Routing Convergence

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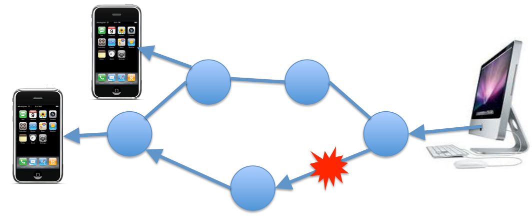
COS 461: Computer Networks

Lectures: MW 10-10:50am in Architecture N101

http://www.cs.princeton.edu/courses/archive/spr13/cos461/

Routing Changes



- Topology changes: new route to the same place
- Host mobility: route to a different place

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Topology Changes

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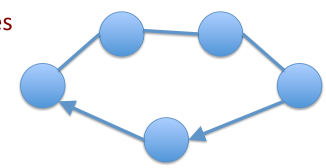
Two Types of Topology Changes

- Planned
  – Maintenance: shut down a node or link
  – Energy savings: shut down a node or link
  – Traffic engineering: change routing configuration
- Unplanned Failures
  – Fiber cut, faulty equipment, power outage, software bugs, …



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Detecting Topology Changes

- Beaconing
  – Periodic "hello" messages in both directions
  – Detect a failure after a few missed "hellos"

- Performance trade-offs
  – Detection delay
  – Overhead on link bandwidth and CPU
  – Likelihood of false detection

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Routing Convergence: Link-State Routing

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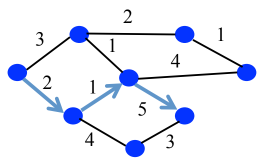
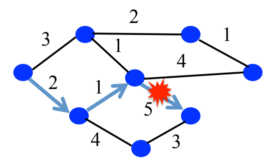
Convergence

- Control plane
  - All nodes have consistent information
- Data plane
  - All nodes forward packets in a consistent way



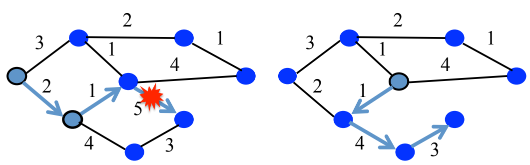
Transient Disruptions

- Detection delay
  - A node does not detect a failed link immediately
  - … and forwards data packets into a "blackhole"
  - Depends on timeout for detecting lost hellos



Transient Disruptions

- Inconsistent link-state database
  - Some routers know about failure before others
  - Inconsistent paths cause transient forwarding loops



Convergence Delay

- Sources of convergence delay
  - Detection latency
  - Updating control-plane information
  - Computing and install new forwarding tables
- Performance during convergence period
  - Lost packets due to blackholes and TTL expiry
  - Looping packets consuming resources
  - Out-of-order packets reaching the destination
- Very bad for VoIP, online gaming, and video

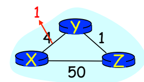
Reducing Convergence Delay

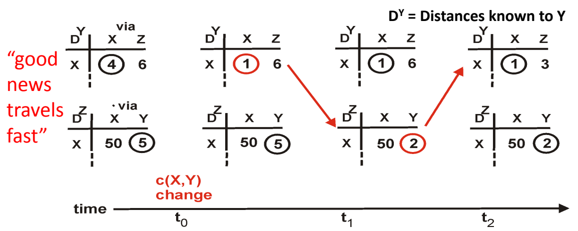
- Faster detection
  - Smaller hello timers, better link-layer technologies
- Faster control plane
  - Flooding immediately
  - Sending routing messages with high-priority
- Faster computation
  - Faster processors, and incremental computation
- Faster forwarding-table update
  - Data structures supporting incremental updates

Slow Convergence in Distance-Vector Routing

Distance Vector: Link Cost Changes

- Link cost decreases and recovery
  - Node updates the distance table
  - If cost change in least cost path, notify neighbors





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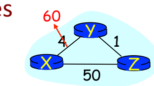
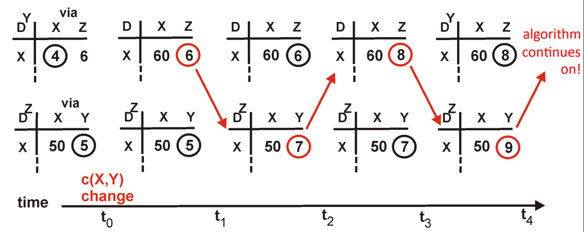
Distance Vector: Link Cost Changes

- Link cost increases and failures
  - Bad news travels slowly
  - "Count to infinity" problem!





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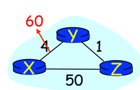
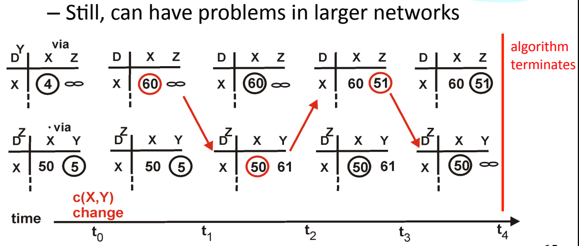
Distance Vector: Poison Reverse

- If Z routes through Y to get to X :
  - Z tells Y its (Z's) distance to X is infinite (so Y won't route to X via Z)
  - Still, can have problems in larger networks





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Redefining Infinity

- Avoid "counting to infinity"
  - By making "infinity" smaller!
- Routing Information Protocol (RIP)
  - All links have cost 1
  - Valid path distances of 1 through 15
  - … with 16 representing infinity
- Used mainly in small networks

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Reducing Convergence Time With Path-Vector Routing (e.g., Border Gateway Protocol)

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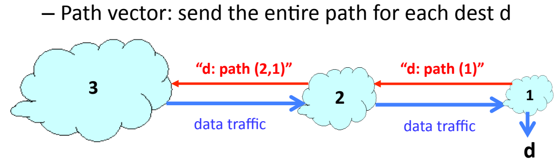
Path-Vector Routing

- Extension of distance-vector routing
  - Support flexible routing policies
  - Avoid count-to-infinity problem
- Key idea: advertise the entire path
  - Distance vector: send distance metric per dest d
  - Path vector: send the entire path for each dest d



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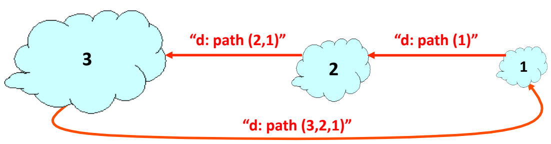
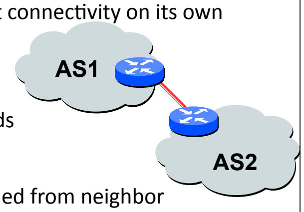
Faster Loop Detection

- Node can easily detect a loop
  - Look for its own node identifier in the path
  - E.g., node 1 sees itself in the path "3, 2, 1"
- Node can simply discard paths with loops
  - E.g., node 1 simply discards the advertisement

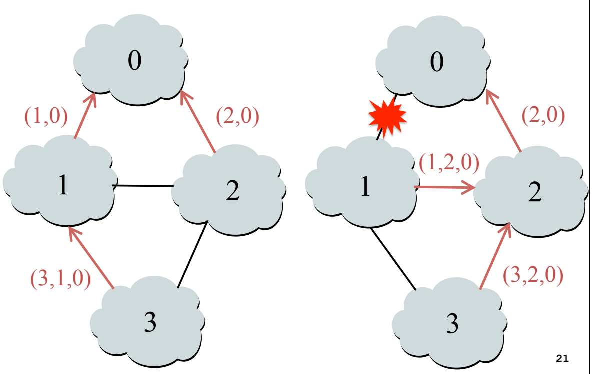


BGP Session Failure

- BGP runs over TCP
  - BGP only sends updates when changes occur
  - TCP doesn't detect lost connectivity on its own
- Detecting a failure
  - Keep-alive: 60 seconds
  - Hold timer: 180 seconds
- Reacting to a failure
  - Discard all routes learned from neighbor
  - Send new updates for any routes that change

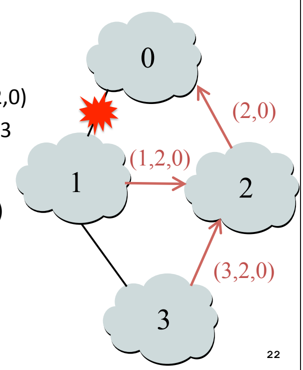


Routing Change: Before and After



Routing Change: Path Exploration

- AS 1
  - Delete the route (1,0)
  - Switch to next route (1,2,0)
  - Send route (1,2,0) to AS 3
- AS 3
  - Sees (1,2,0) replace (1,0)
  - Compares to route (2,0)
  - Switches to using AS 2

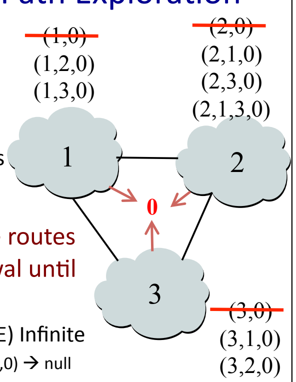


Routing Change: Path Exploration

- Initial: All AS use direct
- Then destination 0 dies
  - All ASes lose direct path
  - All switch to longer paths
  - Eventually withdrawn
- How many intermediate routes following (2,0) withdrawal until no route known to 2?

(A) 1 (B) 2 (C) 3 (D) 4 (E) Infinite

(2,0) → (2,1,0) → (2,3,0) → (2,1,3,0) → null



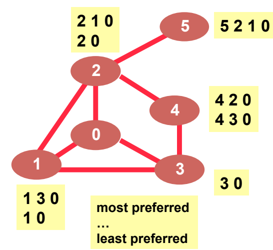
BGP Converges Slowly

- Path vector avoids count-to-infinity
  - But, ASes still must explore many alternate paths to find highest-ranked available path
- Fortunately, in practice
  - Most popular destinations have stable BGP routes
  - Most instability lies in a few unpopular destinations
- Still, lower BGP convergence delay is a goal
  - Can be tens of seconds to tens of minutes

BGP Instability

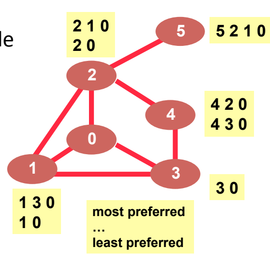
Stable Paths Problem (SPP) Instance

- Node
  - BGP-speaking router
  - Node 0 is destination
- Edge
  - BGP adjacency
- Permitted paths
  - Set of routes to 0 at each node
  - Ranking of the paths



Stable Paths Problem (SPP) Instance

- Solution
  - Path assignment per node
  - Can be the “null” path
- If node u has path uwP
  - {u,w} is edge in graph
  - w is assigned path wP
- Each node is assigned
  - Highest ranked path consistent with its neighbors

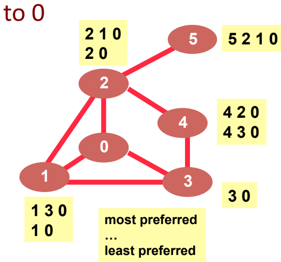


Stable Paths Problem (SPP) Instance

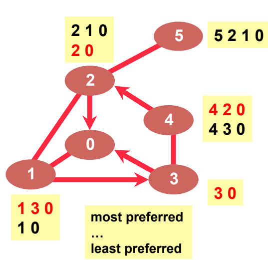
- 1 will use a direct path to 0

  (A) True (B) False
- 5 has a path to 0

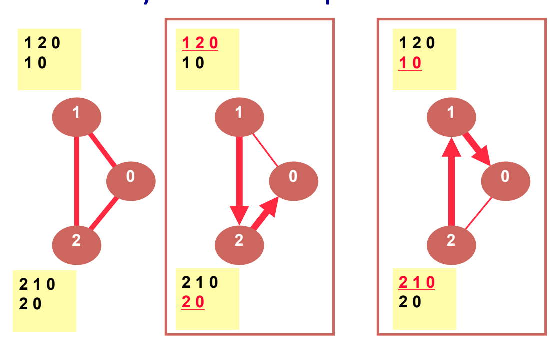
  (A) True (B) False



Stable Paths Problem (SPP) Instance



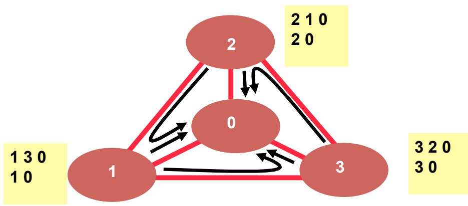
SPP May Have Multiple Solutions



First solution

Second solution

An SPP May Have No Solution



Avoiding BGP Instability

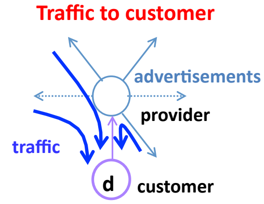
- Detecting conflicting policies
  - Computationally expensive
  - Requires too much cooperation
- Detecting oscillations
  - Observing the repetitive BGP routing messages
- Restricted routing policies and topologies
  - Policies based on business relationships

AS (Autonomous System) Business Relationships

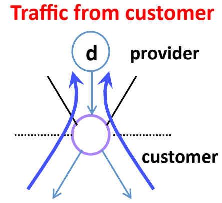
Customer-Provider Relationship

- 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



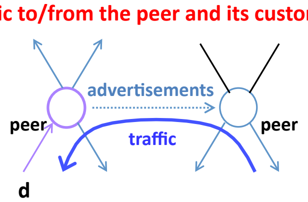
Traffic from customer



Peer-Peer Relationship

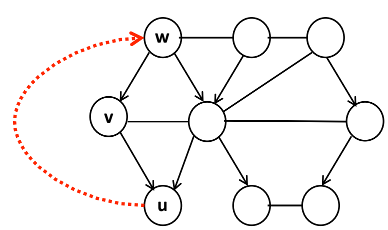
- Peers exchange traffic between their customers
  - AS exports only customer routes to a peer
  - AS exports a peer's routes only to its customers

Traffic to/from the peer and its customers



Hierarchical AS Relationships

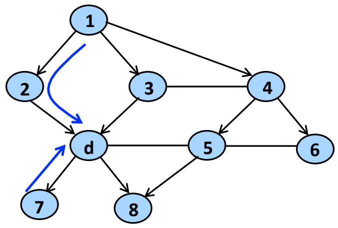
- Provider-customer graph is directed and acyclic
  - If u is a customer of v and v is a customer of w
  - … then w is not a customer of u



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

A) Valid B) Invalid



Provider-Customer
Peer-Peer

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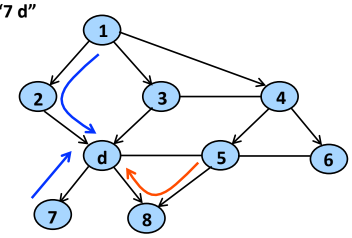
Valid and Invalid Paths

Valid paths: "1 2 d" and "7 d"
Invalid path: "5 8 d"



Provider-Customer
Peer-Peer

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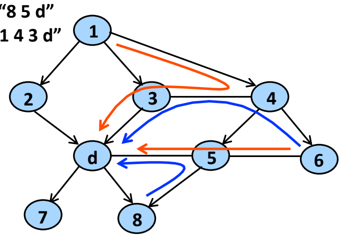
Valid and Invalid Paths

Valid paths: "6 4 3 d" and "8 5 d"
Invalid paths: "6 5 d" and "1 4 3 d"



Provider-Customer
Peer-Peer

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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

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Conclusion

- The only constant is change
  - Planned topology and configuration changes
  - Unplanned failure and recovery
- Routing-protocol convergence
  - Transient period of disagreement
  - Blackholes, loops, and out-of-order packets
- Routing instability
  - Permanent conflicts in routing policy
  - Leading to bi-stability or oscillation

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