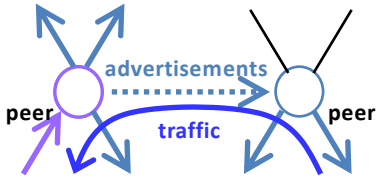


Interdomain Routing

Mike Freedman
COS 461: Computer Networks

http://www.cs.princeton.edu/courses/archive/spr20/cos461/

How to avoid BGP Instability

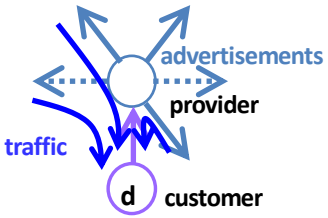
- Detecting conflicting policies
  - CON: Computationally expensive
  - CON: Requires too much cooperation
- Detecting oscillations
  - Observing the repetitive BGP routing messages
  - CON: Requires dynamic, stateful analysis
- **Restricted routing policies and topologies**
  - **Policies based on business relationships**

AS (Autonomous System) Business Relationships

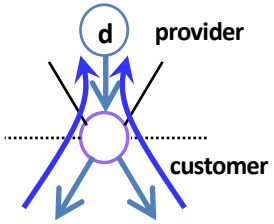
Customer-Provider Relationship

- Customer pays provider for access to Internet
  - Provider exports its customer routes to everybody
  - Customer exports provider routes only to its customers

Traffic to customer



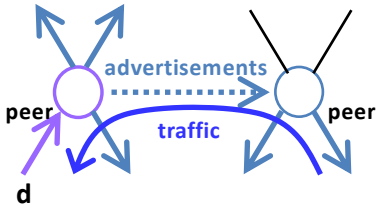
Traffic from customer



Peer-Peer Relationship

- Peers exchange traffic between their customers
  - AS exports only customer routes to a peer
  - AS exports a peer's routes only to its customers

Traffic to/from the peer and its customers



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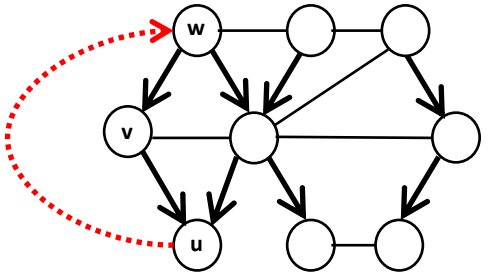
Hierarchical AS Relationships

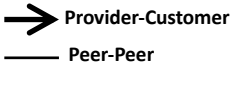
- Provider-customer graph is directed and acyclic
  - If u is a customer of v and v is a customer of w
  - … then w is not a customer of u

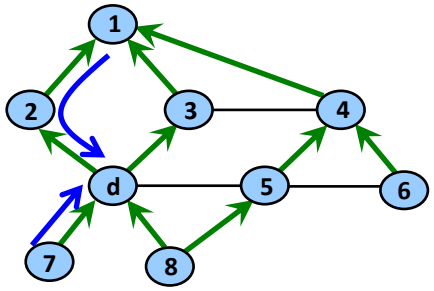


6

Valid and Invalid Paths

Path 1 2 d
Path 7 d
Path 5 8 d
Path 6 4 3 d
Path 8 5 d
Path 6 5 d
Path 1 4 3 d



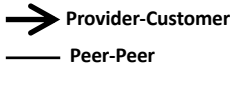


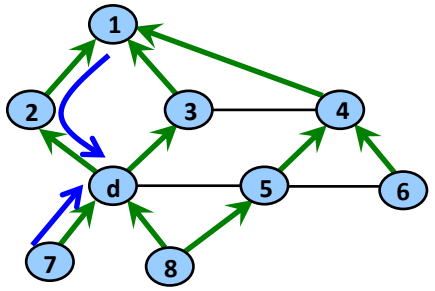
7

Valid and Invalid Paths

Path 1 2 d	**Valid**
Path 7 d	**Valid**
Path 5 8 d	**Invalid**
Path 6 4 3 d	**Valid**
Path 8 5 d	**Valid**
Path 6 5 d	**Invalid**
Path 1 4 3 d	**Invalid**

Y) Valid M) Invalid





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Local Control, Global Stability: "Gao-Rexford Conditions"

1. Route export
   - Don't export routes learned from a peer or provider to another peer or provider
2. Global topology
   - Provider-customer relationship graph is acyclic
   - E.g., my customer's customer is not my provider
3. Route selection
   - Prefer routes through customers over routes through peers and providers

Guaranteed to converge to unique, stable solution

11

How do we implement Interdomain Routing Policy?

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Selecting a Best Path

- Routing Information Base
  - Store all BGP routes for each destination prefix
  - Withdrawal: remove the route entry
  - Announcement: update the route entry
- BGP decision process
  - Highest local preference
  - Shortest AS path
  - Closest egress point
  - Arbitrary tie break

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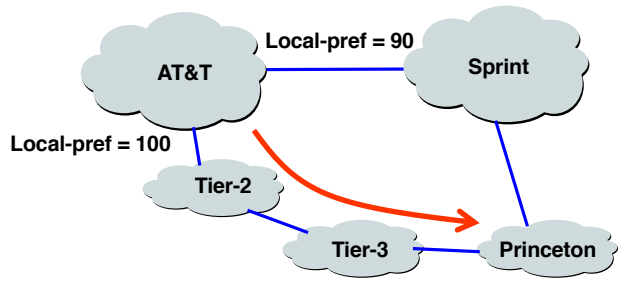
Import Policy: Local Preference

- Favor one path over another
  - Override the influence of AS path length
- Example: prefer customer over peer



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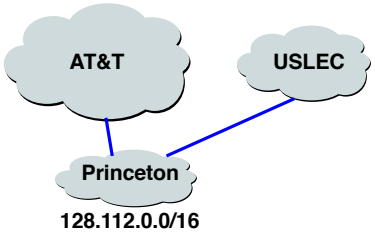
Import Policy: Filtering

- Discard some route announcements
  - Detect configuration mistakes and attacks
- Examples on session to a customer
  - Discard route if prefix not owned by the customer
  - Discard route with other large ISP in the AS path



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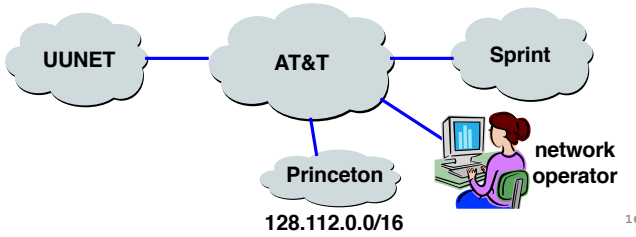
Export Policy: Filtering

- Discard some route announcements
  - Limit propagation of routing information
- Examples
  - Don't announce routes from one peer to another
  - Don't announce routes for management hosts



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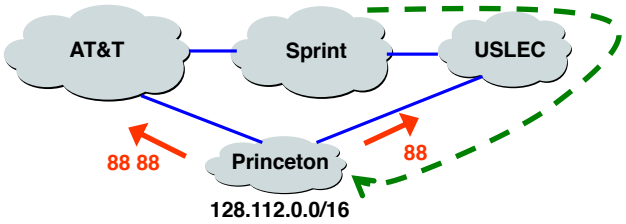
Export Policy: Attribute Manipulation

- Modify attributes of the active route
  - To influence the way other ASes behave
- Example: AS prepending
  - Artificially inflate AS path length seen by others
  - Convince some ASes to send traffic another way



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Reflect Business Relationships

- Common relationships
  - Customer-provider
  - Peer-peer
  - Backup, sibling, …
- ISP terminology:
  - Tier-1 (~15 worldwide): No settlement or transit
  - Tier-2 ISPs: Widespread peering, still buy transit
- Policies implementing in BGP, e.g.,
  - Import: Ranking customer routes over peer routes
  - Export: Export only customer routes to peers and providers

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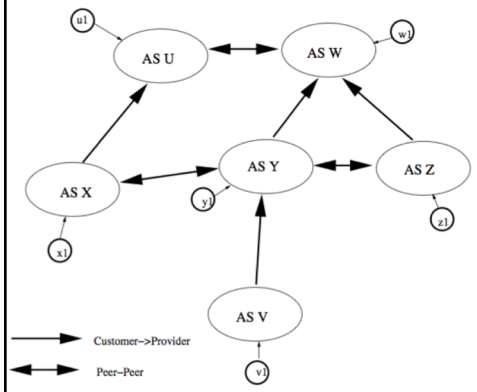
BGP Policy



Tier 1 ISPs?

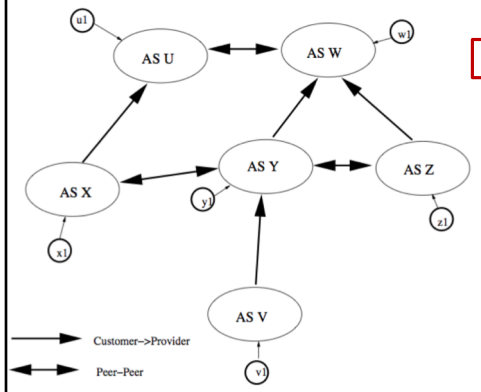
Y. U, W
M. U, X
C. X, Y, Z

Which path may packets take (given commercial policies)?

Y. Red
M. Blue
C. Green
A. Orange

19

BGP Policy



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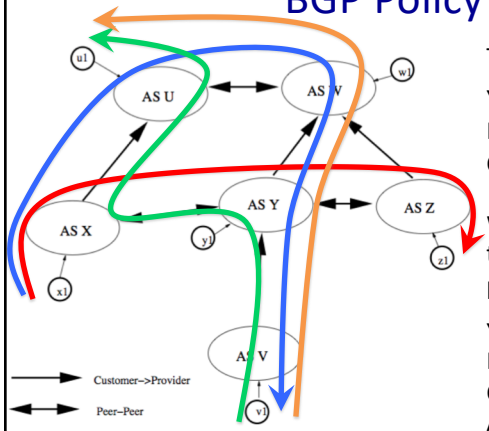
20

BGP Policy



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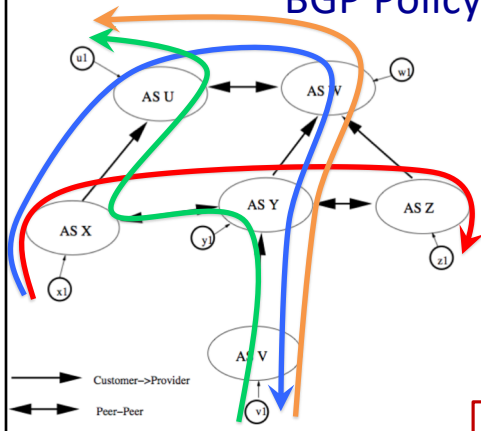
21

BGP Policy



Tier 1 ISPs?

Y. U, W
M. U, X
C. X, Y, Z

Which path may packets take (given commercial policies)?

Y. Red
M. Blue
C. Green
A. Orange

22

BGP Policy Configuration

- Routing policy languages are vendor-specific
  - Not part of the BGP protocol specification
  - Different languages for Cisco, Juniper, etc.
- Still, all languages have some key features
  - List of clauses matching on route attributes
  - … and discarding or modifying the matching routes
- Configuration done by human operators
  - Implementing the policies of their AS
  - Business relationships, traffic engineering, security

23

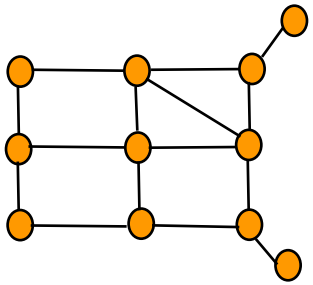
How do backbone AS operate?

Backbone Topology

24

Backbone Networks

- Backbone networks
  - Multiple Points-of-Presence (PoPs)
  - Lots of communication between PoPs
  - Accommodate traffic demands and limit delay



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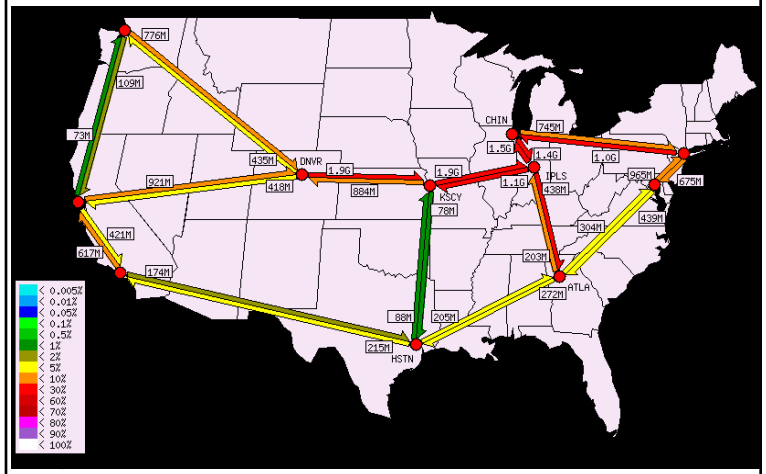
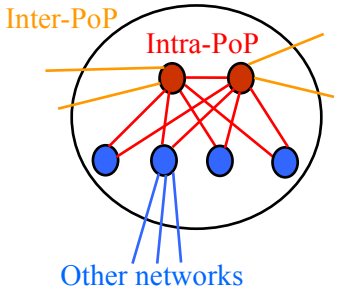
Abilene Internet2 Backbone



Points-of-Presence (PoPs)

- Inter-PoP links
  - Long distances
  - High bandwidth
- Intra-PoP links
  - Short cables between racks or floors
  - Aggregated bandwidth
- Links to other networks
  - Wide range of media and bandwidth



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Where to Locate Nodes and Links

- Placing Points-of-Presence (PoPs)
  - Large population of potential customers
  - Other providers or exchange points
  - Cost and availability of real-estate
  - Mostly in major metropolitan areas ("NFL cities")
- Placing links between PoPs
  - Already fiber in the ground
  - Needed to limit propagation delay
  - Needed to handle the traffic load

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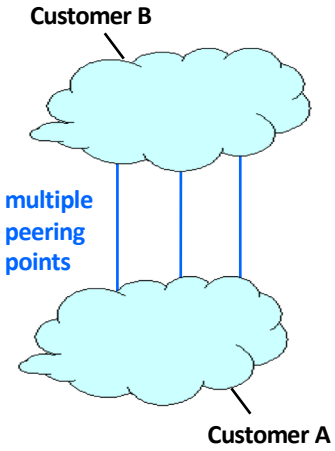
Peering



- Exchange traffic between customers
  - Settlement-free
- Diverse peering locations
  - Both coasts, and middle
- Comparable capacity at all peering points
  - Can handle even load

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Combining Intradomain and Interdomain Routing

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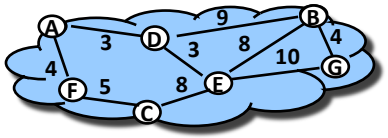
Intradomain Routing



- Compute shortest paths between routers
  - Router C takes path C-F-A to router A
- Using link-state routing protocols
  - E.g., OSPF, IS-IS

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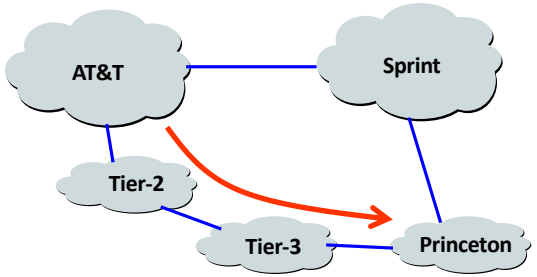
Interdomain Routing

- Learn paths to remote destinations
  - AT&T learns two paths to Yale
- Applies local policies to select a best route



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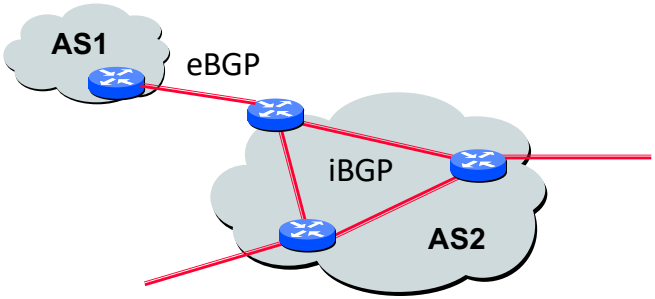
An AS is Not a Single Node

- Multiple routers in an AS
  - Need to distribute BGP information within the AS
  - Internal BGP (iBGP) sessions between routers



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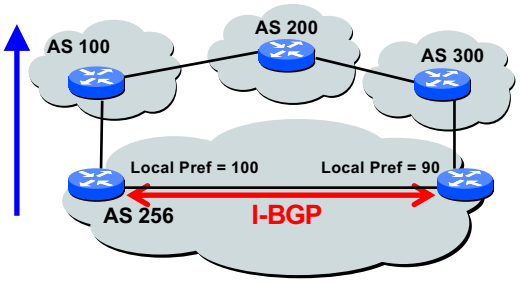
Internal BGP and Local Preference

- Both routers prefer path through AS 100
- … even though right router learns external path



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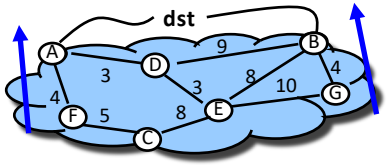
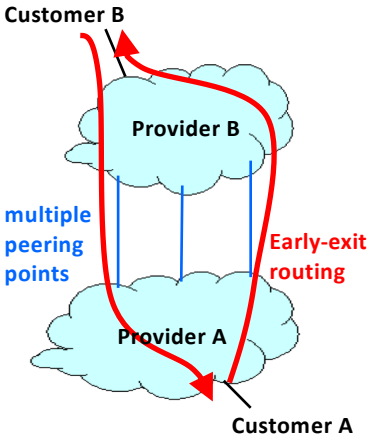
Hot-Potato (Early-Exit) Routing

- Hot-potato routing
  - Each router selects the closest egress point
  - … based on the path cost in intradomain protocol
- BGP decision process
  - Highest local preference
  - Shortest AS path
  - Closest egress point
  - Arbitrary tie break



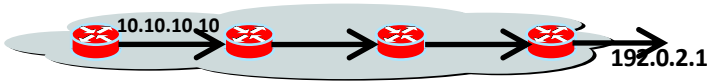
Hot-Potato Routing



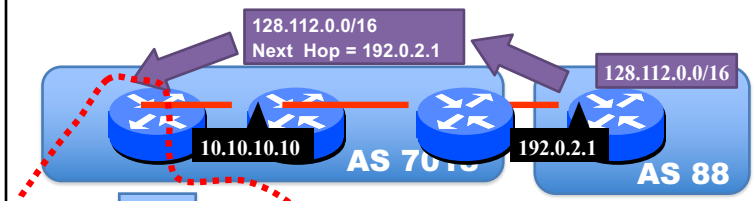
- Selfish routing
  - Each provider dumps traffic on the other
  - As early as possible
- Asymmetric routing
  - Traffic does not flow on same path in both directions

Joining BGP and IGP Information

- Border Gateway Protocol (BGP)
  - Announces reachability to external destinations
  - Maps a destination prefix to an egress point
    - 128.112.0.0/16 reached via 192.0.2.1
- Interior Gateway Protocol (IGP)
  - Used to compute paths within the AS
  - Maps an egress point to an outgoing link
    - 192.0.2.1 reached via 10.10.10.10



Joining BGP with IGP Information



IGP

destination	next hop
192.0.2.0/30	10.10.10.10

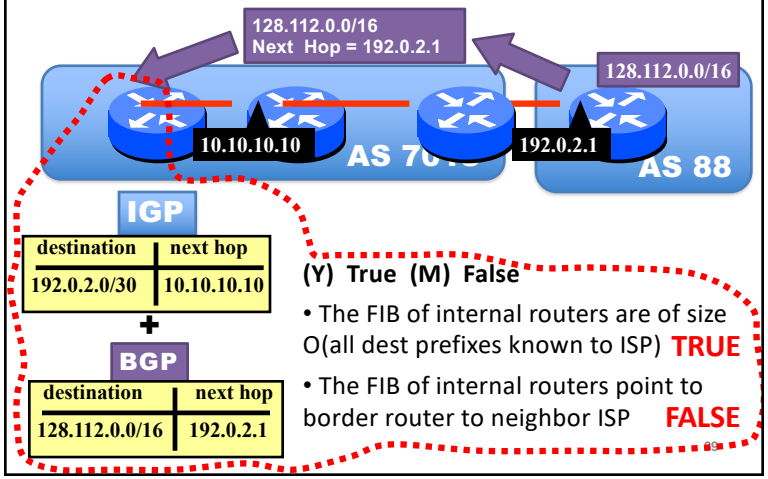
BGP

destination	next hop
128.112.0.0/16	192.0.2.1

(Y) True (M) False

- The FIB of internal routers are of size O(all dest prefixes known to ISP)
- The FIB of internal routers point to border router to neighbor ISP

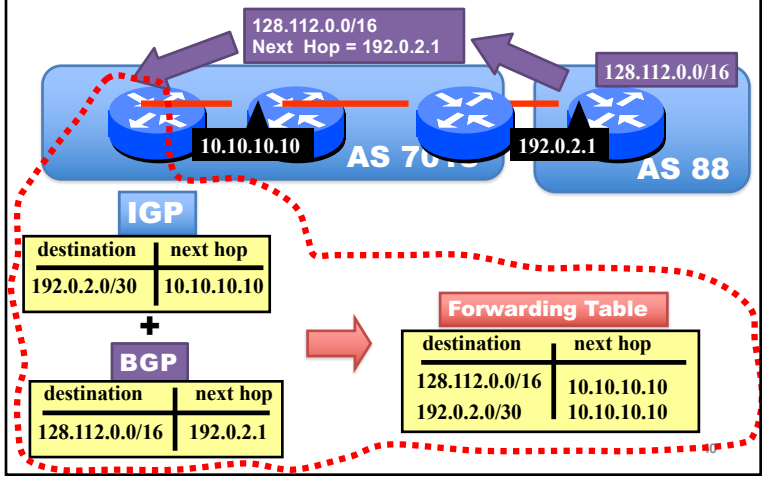
Joining BGP with IGP Information



(Y) True (M) False

- The FIB of internal routers are of size O(all dest prefixes known to ISP) **TRUE**
- The FIB of internal routers point to border router to neighbor ISP **FALSE**

Joining BGP with IGP Information



Backbone Traffic Engineering

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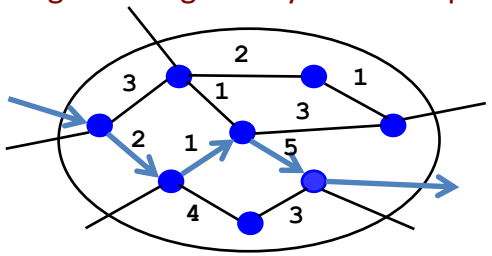
Routing With "Static" Link Weights

- 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



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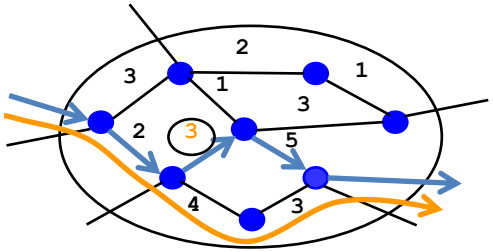
Setting the Link Weights

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



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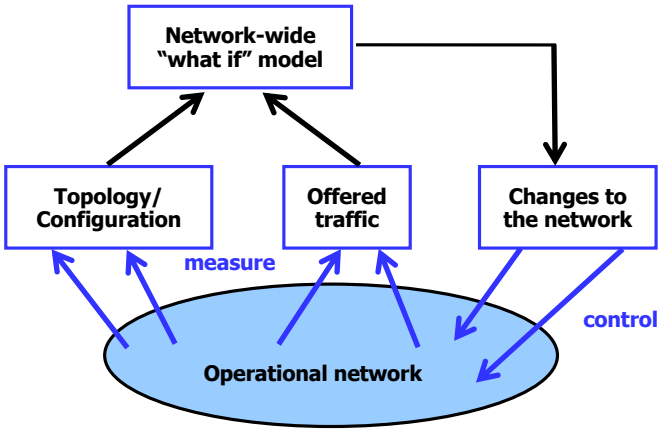
Measure, Model, and Control



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Limitations of Shortest-Path Routing

- Sub-optimal traffic engineering
  - Restricted to paths expressible as link weights
- Limited use of multiple paths
  - Only equal-cost multi-path, with even splitting
- Disruptions when changing the link weights
  - Transient packet loss and delay, and out-of-order
- Slow adaptation to congestion
  - Network-wide re-optimization and configuration
- Overhead of the management system

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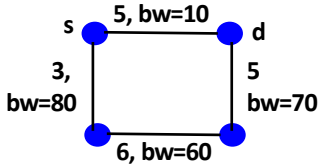
Constrained Shortest Path First

- Run a link-state routing protocol
  - Configurable link weights
  - Plus other metrics like available bandwidth
- Constrained shortest-path computation
  - Prune unwanted links (e.g., not enough bw)
  - Compute shortest path on the remaining graph



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Conclusions

- Interdomain routing
  - Business relationships reflected in interdomain routing, leads to more stable paths
  - Peering and transit key ideas between providers, peers, and customer AS
- Backbone networks
  - Transit service for customers
  - Combine inter and intradomain routing
  - Glue that holds the Internet together

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