Backbone Traffic Engineering

Lecture 20, Computer Networks (198:552)

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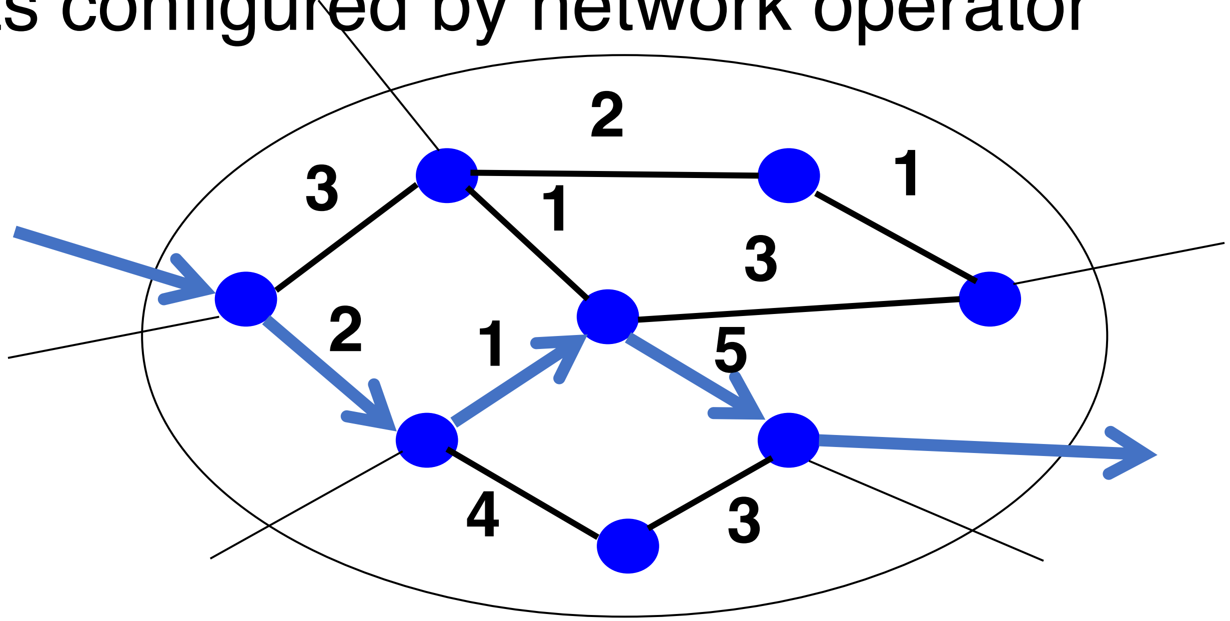
Do IP Networks Manage Themselves?

- In some sense, yes:
    - TCP senders send less traffic during congestion
    - Routing protocols adapt to topology changes
- But, does the network run *efficiently*?
    - Congested link when idle paths exist?
    - High-delay path when a low-delay path exists?
- How should routing adapt to the traffic?
    - Avoiding congested links in the network
    - Satisfying application requirements (e.g., delay)
- … these are the essential questions of **traffic engineering**

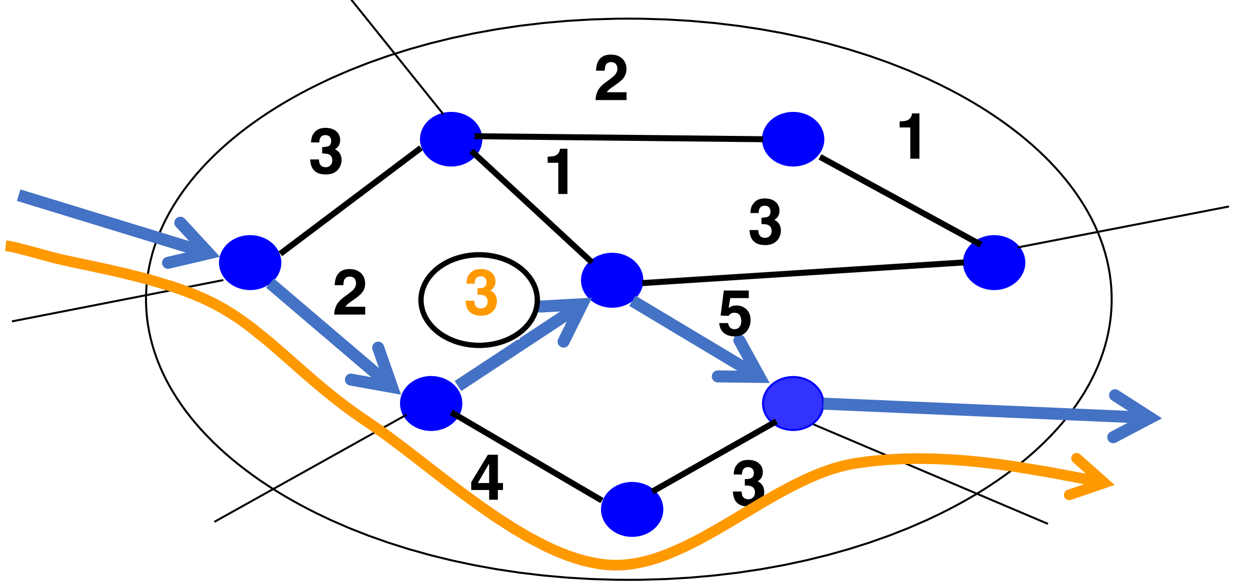
Routing With "Static" Link Weights

- Routers flood information to learn topology
  - Determine "next hop" to reach other routers…
  - Compute shortest paths based on link weights
- Link weights configured by network operator

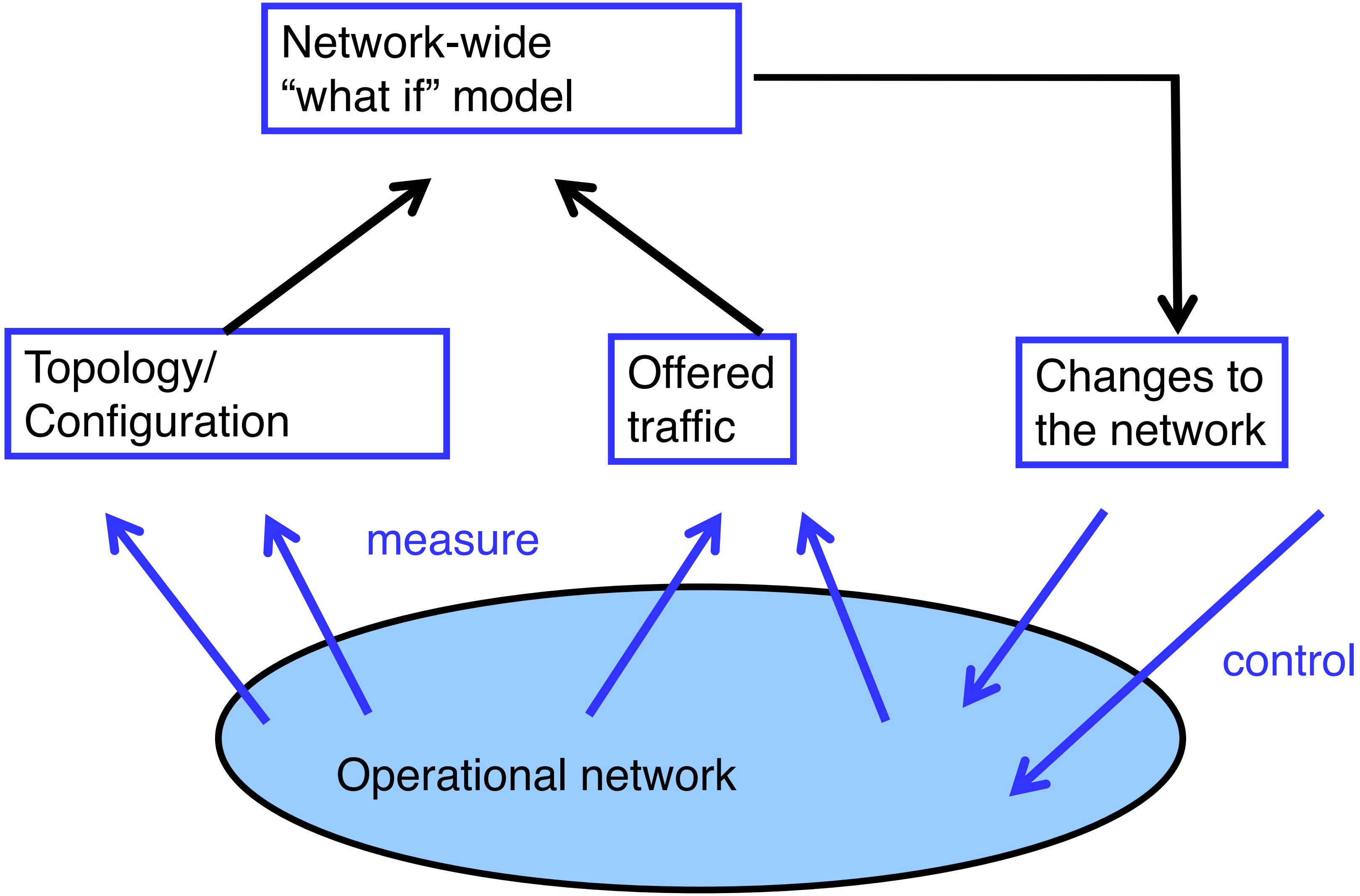


Setting the Link Weights

- How to set the weights
  - Inversely proportional to link capacity?
  - Proportional to propagation delay?
  - Network-wide optimization based on traffic?



Measure, Model, and Control



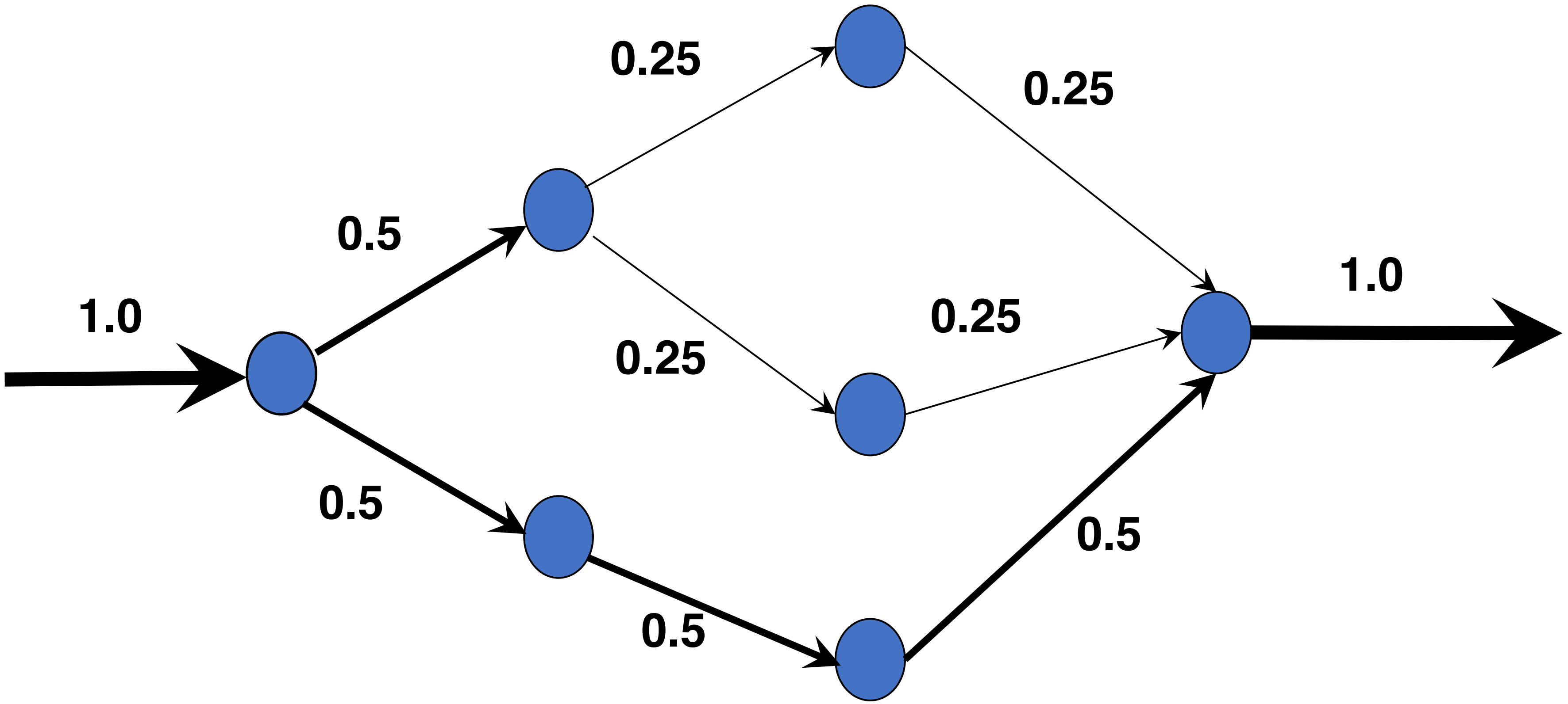
Key Ingredients

- Measurement
  - Topology: monitoring of the routing protocols
  - Traffic matrix: passive traffic measurement
- Network-wide models
  - Representations of topology and traffic
  - “What-if” models of shortest-path routing
- Network optimization
  - Efficient algorithms to find good configurations
  - Operational experience to identify constraints

Optimization Problem

- Input: graph $G(R,L)$
  - R is the set of routers
  - L is the set of unidirectional links
  - c_l is the capacity of link l
- Input: traffic matrix
  - $M_{i,j}$ is traffic load from router i to j
- Output: setting of the link weights
  - w_l is weight on unidirectional link l
  - $P_{i,j,l}$ is fraction of traffic from i to j traversing link l

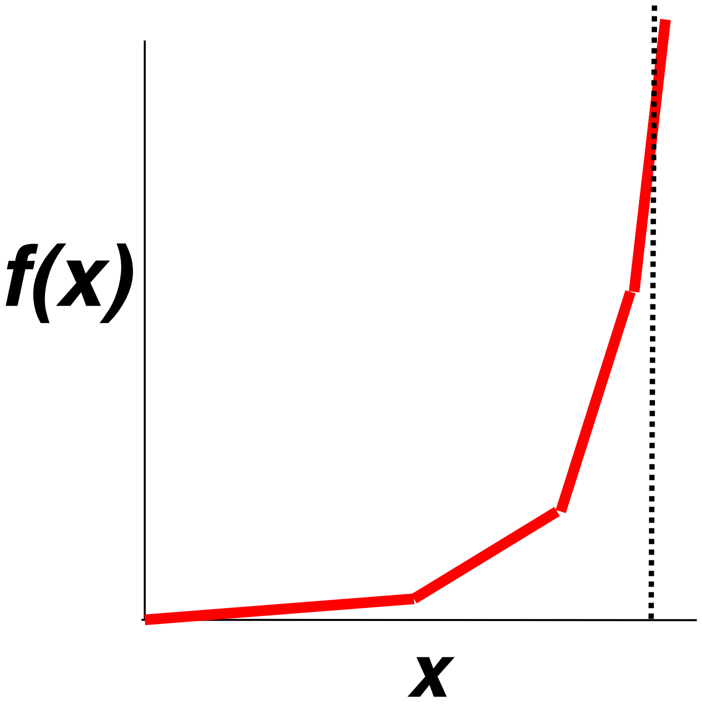
Equal-Cost Multipath (ECMP)



Values of $P_{i,j,l}$

Objective Function

- Computing the link utilization
  - Link load: $u_l = \sum_{i,j} M_{i,j} P_{i,j,l}$
  - Utilization: u_l/c_l
- Objective functions
  - $min(max_l(u_l/c_l))$
  - $min(\sum_l f(u_l/c_l))$



Complexity of Optimization Problem

- NP-complete optimization problem
  - No efficient algorithm to find the link weights
  - Even for simple objective functions
- What are the implications?
  - Have to resort to *searching* through weight settings
- Clearly suboptimal, but effective in practice
  - Fast computation of the link weights
  - Good performance, compared to “optimal” solution

Incorporating Operational Realities

- Minimize number of changes to the network
    - Changing just 1 or 2 link weights is often enough
- Tolerate failure of network equipment
    - Weights settings usually remain good after failure
    - … or can be fixed by changing one or two weights
- Limit dependence on measurement accuracy
    - Good weights remain good, despite random noise
- Limit frequency of changes to the weights
    - Joint optimization for day & night traffic matrices

Central Control over Distributed Routing

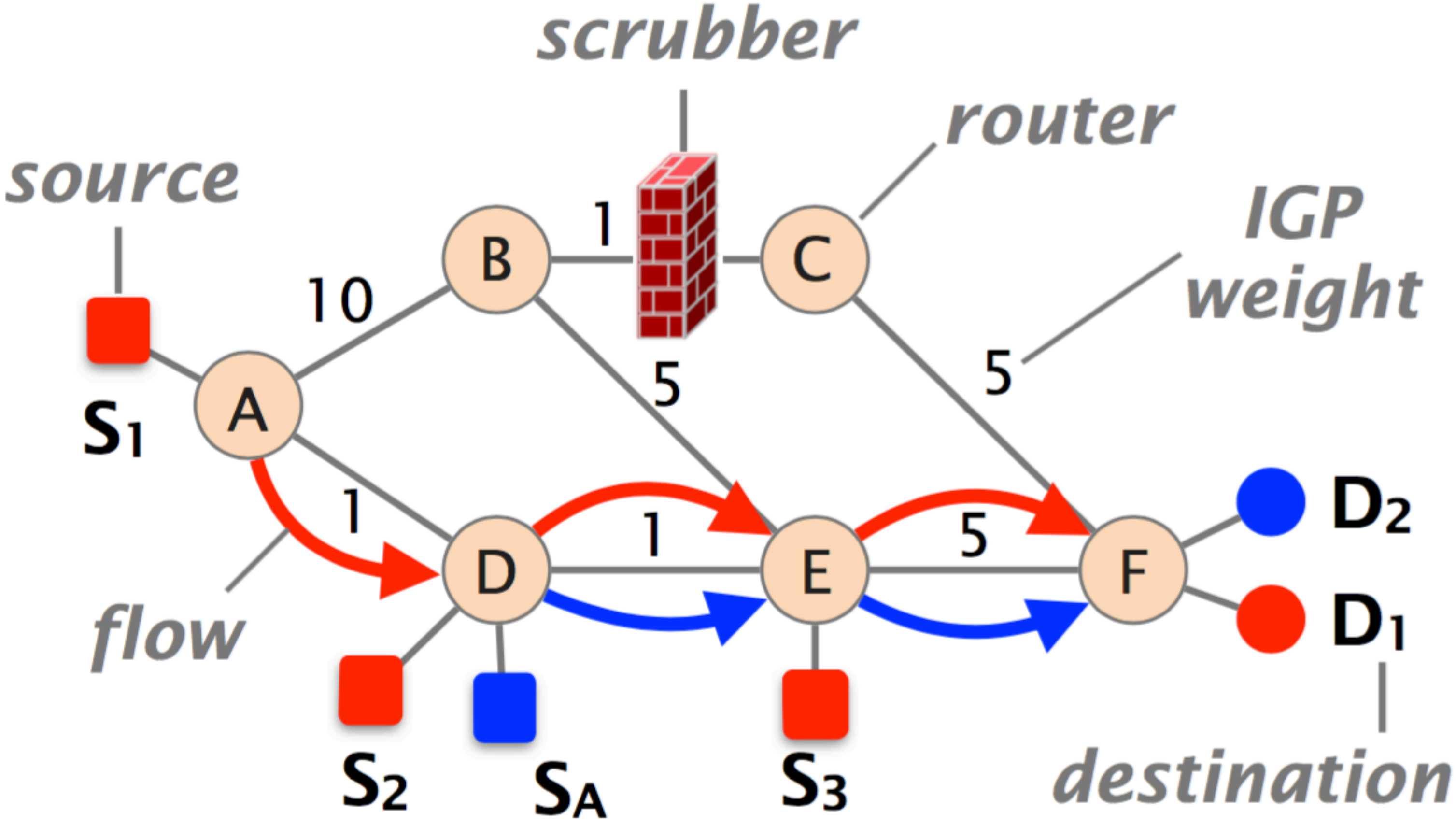
Stefano Visicchio et al., ACM SIGCOMM'15

Context: Scalable & robust backbone TE

- Traditional IGPs perform distributed computations
  - Scalable
  - Robust to link and node failures
  - But not flexible in terms of expressed paths
- SDNs perform (logically) centralized path computations
  - Highly flexible
  - But handling large networks is challenging
  - Handling topology updates is challenging

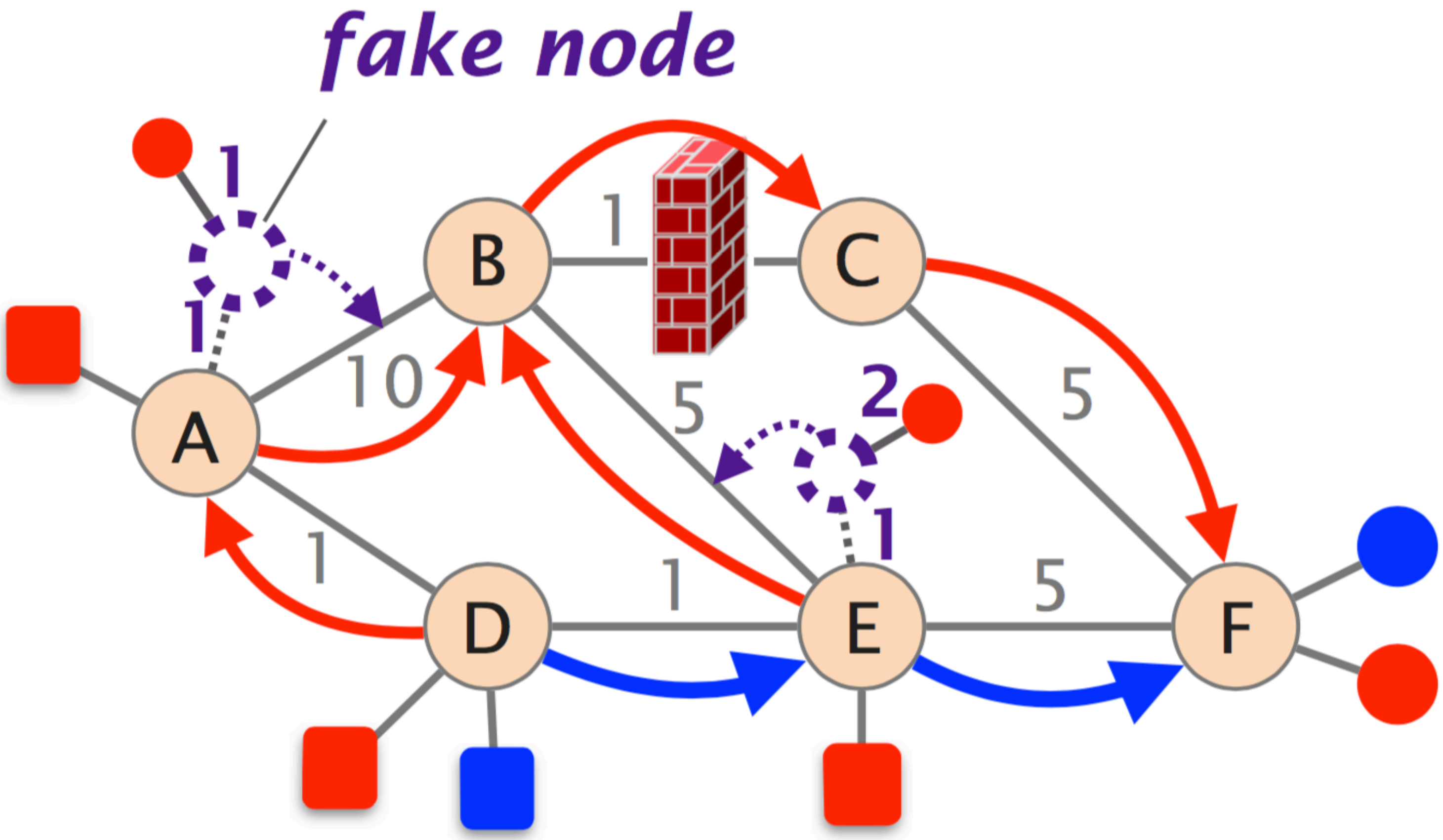
- Could we combine the best of both worlds?

An example

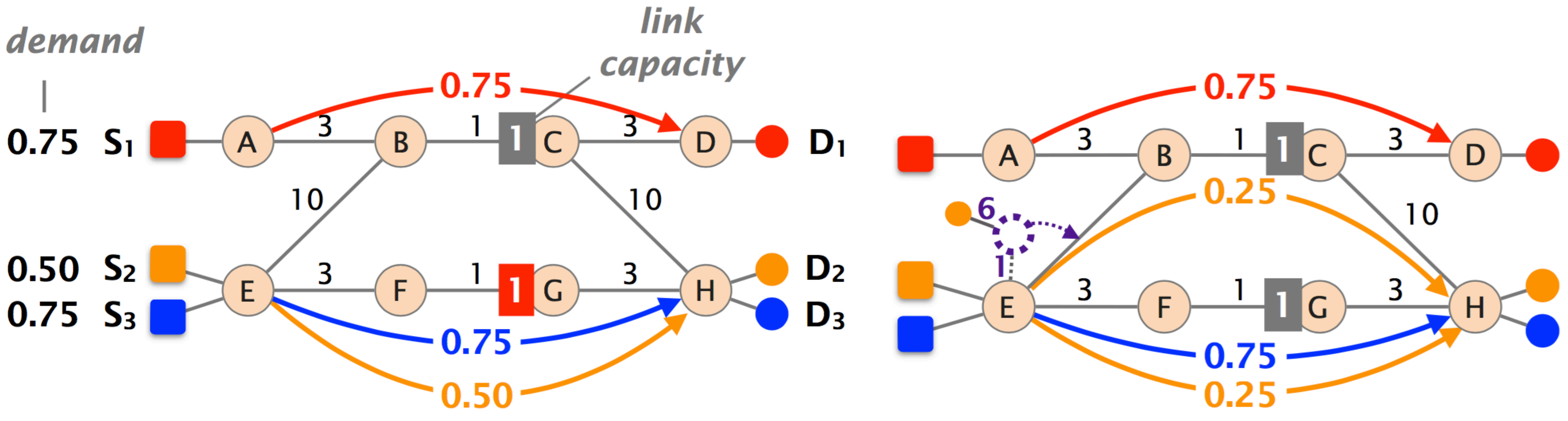


scrubber
router
source
IGP weight
B
C
A
D
E
F
1
10
5
5
1
1
5
S1
S2
SA
S3
D2
D1
flow
destination

Key idea: Lies to the routers

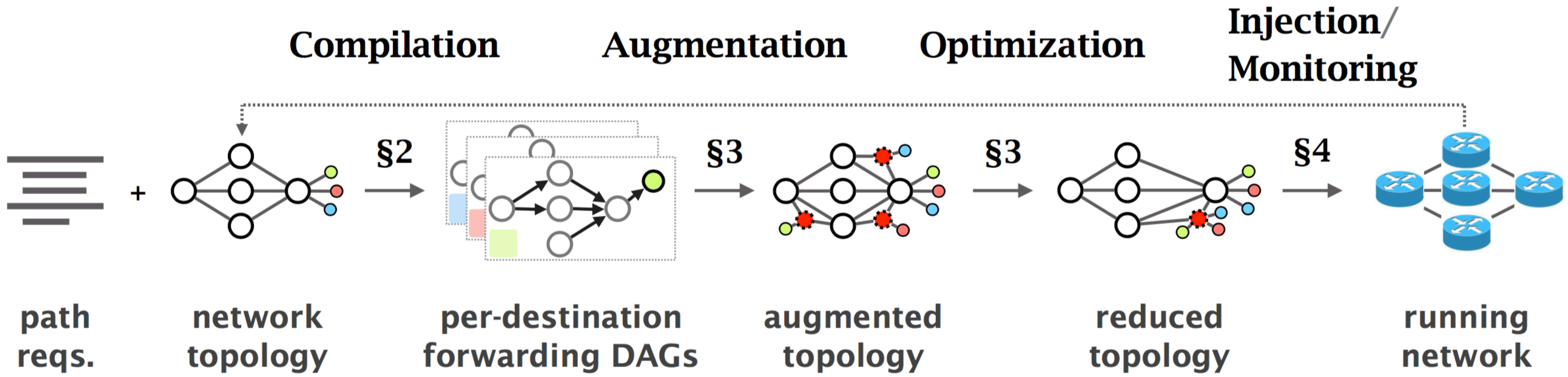


Another example



(a) Initial topology (b) Augmented topology

Workflow


Compilation
Augmentation
Optimization
Injection/
Monitoring
§2
§3
§3
§4
+
path
reqs.
network
topology
per-destination
forwarding DAGs
augmented
topology
reduced
topology
running
network

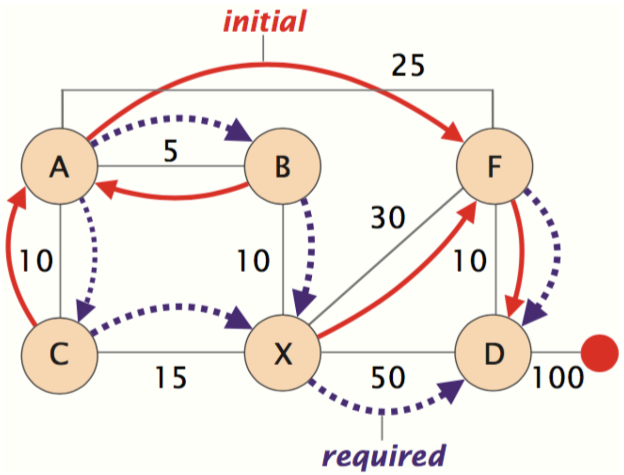
Fibbing: Expressiveness

THEOREM 1. *Any set of per-destination forwarding DAGs can always be enforced by augmenting a Fibbing-compliant topology even only with globally-scoped lies.*

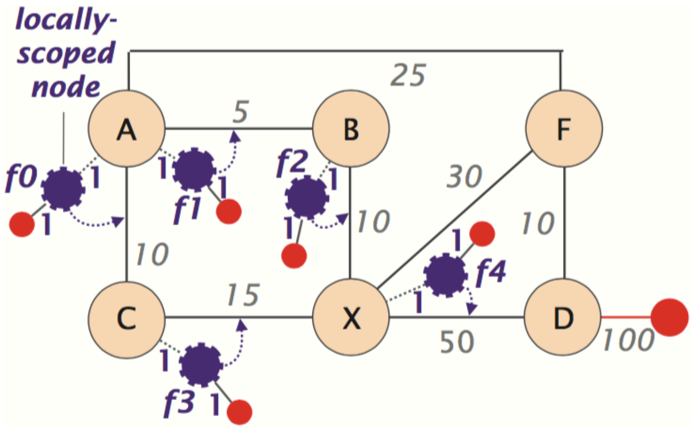
Key primitives required

- Initial setting of static routing weights: “Fibbing-compliance”
- Local and global scoping of IGP announcements
- Forwarding traffic to fake nodes on any desired link

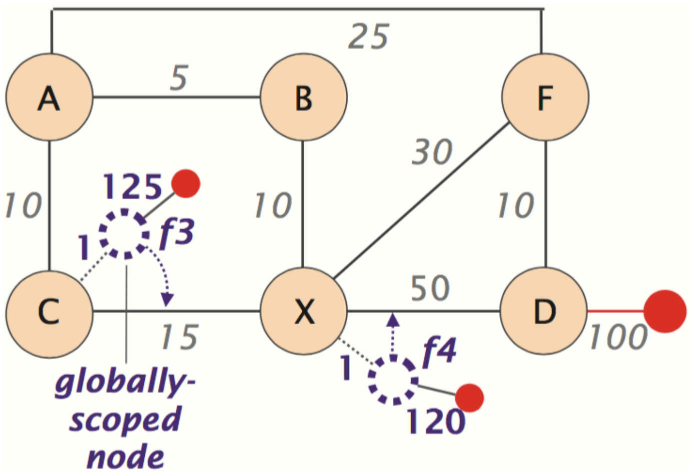
Augmentation algorithms



(a) Requirements

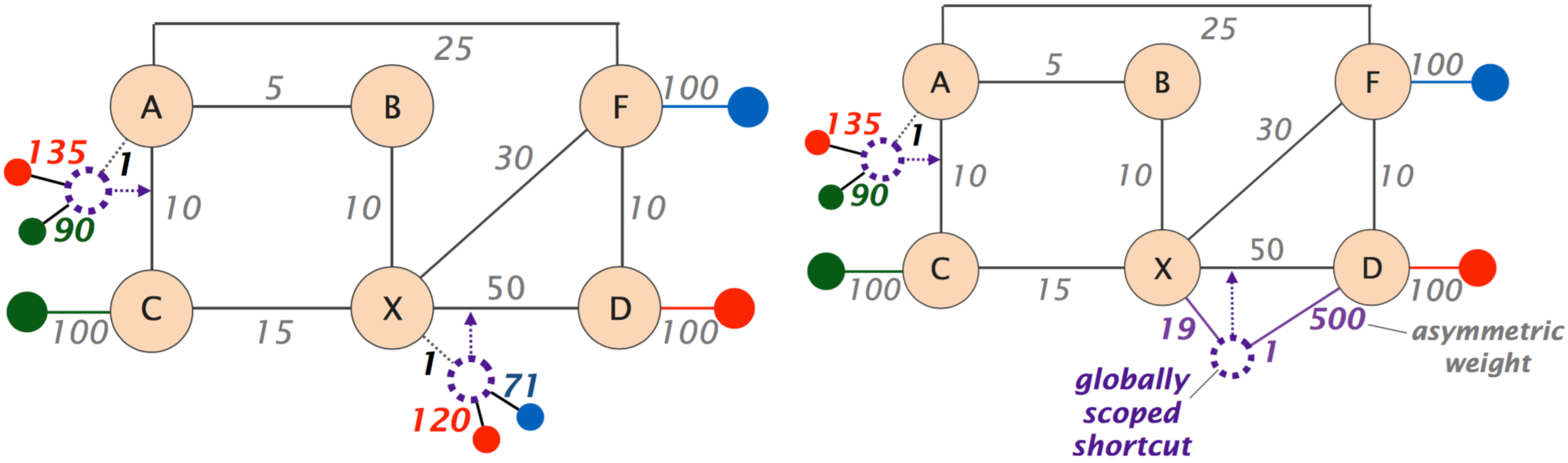


(b) Simple augmentation



(c) Merger augmentation

Cross-destination optimization



A comparison of approaches

	centralized/SDN OpenFlow [2], PCE [3], SR [4]	*distributed/traditional* IGP [5, 6], RSVP-TE [1]	***hybrid*** **Fibbing**
forwarding paths:			
- *configuration*	simple (declarative & global)	complex (indirect & per-device)	**simple** (declarative & global)
- *manageability*	high (direct control)	low [7, 8] (need for coordination)	**high** (direct control)
- *path installation*	slow (by controller, per-device)	fast (by device, distributed)	**fast** (by device, distributed)
robustness:			
- *network failures*	slow (by controller)	fast (local)	**fast** (local)
- *controller failures*	hard (ad-hoc synch)	native (distributed)	**easy** (synch via IGP)
- *partitions*	hard (uncontrollable devices)	best (distributed)	**best** (fallback on distributed)
routing policies:	highest (any path)	- low for IGP (shortest paths) - highest for RSVP (any path)	**high** (any non-loopy paths)

Acknowledgment

- Slides heavily adapted from material by Jennifer Rexford and Stefano Visicchio