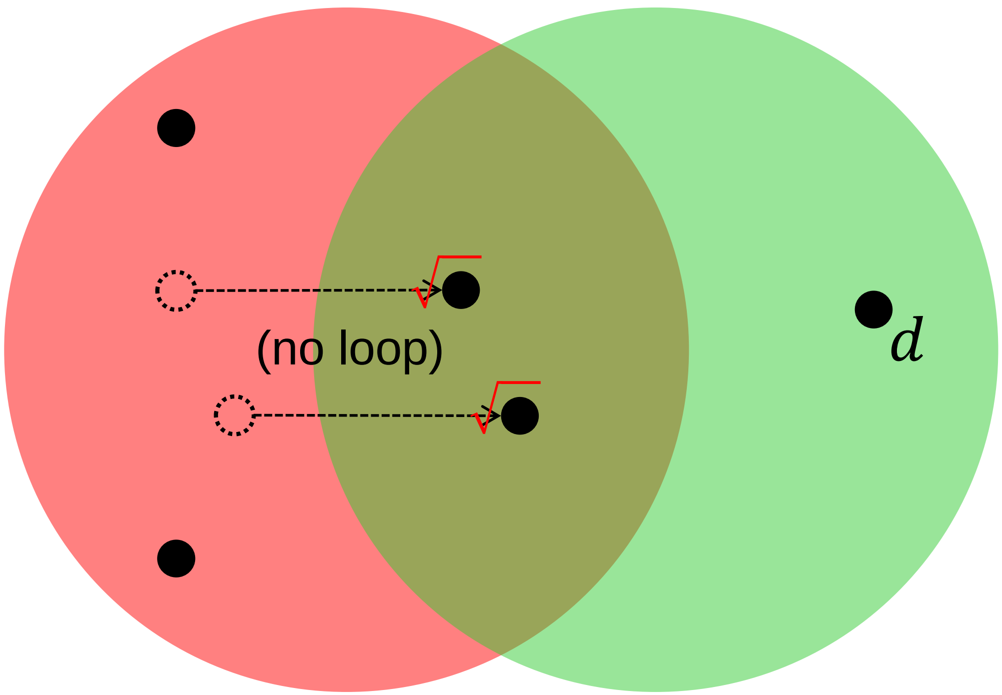
- Each node in one of three states: old, new, and limbo (both old *and* new)
- Originally, destination node in new state, all other nodes in old state
- Invariant: No loop!



Algorithm for Minimal Dependency Forest

Initialization

- Old node u: No loop* when adding new pointer, move node to limbo!
- This node u will be a root in dependency forest



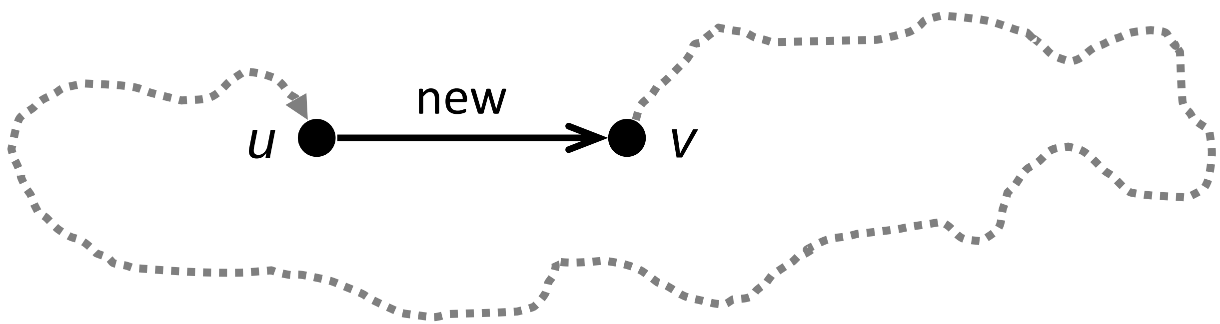
*Loop Detection: Simple procedure, see next slide

Loop Detection

- Will a new rule *u.new = v* induce a loop?

  - We know that the graph so far has no loops
  - Any new loop *must* contain the edge (*u,v*)

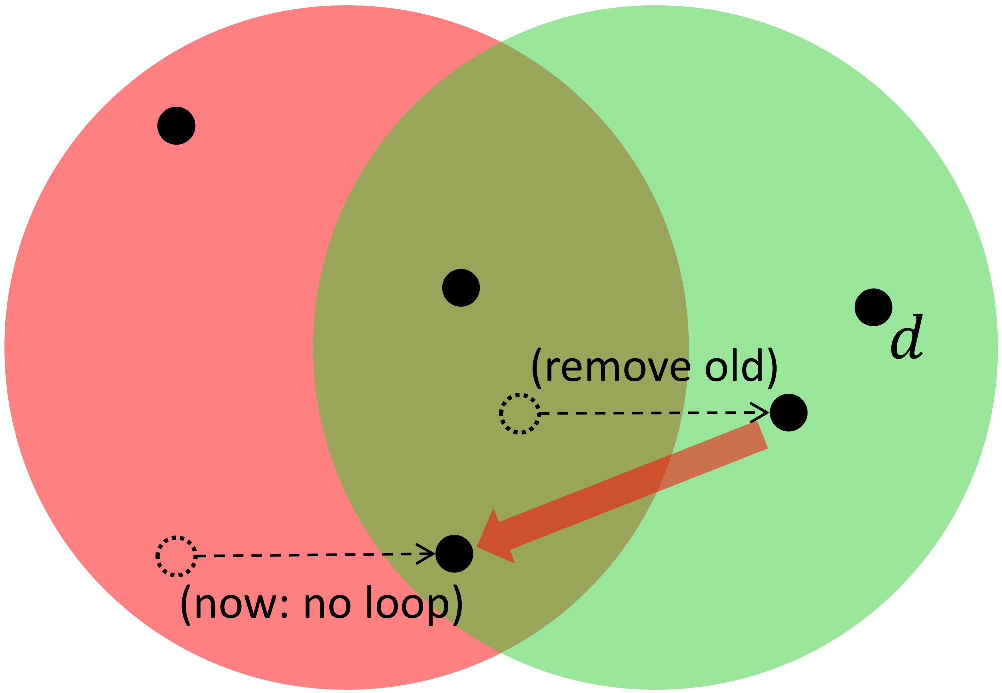
- In other words, is node *u* now *reachable* from node *v*?



- Depth first search (DFS) at node *v*
  - If we visit node *u*: the new rule induces a loop
  - Else: no loop

Algorithm for Minimal Dependency Forest

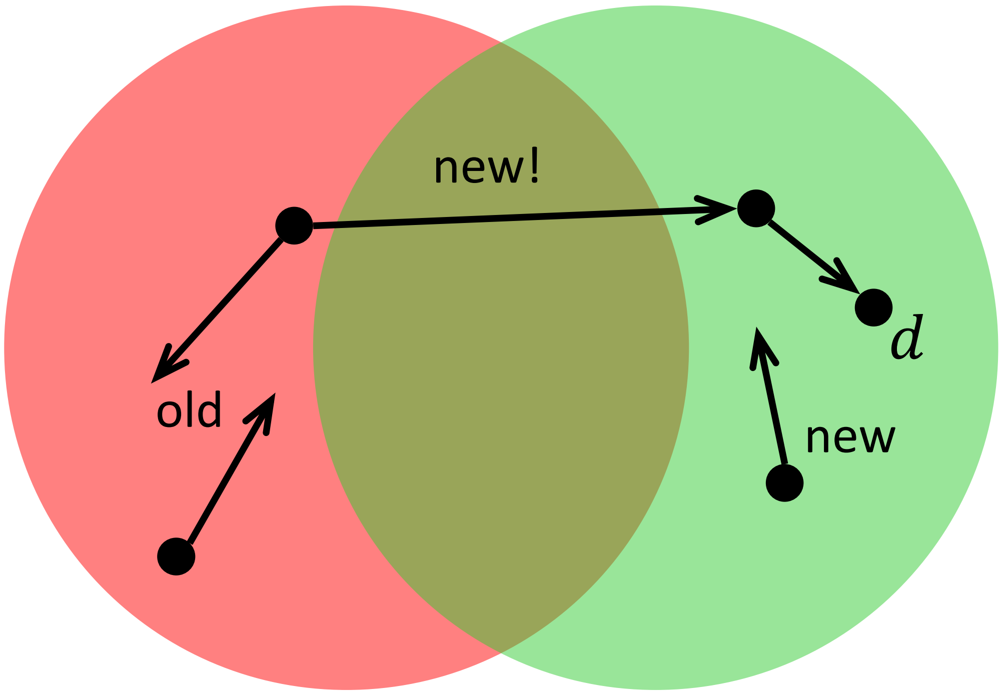
- Limbo node u: Remove old pointer (move node to new)
- Consequence: Some old nodes v might move to limbo!
- Node v will be child of u in dependency forest!



Algorithm for Minimal Dependency Forest

Process terminates

- You can always move a node from limbo to new.
- Can you ever have old nodes but no limbo nodes? No, because…



…one can easily derive a contradiction!

Main Contribution

For a given consistency property, what is the minimal dependency possible?

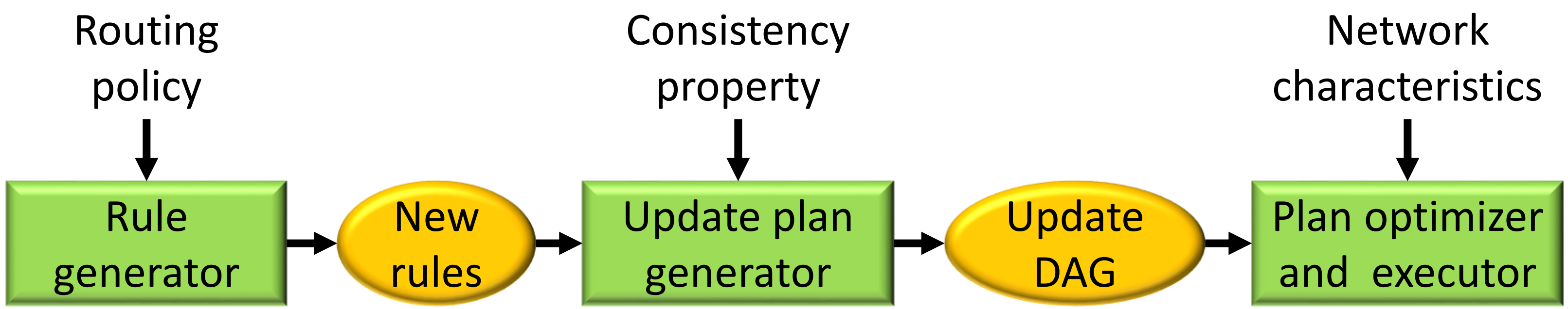
Consistency Space

	None	**Self**	**Downstream subset**	**Downstream all**	**Global**
Eventual consistency	Always guaranteed				
Drop freedom	Impossible	Add before remove			
Memory limit	Impossible	Remove before add			
Loop freedom	Impossible		Rule dep. forest	Rule dep. tree	
Packet coherence	Impossible			Per-flow ver. numbers	Global ver. numbers
Bandwidth limit	Impossible				Staged partial moves

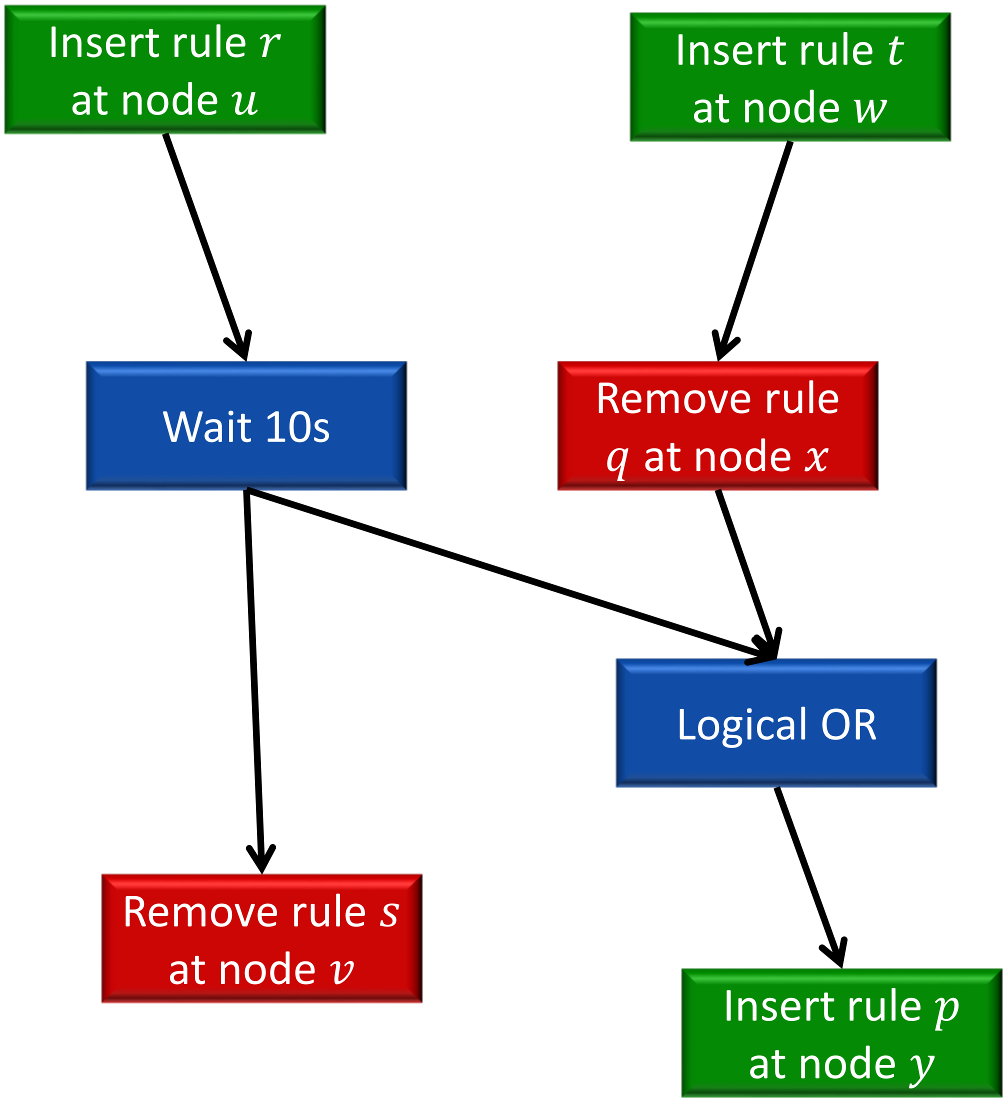
It's *not* just how to compute new rules.

It is also how to gracefully get from current to new configuration, respecting consistency.

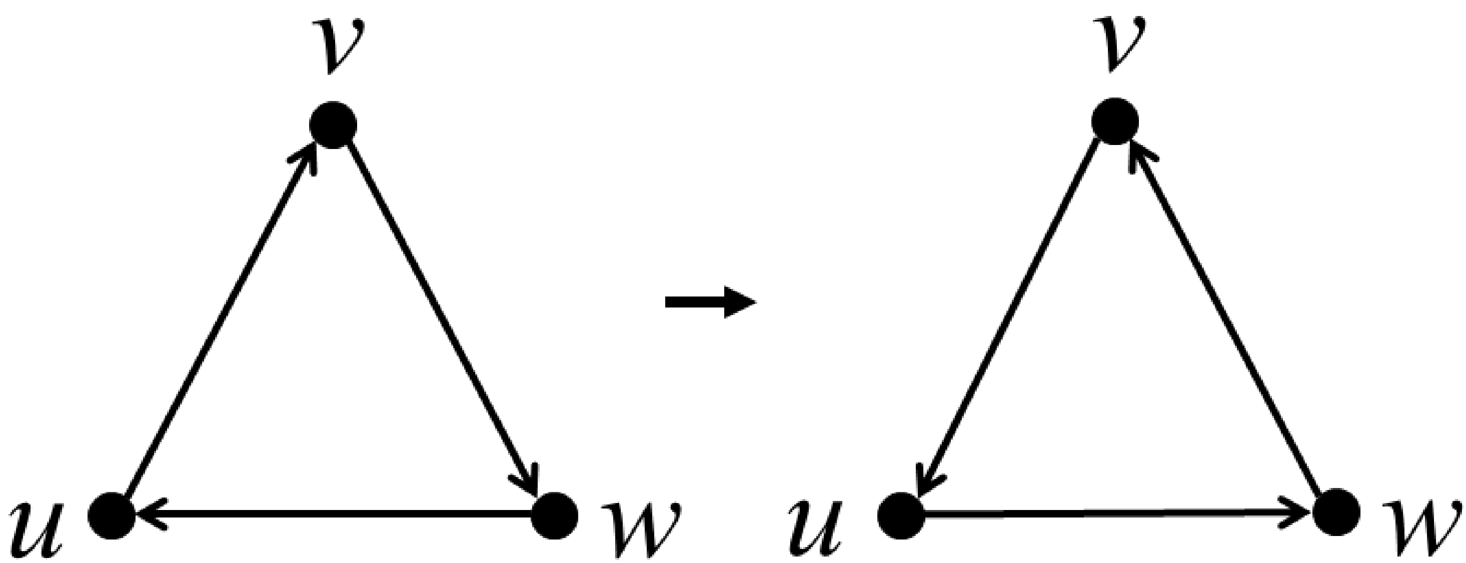
Architecture



Update DAG

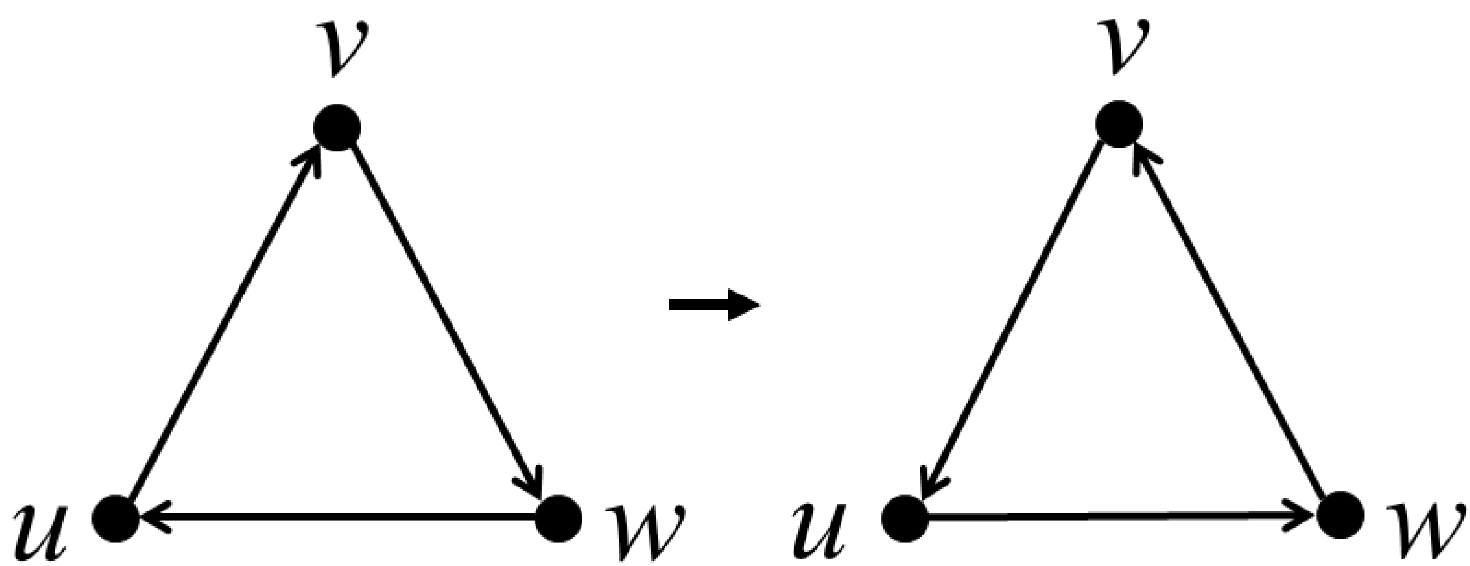

Insert rule r at node u
Insert rule t at node w
Wait 10s
Remove rule q at node x
Logical OR
Remove rule s at node v
Insert rule p at node y

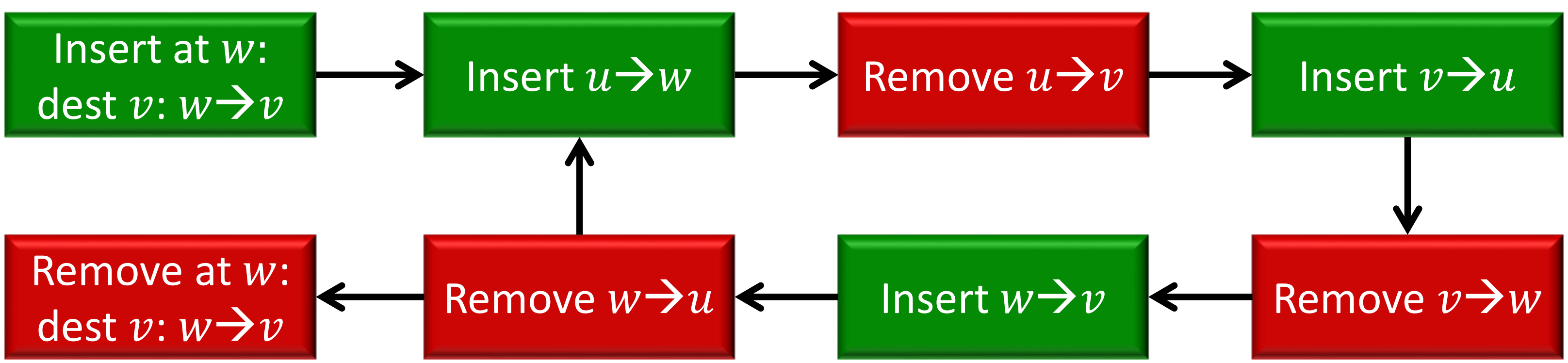
Multiple Destinations using Prefix-Based Routing



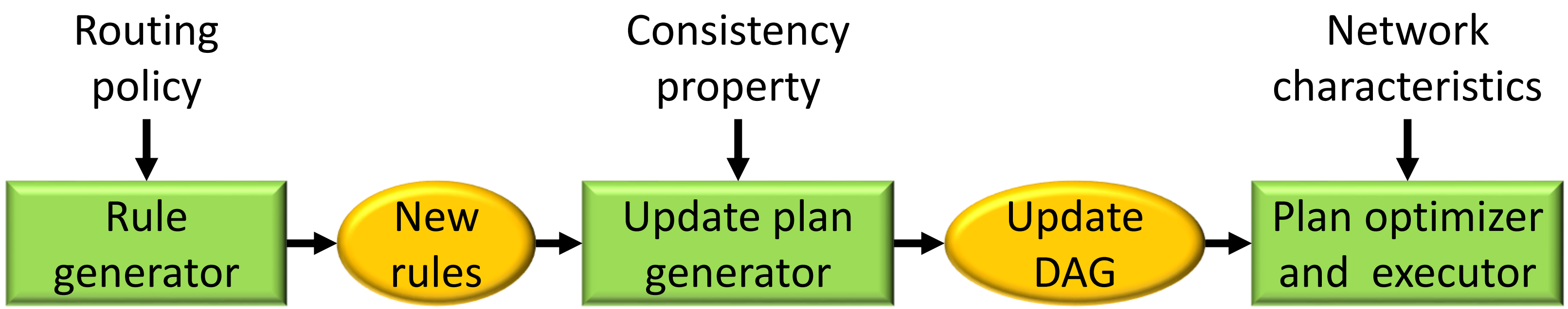
- No new “default” rule can be introduced without causing loops
- Solution: Rule-Dependency Graphs!
- Deciding if simple update schedule exists is hard!

Breaking Cycles

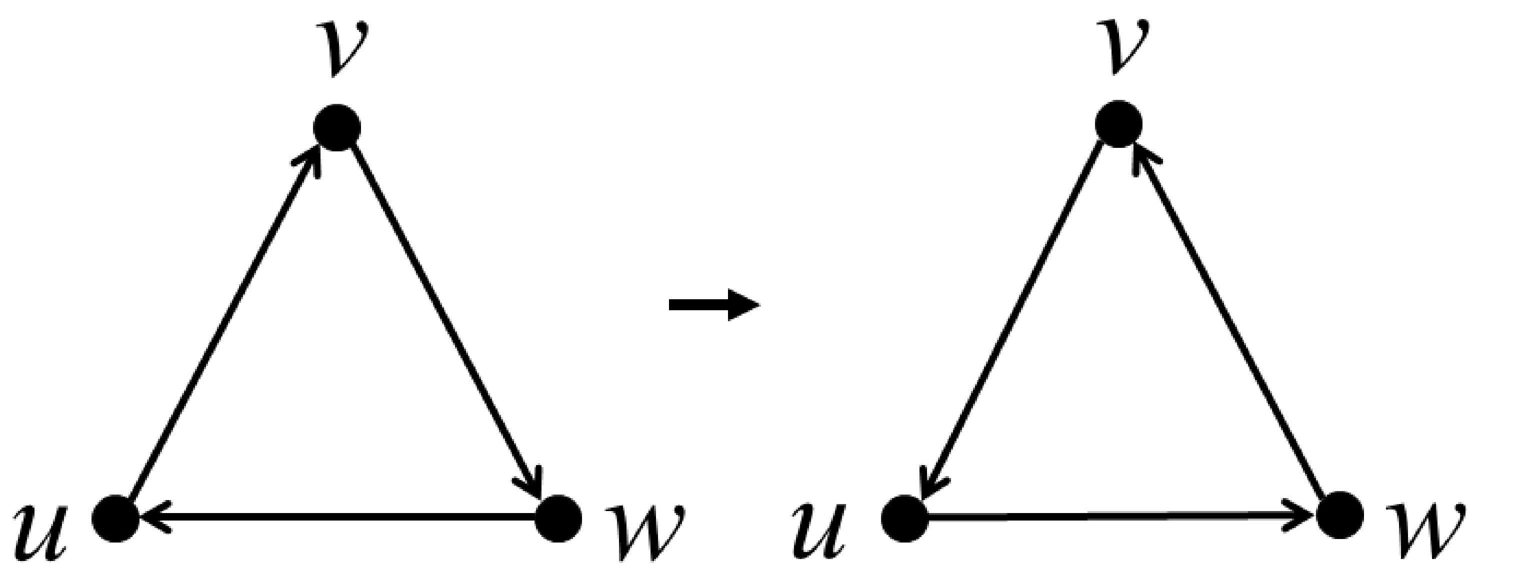




Architecture



Breaking Cycles



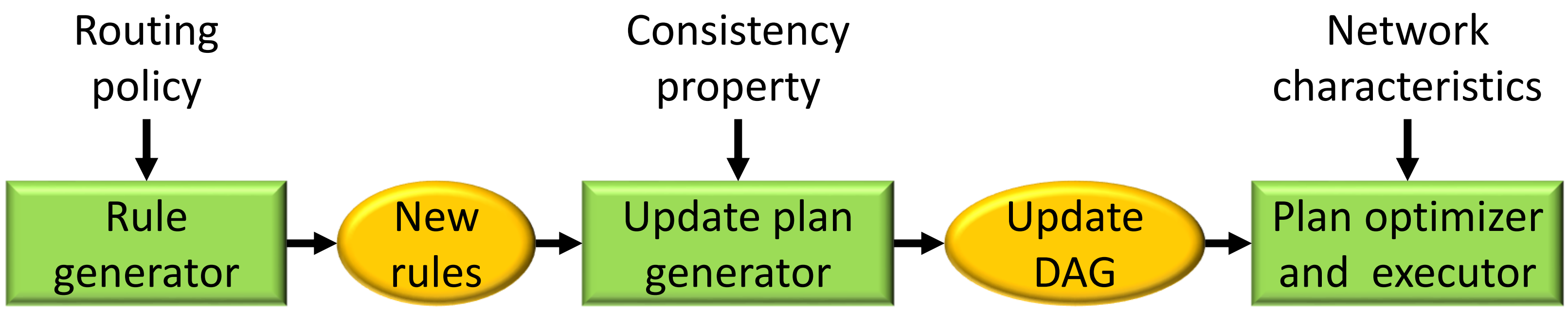
Insert at w: dest v: $w \rightarrow v$ → Insert $u \rightarrow w$ → Remove $u \rightarrow v$ → Insert $v \rightarrow u$ → Remove $v \rightarrow w$ → Insert $w \rightarrow v$ → Remove $w \rightarrow u$ → Remove at w: dest v: $w \rightarrow v$

Are Minimal Dependencies Good?

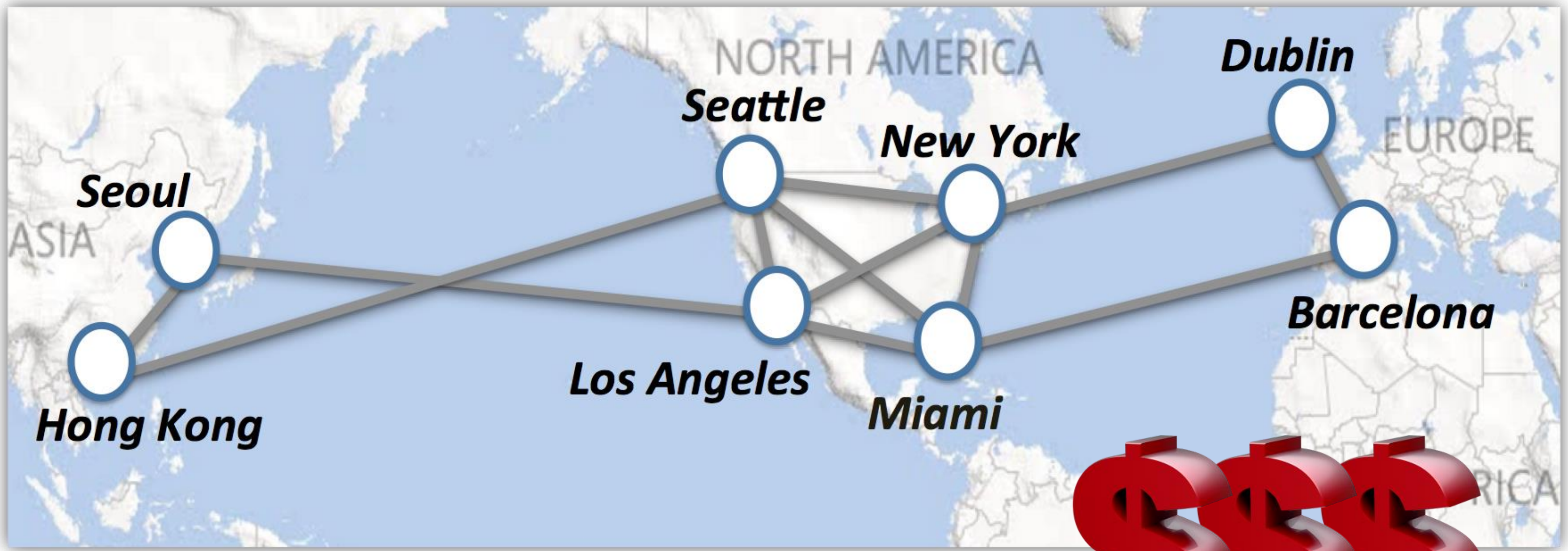
…it depends

(But Plan optimizer and executor will fix it.)

Architecture

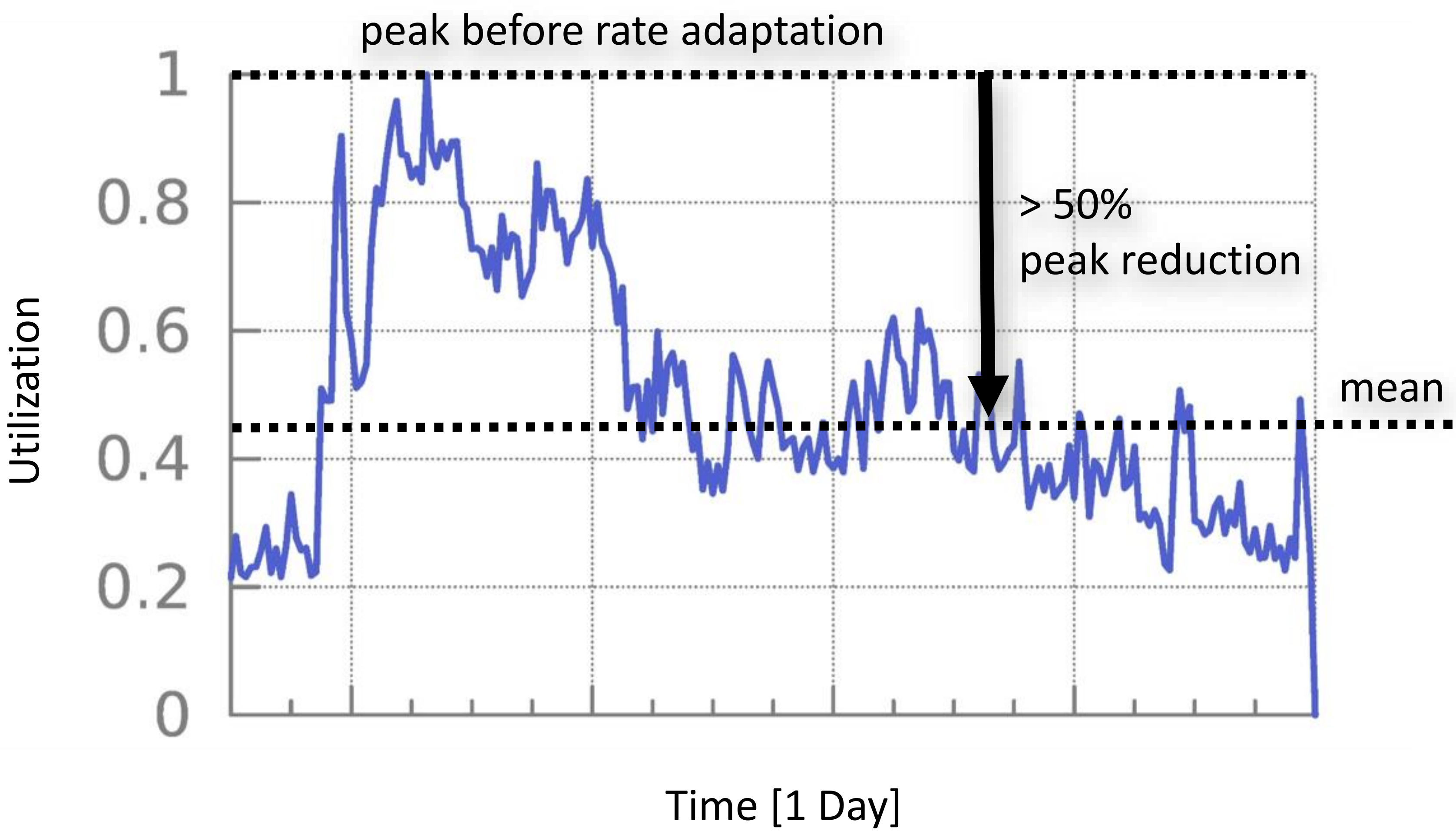


Real Application: Inter-Data Center WANs



Think: Google, Amazon, Microsoft

Problem: Typical Network Utilization



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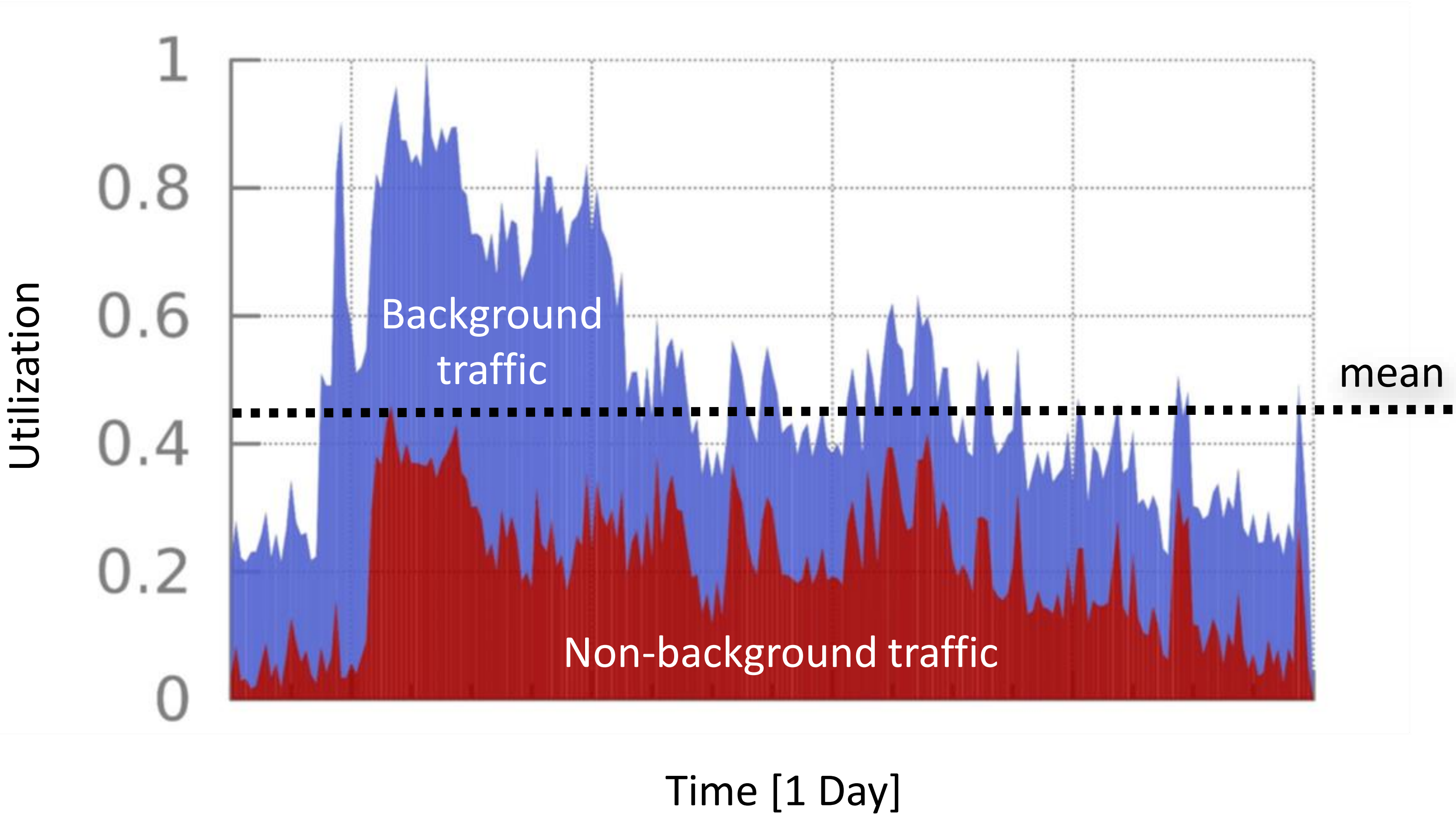

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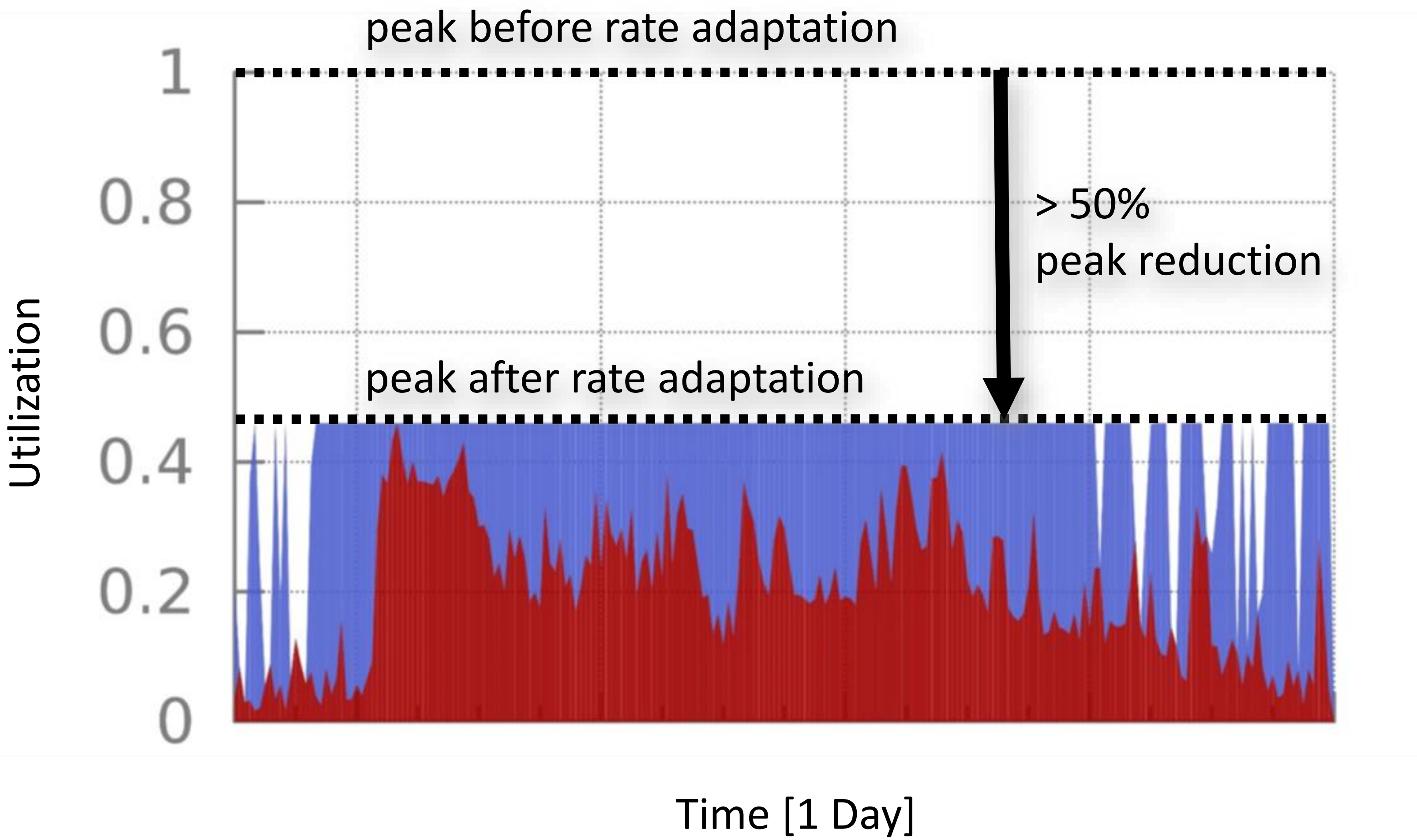
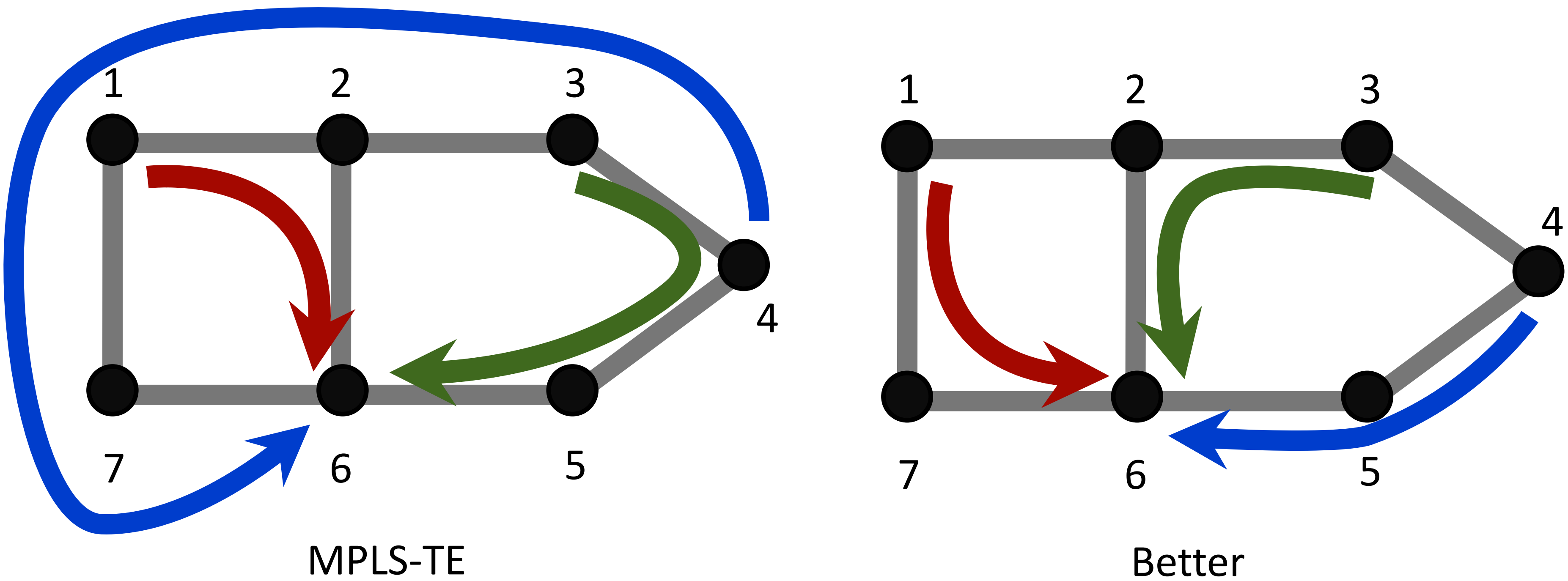


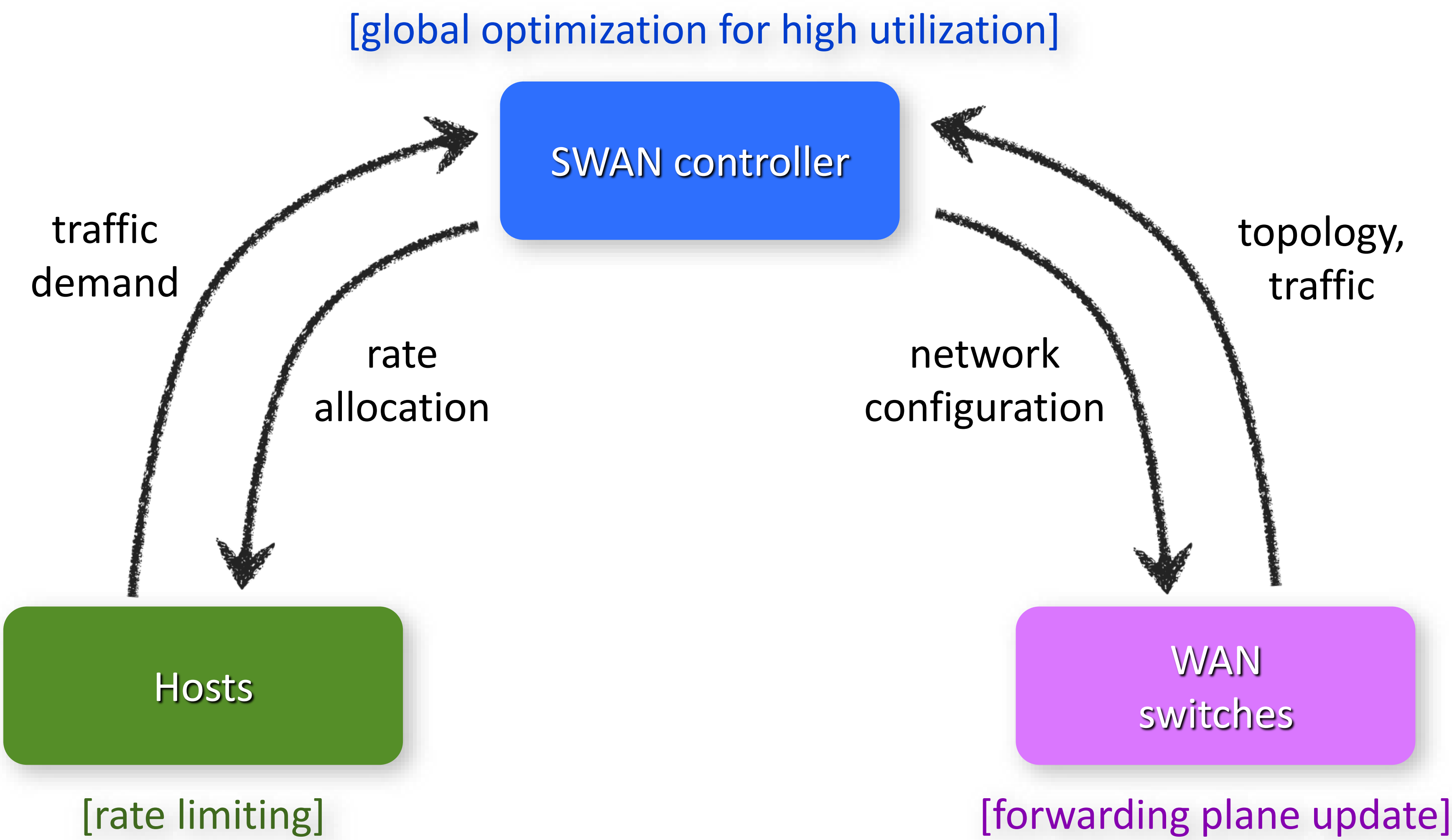
Another Problem: Online Routing Decisions

flow arrival order: A, B, C

each link can carry at most one flow (in both directions)



The SWAN Project



Algorithms?

- Priority classes (2-3)
- Allocate highest priority first

- Solve with multi-commodity flow (LP) within each class
  - Flows are splittable
  - Well understood, fast enough for our input (seconds)

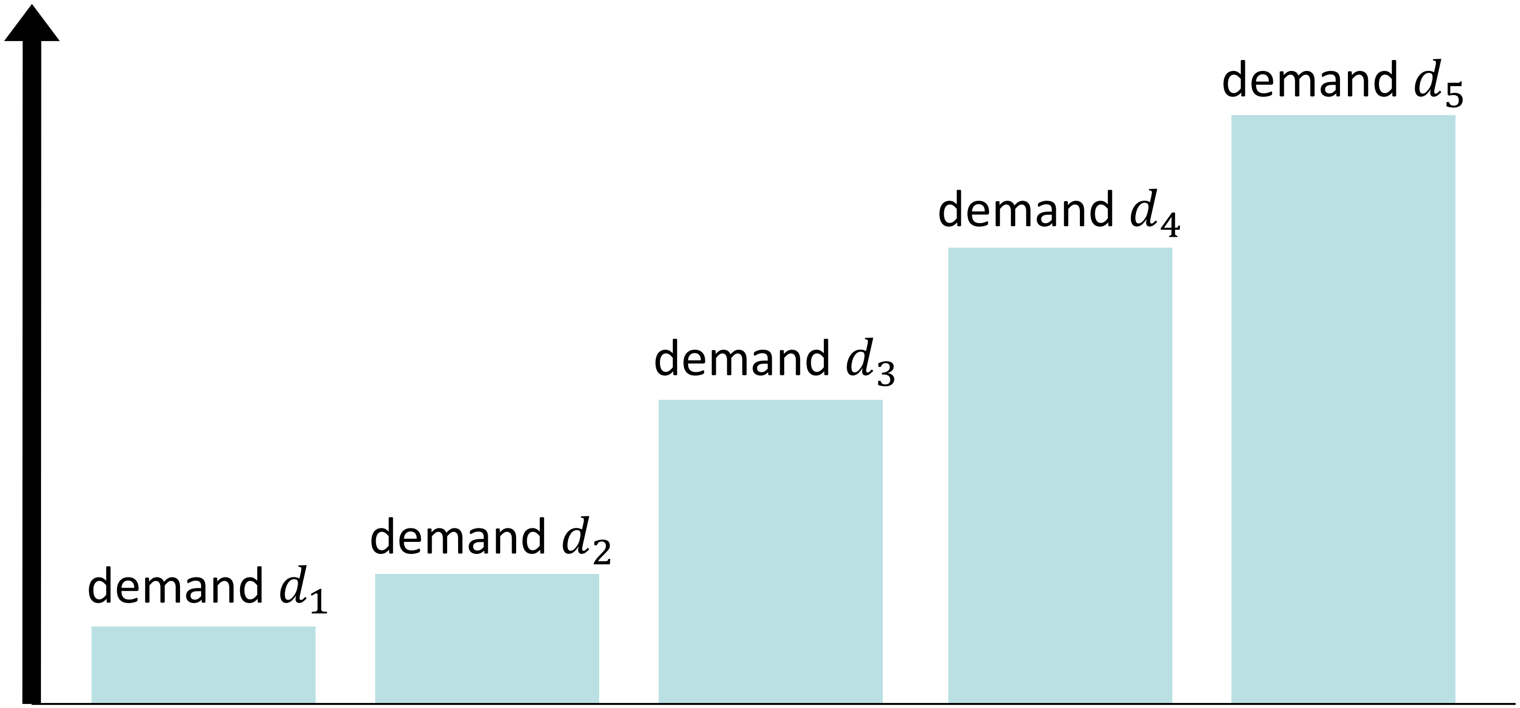
- But: Within a priority class we want max-min fairness (“$f_i \geq f, \max f$”)
  - Definition: Make nobody richer at cost of someone poorer
  - Works, but now one has to solve linearly many LPs, which is too slow (hours)
  - A perfect example of algorithm engineering?

- Solution: Fairness approximation!

Multicommodity Flow LP

Maximize throughput	$\max \sum_i f_i$
Flow less than demand	$0 \leq f_i \leq d_i$
Flow less than capacity	$\sum_i f_i(e) \leq c(e)$
Flow conservation on inner nodes	$\sum_u f_i(u,v) = \sum_w f_i(v,w)$
Flow definition on source, destination	$\sum_v f_i(s_i,v) = \sum_u f_i(u,t_i) = f_i$

Approximated max-min fairness



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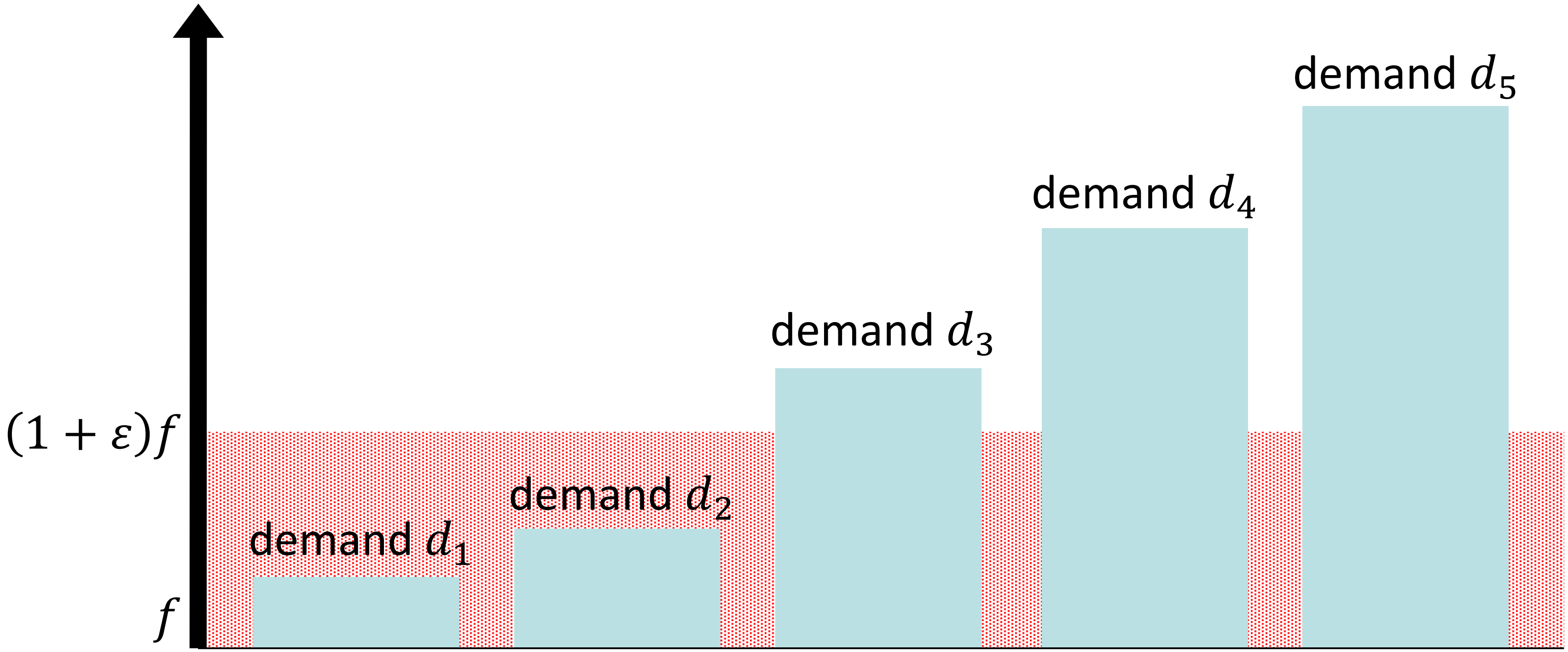
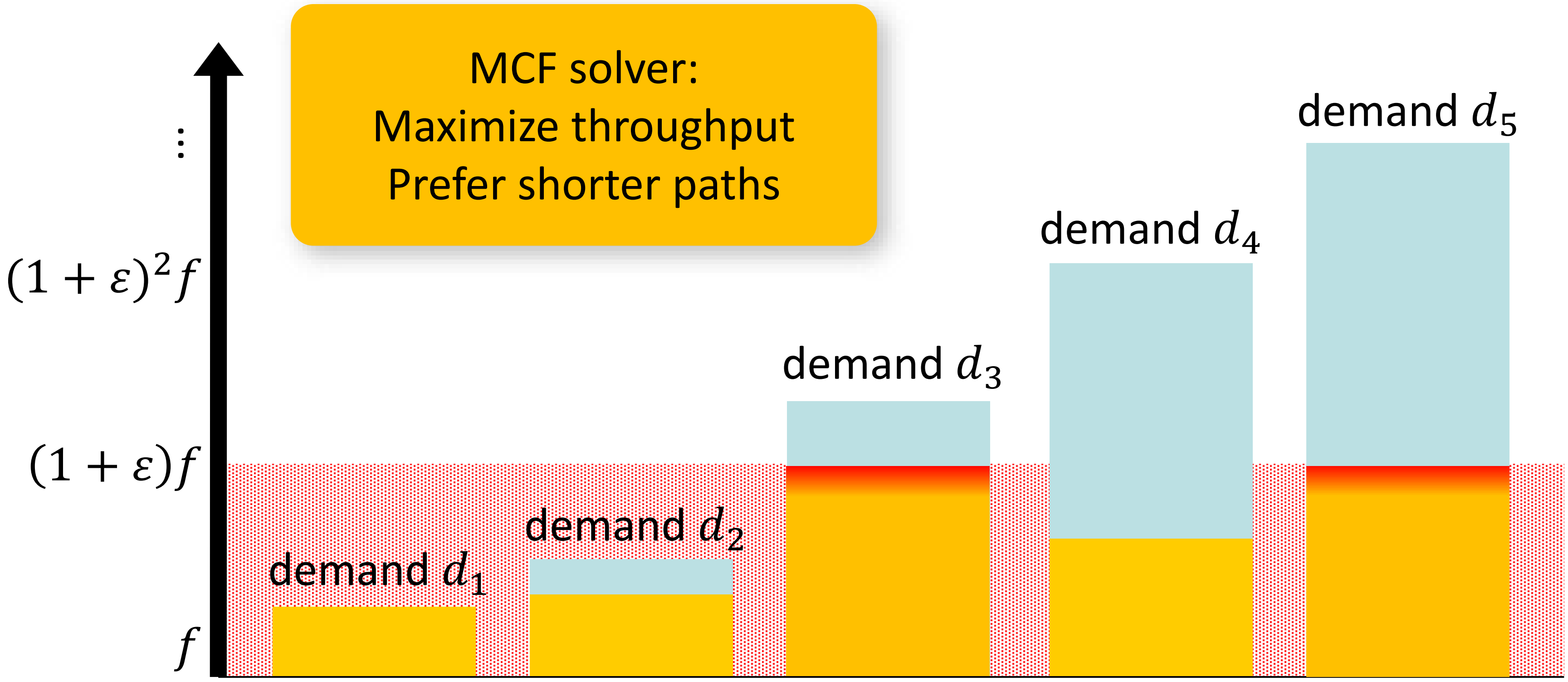


Approximated max-min fairness



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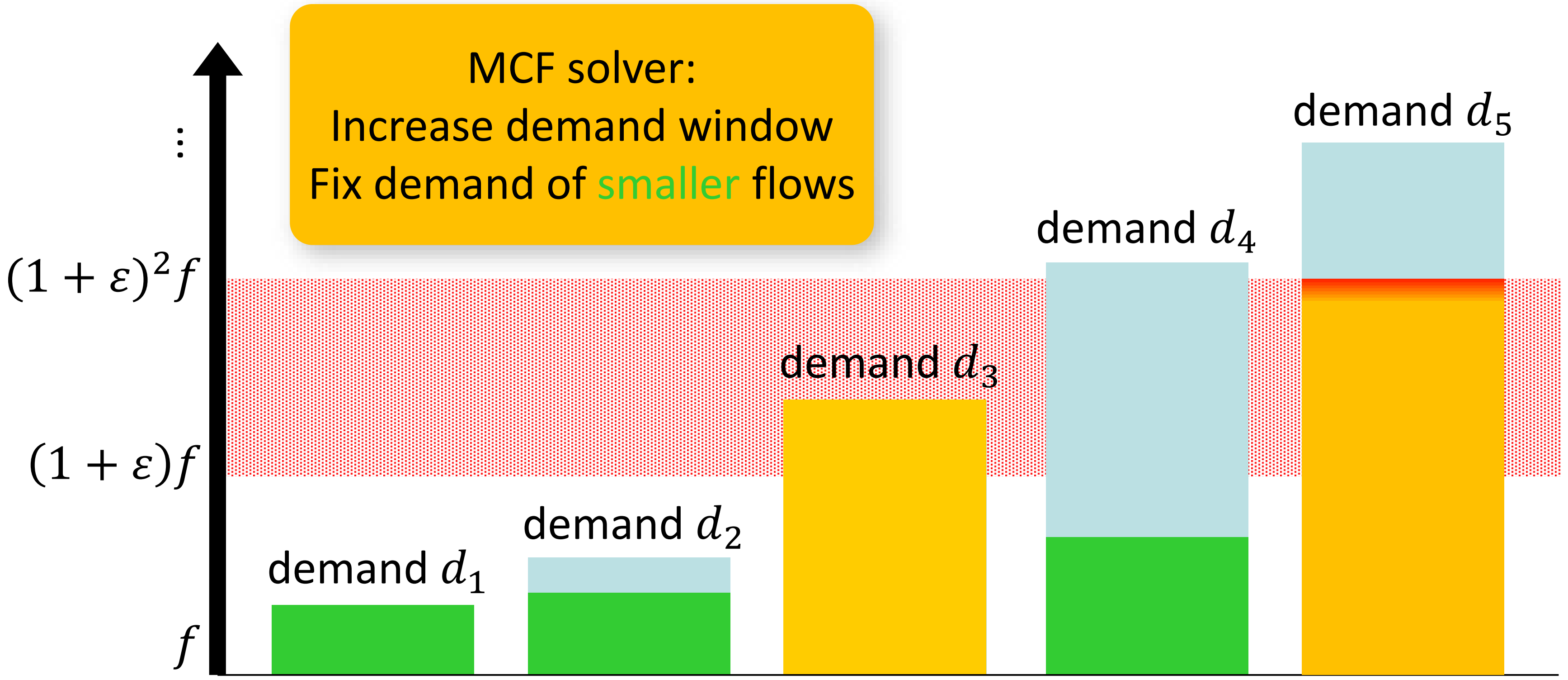

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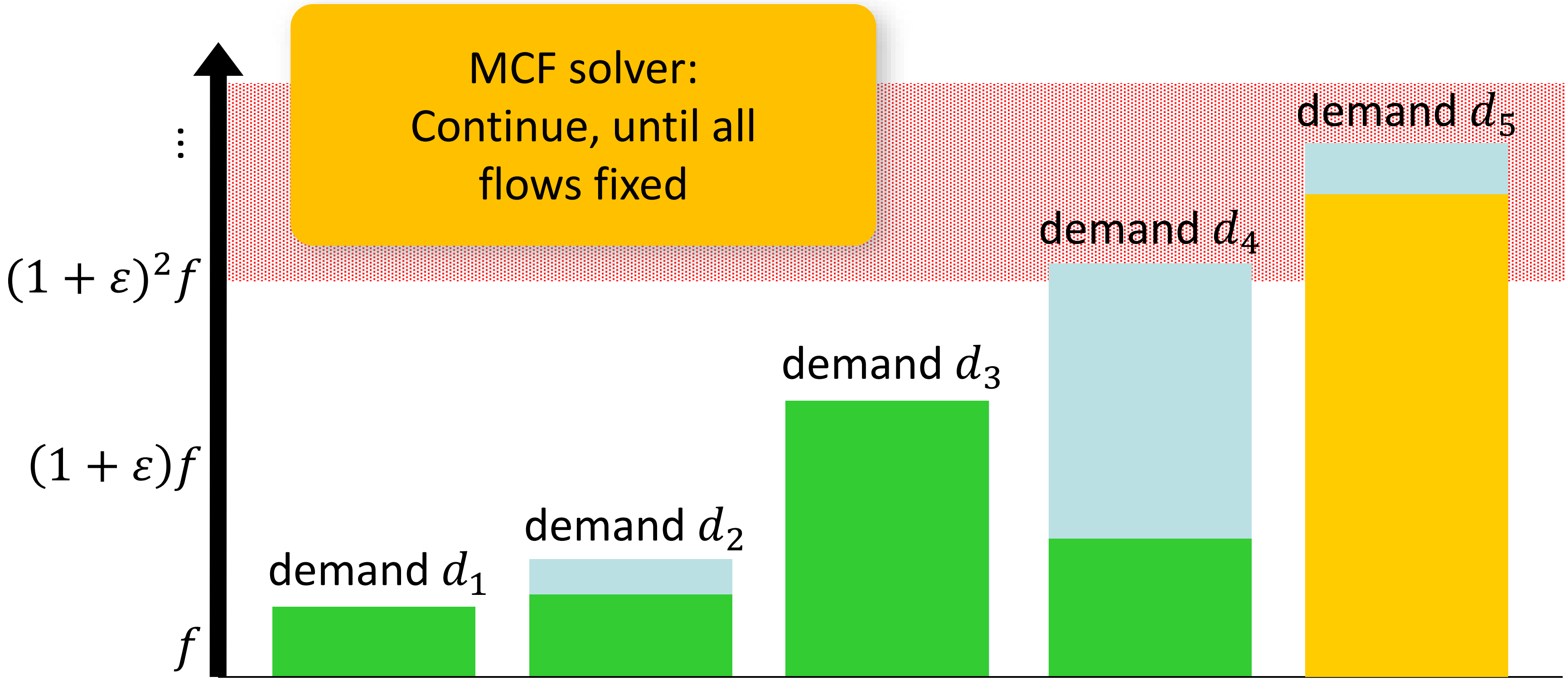

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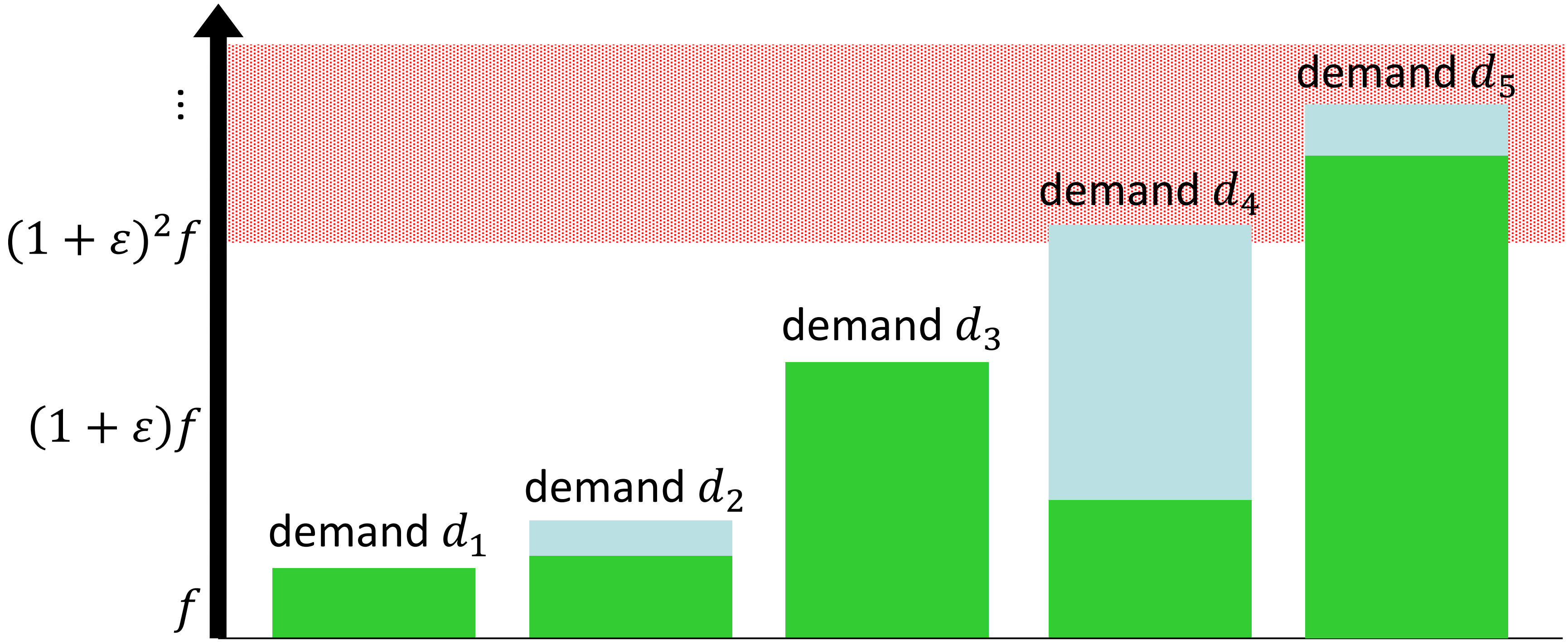
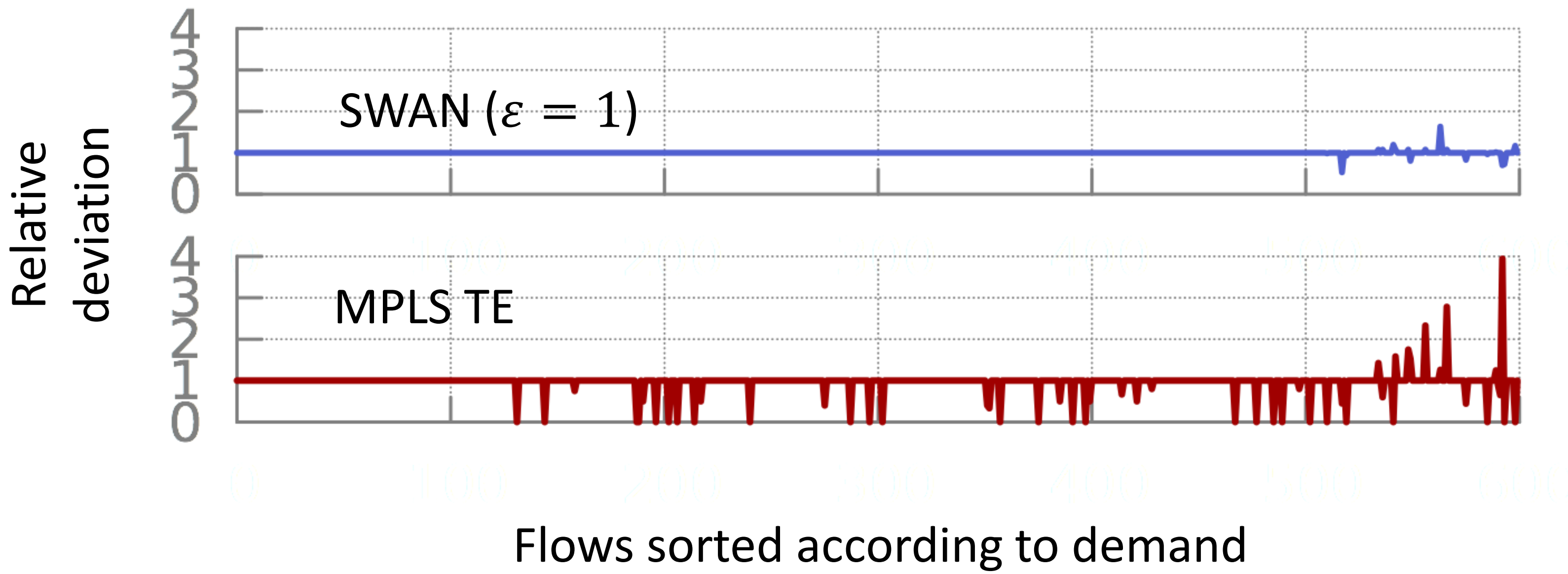
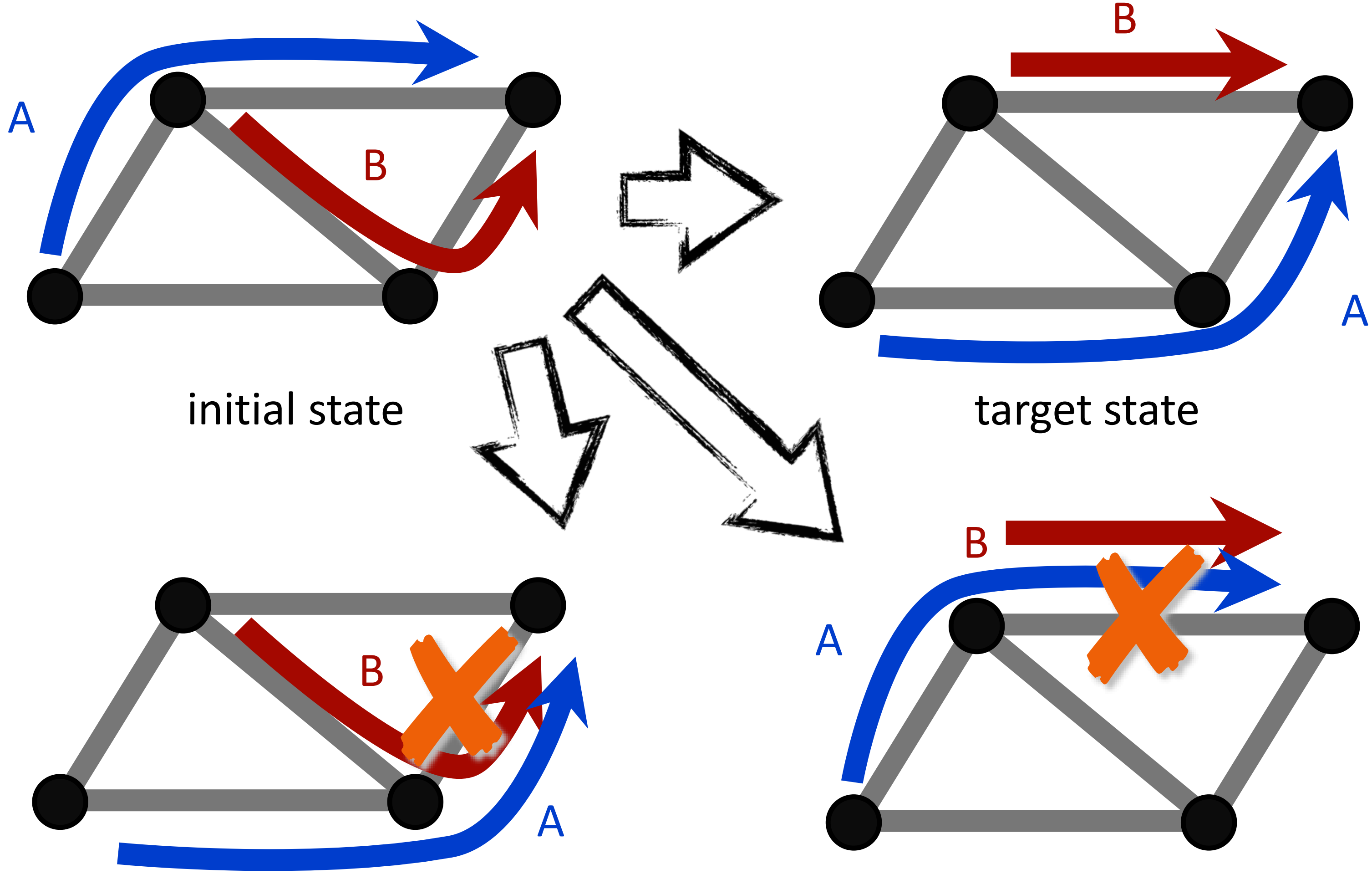


- In theory, this process is $(1+\varepsilon)$ competitive
- In practice, with $\varepsilon = 1$, only 4% of flows deviate over 5% from their fair share

Fairness: SWAN vs. MPLS TE



Problem: Consistent Updates



Capacity-Consistent Updates

- Not directly, but maybe through intermediate states?
- Solution: Leave a fraction s slack on each edge, less than $1/s$ steps
- Example: Slack = 1/3 of link capacity

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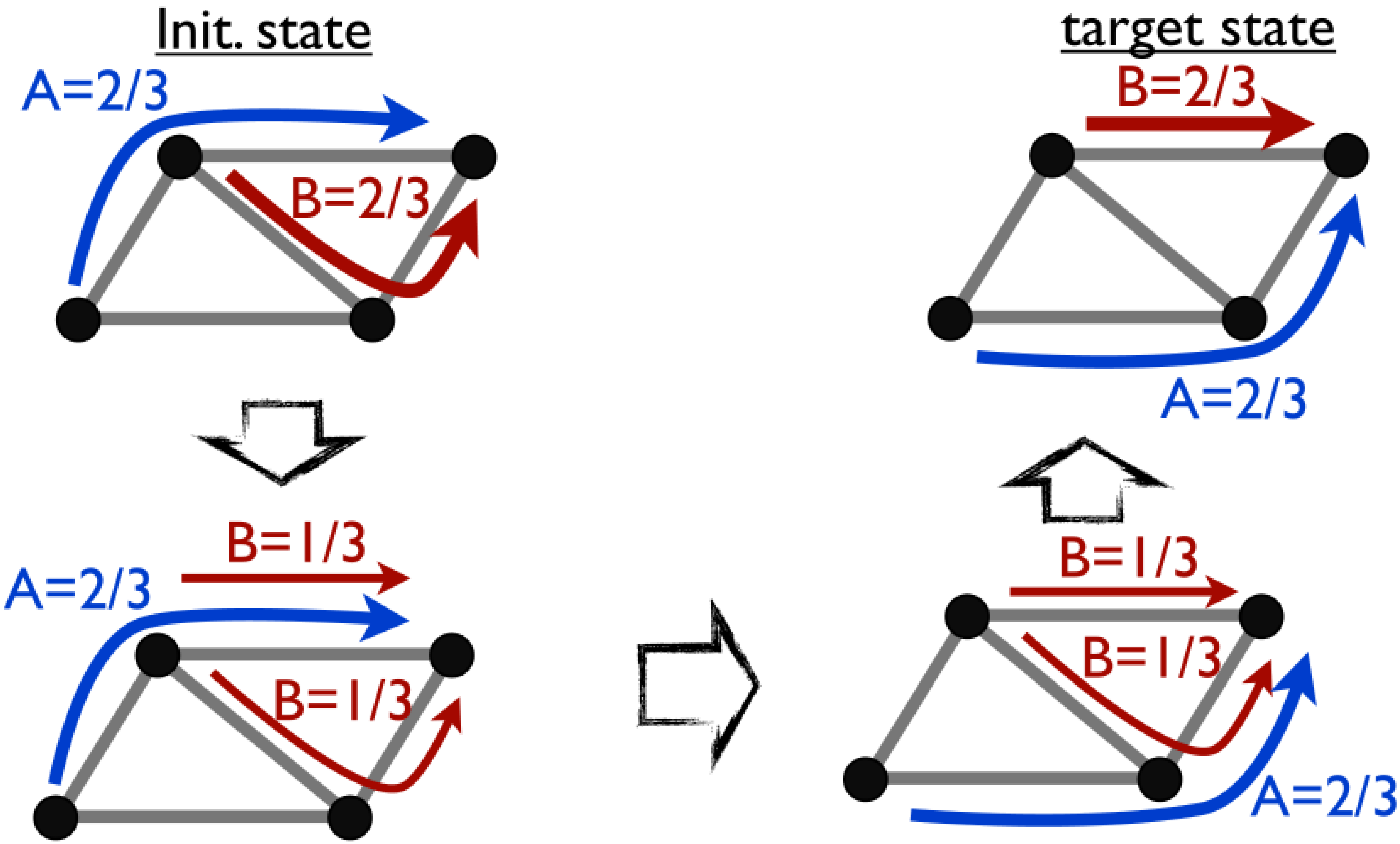


Capacity-Consistent Updates

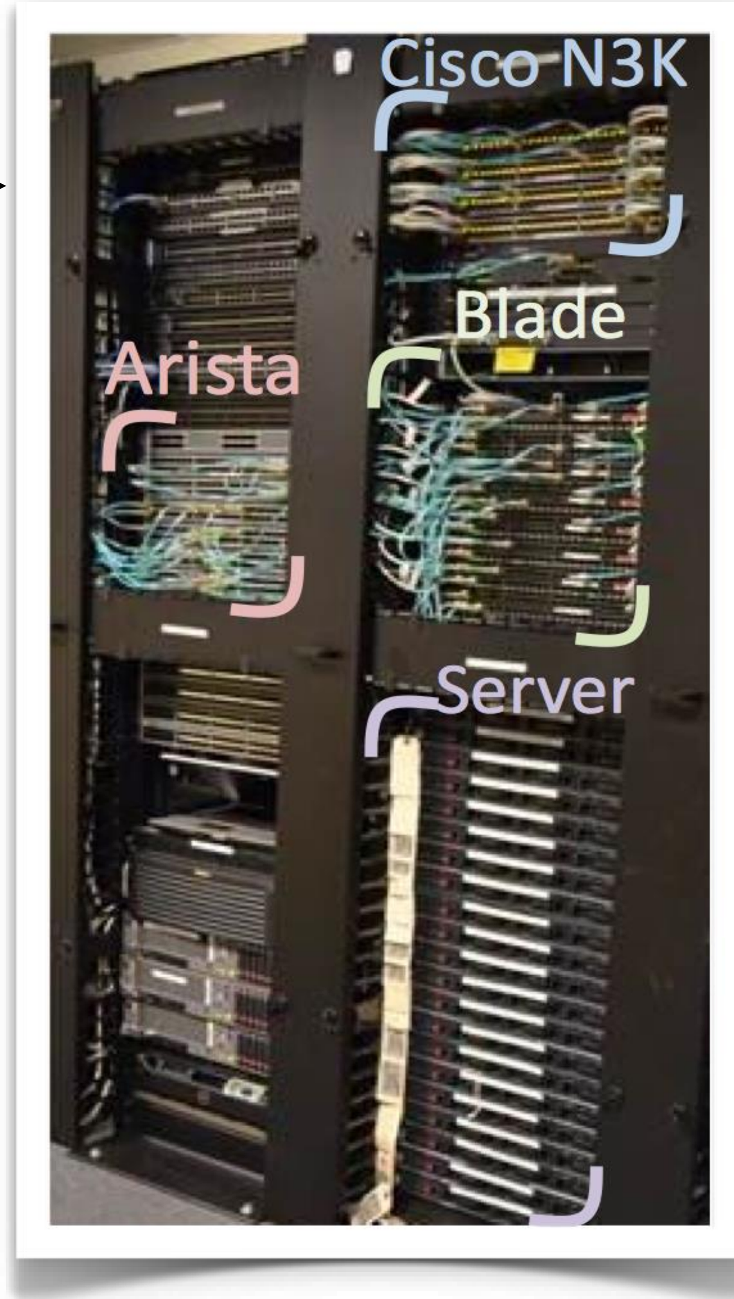
- Alternatively: Try whether a solvable LP with k steps exist, for $k = 1, 2, 3$ ...
  - Sum of flows in steps j and $j + 1$, together, must be less than capacity limit

Only growing flows	$f_i^0 \leq f_i^k$
Flow less than capacity	$\sum_i \max\left(f_i^j(e), f_i^{j+1}(e)\right) \leq c(e)$
Flow conservation on inner nodes	$\sum_u f_i^j(u,v) = \sum_w f_i^j(v,w)$
Flow definition on source, destination	$\sum_v f_i^j\,(s_i, v) = \sum_u f_i^j\,(u, t_i) = f_i^j$

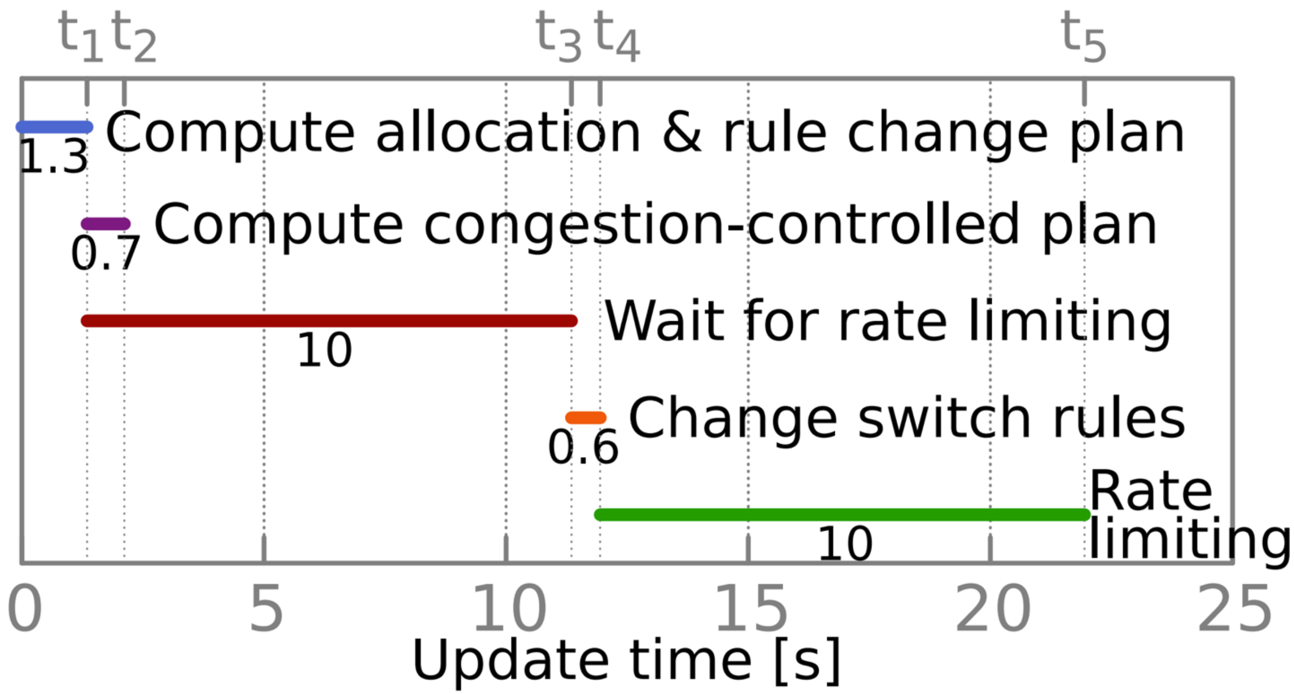
Evaluation platforms

- Prototype
  - 5 DCs across 3 continents
  - 10 switches

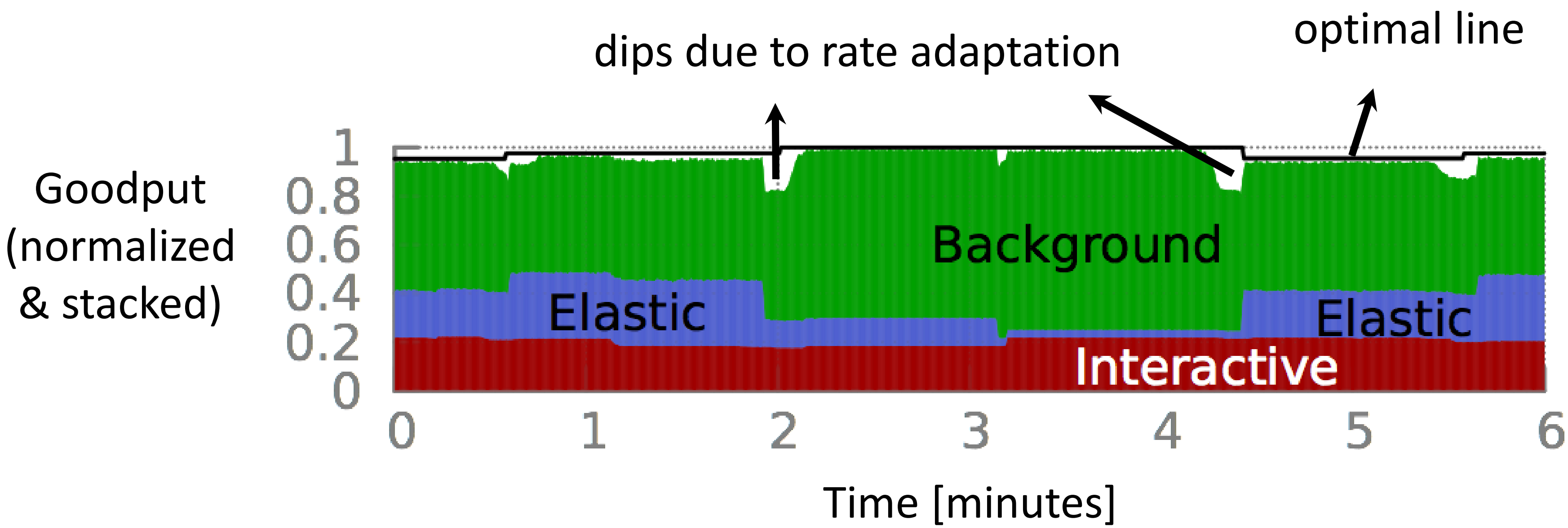
- Data-driven evaluation
  - 40+ DCs across 3 continents
  - 80+ switches



Time for One Network Update



Prototype Evaluation

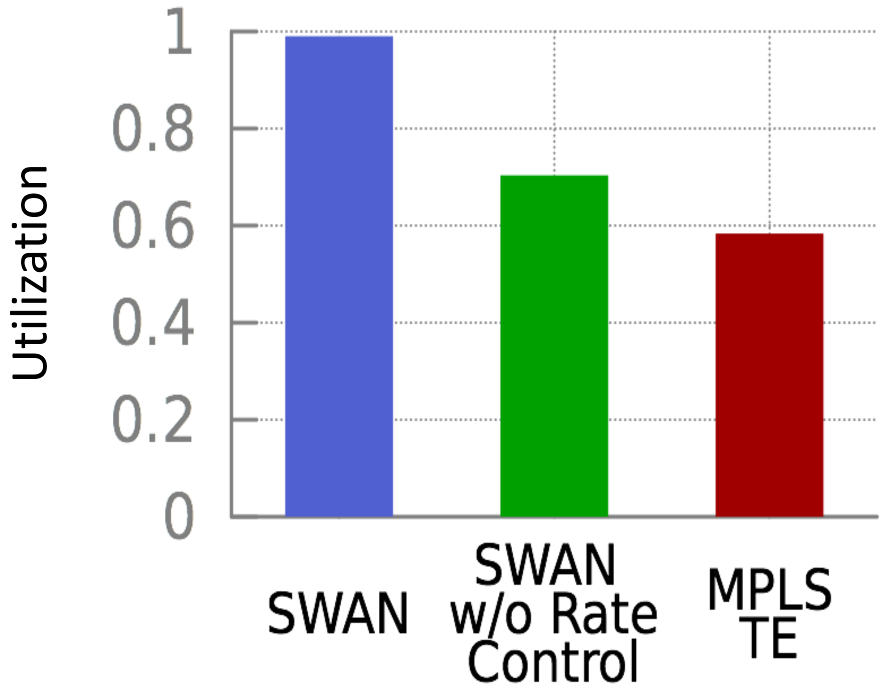


Traffic: (∀DC-pair) 125 TCP flows per class

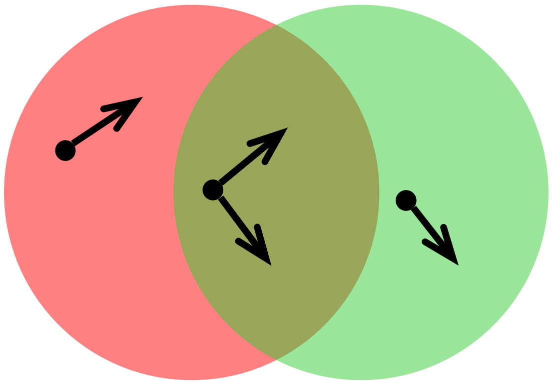
High utilization
SWAN's goodput:
98% of an optimal method

Flexible sharing
Interactive protected;
background rate-adapted

Data-driven Evaluation of 40+ DCs



Summary



	None	Self	Downstream subset	Downstream all	Global
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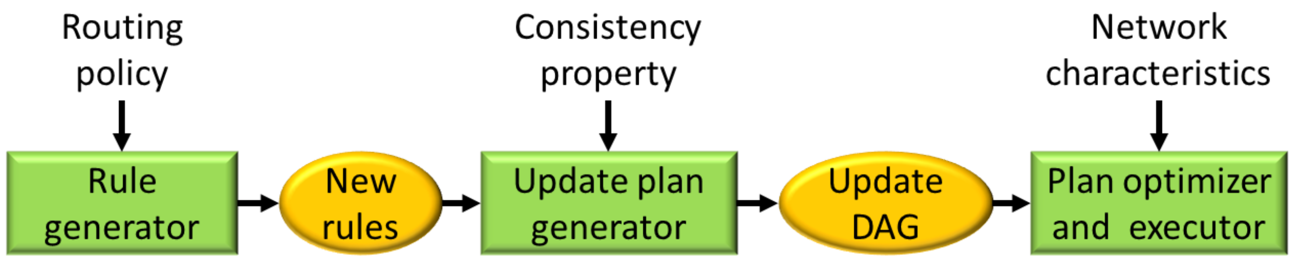

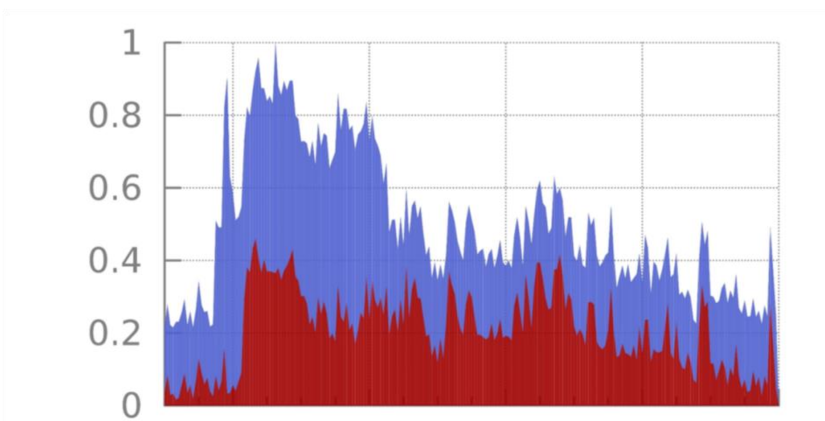

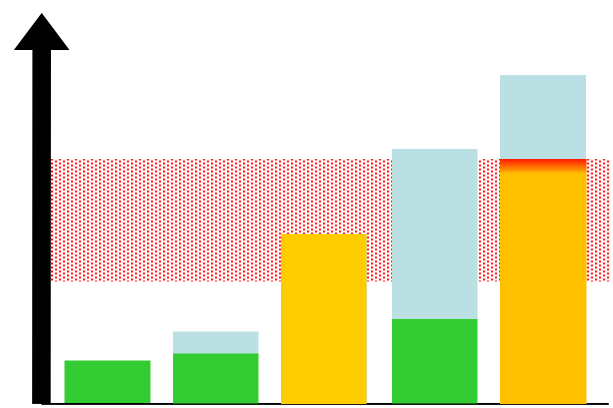

References

- Introducing consistent network updates was done in Mark Reitblatt et. al., SIGCOMM 2012
- For minimal loop-free updates and more see Ratul Mahajan et. al., HotNets 2013
- Deciding if a simple update schedule exists is hard was proven in Laurent Vanbever et. al., IEEE/ACM Trans. Netw. 2012
- For one of the first papers on loop-detection you can look at Robert Tarjan, Depth-first search and linear graph algorithms, 1972
- For more on the SWAN-project see Chi-Yao Hong et. al., SIGCOMM 2013

Thank You!

Questions & Comments?

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Evaluation