6.033 - Networking: Routing (BGP)
Lecture 9
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0. Introduction
  - Today: routing, some addressing
  - Enormous growth of Internet => routing protocols redesigned to scale, and also to enforce policy.

1. Routing
  - Goal: allow each switch to know, for every node in the network, a min-cost route to that node (if one exists).
  - Remember: networks aren't static. Link costs change, machines/links go down, etc.
  - Our approach: distributed routing. Each node learns about the network and determines its own routes. In general:
    - Nodes use a HELLO protocol to discover neighbors
    - Nodes receive advertisements to learn about the network
    - Nodes integrate those advertisements to figure out routes
  - Protocol 1: Distance-vector. Nodes advertise to neighbors with their cost to all known nodes, and update routes when an advertise-
    ment indicates that there is a better route.
  - Protocol 2: Link-state: Nodes advertise to everyone (via flooding) their costs to their neighbors, and integrate using Dijkstra's.
    - You do NOT need to know Dijkstra's Algorithm for 6.033.
  - Problem: DV and LS don't scale to the Internet
    - DV = low overhead, but convergence time is proportional to longest path. Good for small networks.
    - LS = fast convergence, but high overhead because of flooding. Good for MIT-sized networks, but not the Internet.

2. (Three ways we deal with) scale
  - Path-vector routing
    - Like DV, but include the full path in the routing advertisements. Overhead increases (advs are larger), but convergence time decreases (avoid counting to infinity).
    - Overhead is still lower than LS's
  - Routing Hierarchy
    - Internet is divided into Autonomous Systems (ASes). ASes are universities, ISPs, government branches, etc. Each AS has a unique ID (its AS number). There are tens of thousands of them (but not billions)
    - Use one routing protocol to route across ASes, and a different protocol to route within ASes.
      - Implies that there are devices on the edge of each AS that can "translate" between or "speak" both protocols.
    - BGP is the path-vector protocol used across ASes.
  - Topological addressing
    - Despite being between ASes, BGP still routes to IP addresses

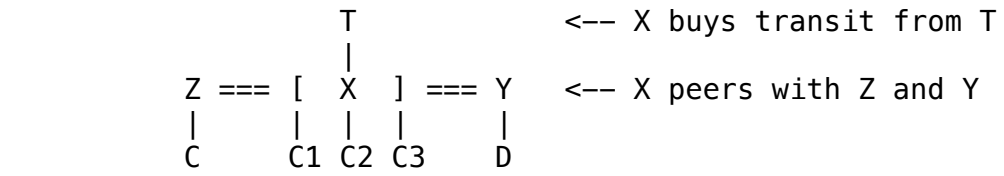
(e.g., to 18.0.0.1, not to AS3)
- Addresses are given to ASes in contiguous blocks, so that they can be specified succinctly via a particular notation ("CIDR" notation).
- Keeps advertisements small(er than they would be otherwise)

3. Policy Routing
- ASes also want to implement policy; they want "policy routing"
- Policy routing: switches make routing decisions based on some set of policies set by a human. Routing protocol must disseminate enough information to enable those policies
- What policies are typical in BGP? ASes don't want to send traffic on a path unless they have financial incentive to do so.
- Mechanism of enforcement: selective advertisements. AS1 won't tell AS2 about a path unless it will make money by letting AS2 use the path.
  => each AS will have a different view of the network, and that view will (almost certainly) *not* contain every physical link

4. Typical BGP Relationships (which will eventually lead us to typical BGP policies)
- Customer/provider
  - Customers pay for access (transit), which the provider provides
- Peers
  - Peers provide mutual access to a subset of each other's routing tables, namely, the subset that contains their transit customers
  - Why peer? Can save money and improve performance. Sometimes, it may be the only way to connect your customers to some part of the Internet.
  - Why *not* peer? You'd rather have customers.

5. BGP Relationships => BGP Export Policies
- First decision: which routes do I advertise to which neighbors? These are an AS's "export policies"
  - High-level: "Tell everyone about yourself (your internal IPs) and your customers; tell your customer about everyone."
  - More specifically:
    - Providers export customer's routes to everyone
    - A customer exports its provider's routes to *its* customers
      - These two should make sense: since the customer is paying for Internet, the provider should give them a route to as many destinations as possible. Similarly, the provider should allow *other* parts of the network to reach its customers.
    - AS exports *only* customer routes to peers.
      - Why not full table? AS doesn't want to provide transit for its peers; they're not paying it for transit.

Example: (Very similar to the example I gave in lecture)



- Z will tell X about C; C is a customer of Z, and X and Z are peers
- X will tell Z, Y, and T about C1, C2, and C3.
- Y will tell X about D.
- X will *not* tell Y about C; it makes no money to provide transit from Y to C
- X doesn't tell Y about T; it would lose money to provide transit from Y to T.

- In example, Y appears disconnected from part of the network. BGP doesn't prevent this. In practice, it never happens.
  - Almost every AS is a customer of someone else (i.e., Y would buy transit from someone)
    - Typically: small ASes buy Internet from Tier-3 ISPs, which buy Internet from Tier-2 ISPs, which buy Internet from Tier-1 ISPs. Tier-1's are huge; there are only a handful (10-15)
  - Additionally, all Tier-1 ISPs peer with one another. So each Tier-1 ISP can provide global connectivity.
    - This is an example where we need peering in order to reach part of the Internet.

6. BGP Relationships => BGP Import Policies
  - If an AS hears about a route to X from multiple neighbors, how does it decide? These are its "import policies".
  - First: make money. Prefer routes via customers -- which you make money on -- to routes via peers -- which you don't make, but don't lose money on -- to routes via providers -- which you lose money on.
  - In the case of a tie (which happens often): there are a whole host of other attributes that BGP provides. A common one is AS-hop-count.
  - Each AS sets its own policies

7. BGP in light of distributed routing
  - HELLO protocol: BGP sends KEEPALIVE messages to neighbors.
  - Advertisements: sent to neighbors. Look different depending on which neighbor.
    - BGP runs on top of TCP, a reliable-transport protocol. Doesn't have to do periodic advertisements to handle failure. Instead, push advs when routes change.
  - Integration: via policies described above
  - Failures: routes can be explicitly withdrawn in BGP when they fail. Routing loops avoided because BGP is path-vector.

8. Problems with BGP

- Does it scale? Well, it works on the Internet. But..
  - BGP routing tables are getting big (exceeding the amount of memory dedicated to the table in some switches).
  - We see route instability due to misconfigurations or conflicting AS policies. "Route-flap damping" (ignore advs about frequently-changing routes) helps with this, but increases convergence time.
  - ASes can multi-home: buy Internet from more than one ISP, usually for back-up or load-balancing. More multi-homed networks => bigger routing tables. The load-balancing itself is also tricky.
  - iBGP. An AS actually has multiple BGP routers on its edge, and a protocol called iBGP keeps them all in sync. iBGP requires an AS's BGP routers to be connected in a complete graph, and so it doesn't scale particularly well.
  - Basically: Internet has grown enough that scalability of BGP is becoming a concern.
- Is it secure?
  - Goodness no. ASes can advertise about a prefix that they don't actually own.
  - Similar problem (and solution) as in DNS. We'll talk more about it after spring break.
- Is it simple?
  - The protocol itself: yes.
  - BGP in practice: no. Again, mo' money, mo' problems. Also, human operator error due to the complexity of setting the policies.