Lecture 11: Inter-Domain Routing (Part I)

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COS 461: Computer Networks

Slides adapted from H. Balakrishnan, N. Feamster, M. Freedman, B. Karp

Outline

- Context: Inter-Domain Routing
- Relationships between ASes
- Enforcing Policy, not Optimality
- BGP Design Goals
- BGP Protocol

- eBGP and iBGP
- BGP Route Attributes
- Synthesis: Policy through Route Attributes

Context: Inter-Domain Routing

- So far, have studied intra-domain routing
  - Domain: group of routers owned by a single entity, typically numbering at most 100s
  - Distance Vector, Link State protocols: types of Interior Gateway Protocol (IGP)
- Today's topic: inter-domain routing
  - Routing protocol that binds domains together into global Internet
  - Border Gateway Protocol (BGP): type of Exterior Gateway Protocol (EGP)

Context: Why Another Routing Protocol? (1/2)

- Scaling challenge:
  - ~~millions~~ billions of hosts on global Internet
  - ultra-naïve approach: use DV or LS routing, each 32-bit host address is a destination
  - naïve approach: use DV or LS routing, each subnet's address prefix (i.e., Ethernet broadcast domain) is a destination

Context: Why Another Routing Protocol? (2/2)

- Scaling challenge

- DV and LS cannot scale to these levels
  - prohibitive message complexity for LS flooding
  - loops and slow convergence for DV
  - Keeping routes current costs traffic proportional to product of number of nodes and rate of topological change

Context: Scaling Beyond the Domain

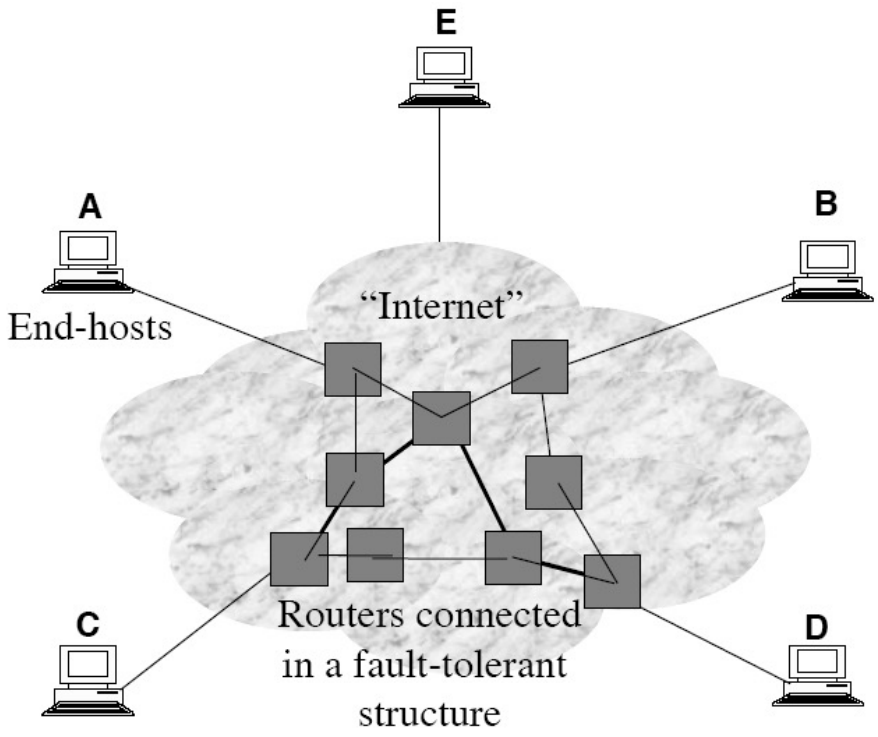
- Address allocation challenge:
  - Each host on Internet must have unique 32-bit IP address
  - How to enforce global uniqueness?
  - Onerous to consult central authority for each new host

- Hierarchical addressing: solves scaling and address allocation challenges

Context: Autonomous Systems

- A routing domain: called an Autonomous System (AS)
- Each AS known by unique 16-bit number
- IGPs (e.g., DV, LS) route among individual subnets
- EGPs (e.g., BGP) route among ASes
- AS owns one or handful of address prefixes; allocates addresses under those prefixes
- AS typically a commercial entity or other organization
- ASes are often competitors (e.g., different ISPs)

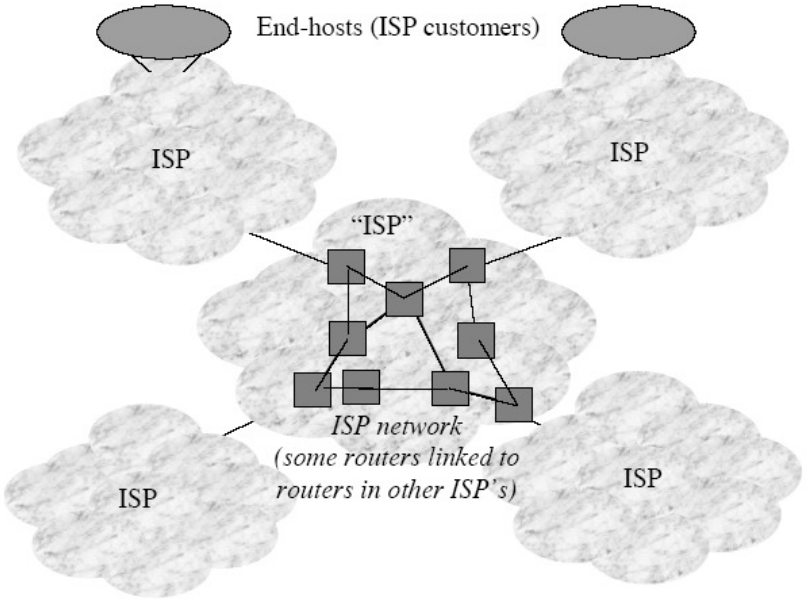
Global Internet Routing: Naïve View



- Find globally-shortest paths
- Dense connectivity with many redundant paths
- Route traffic cooperatively onto lightly loaded paths

No correspondence to reality!

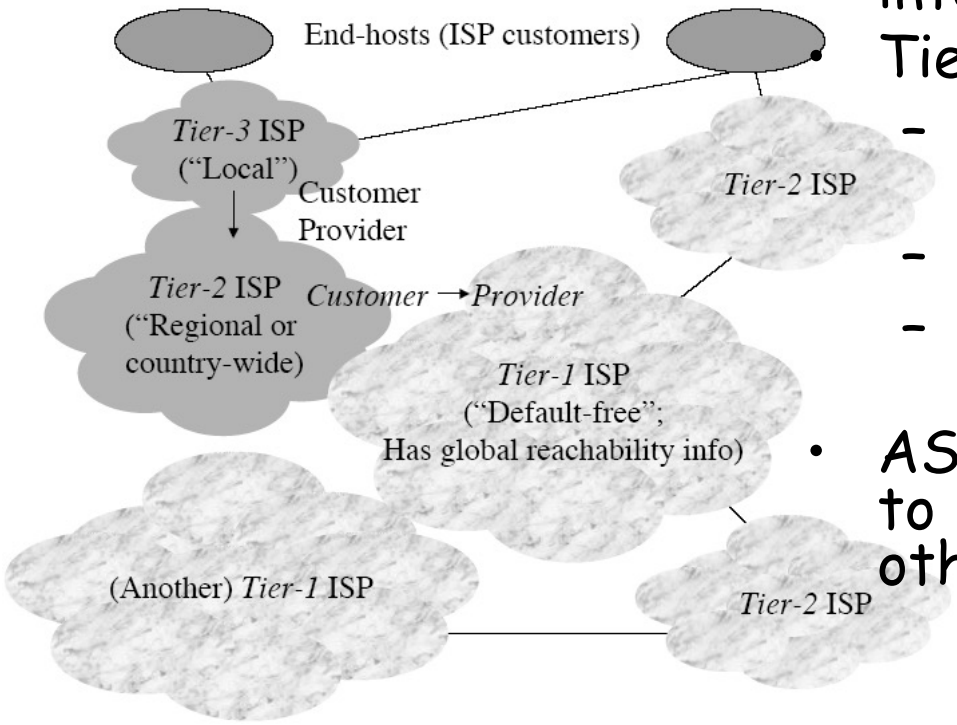
Global Internet Routing, Equal ISPs



- Multiple, interconnected ISPs
- ISPs all equal:
  - in how connected they are to other ISPs
  - in geographic extent of their networks

Little correspondence to reality!

Global Internet Routing: Status Quo



- Each ISP an AS, runs own IGP internally
- Tiers of ISPs:
  - Tier 3: local geographically, end customers
  - Tier 2: regional geographically
  - Tier 1: global geographically, ISP customers, no default routes
- AS operator sets policies for how to route to others, how to let others route to their AS

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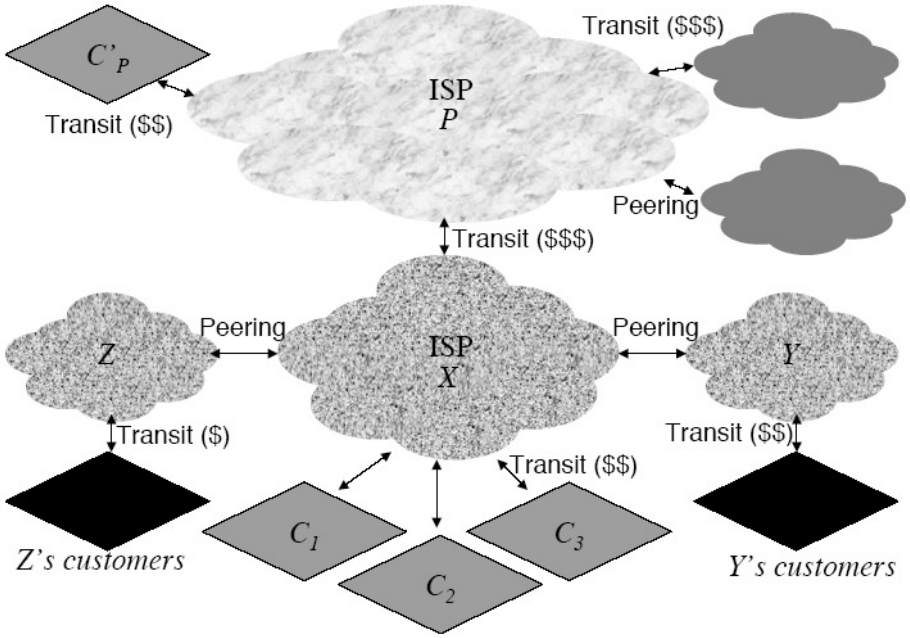
AS-AS Relationships: Customers and Providers

- Smaller ASes (corporations, universities) typically purchase connectivity from ISPs
- Regional ISPs typically purchase connectivity from global ISPs
- Each such connection has two roles:
  - Customer: smaller AS paying for connectivity
  - Provider: larger AS being paid for connectivity

AS-AS Relationship: Transit

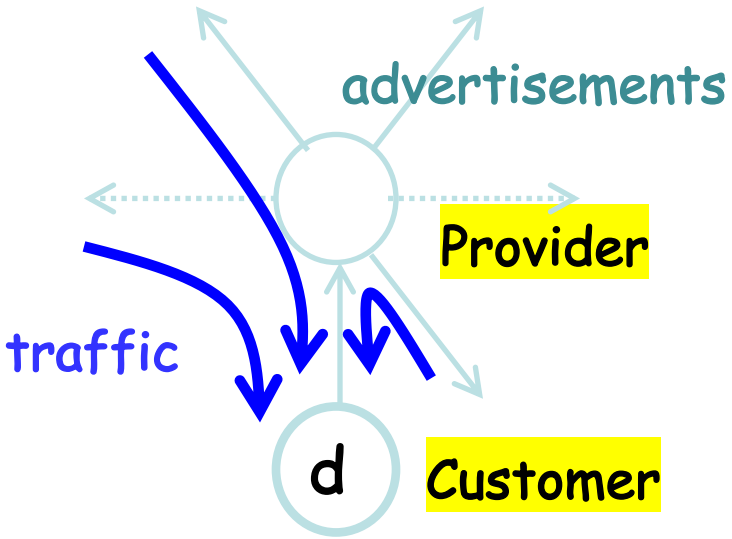


- Provider-Customer AS-AS connections: **transit**
- Provider allows customer to route to (nearly) all destinations in its routing tables
- Transit nearly always involves payment from customer to provider

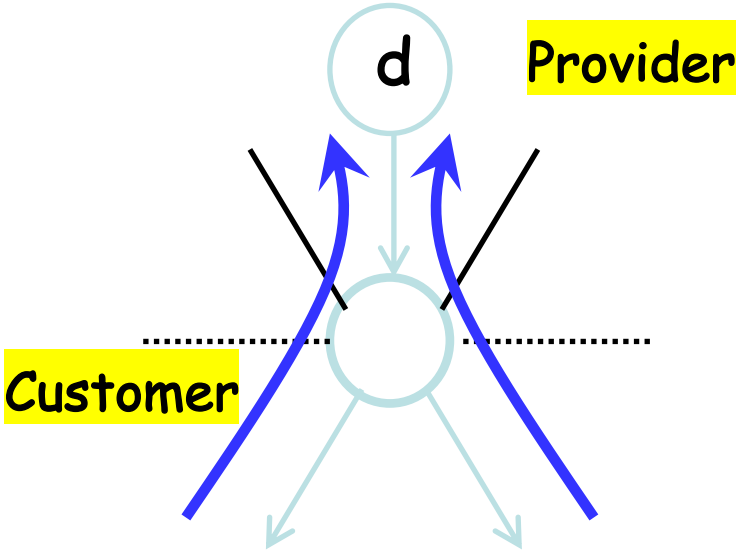
Provider-Customer Relationship

- 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



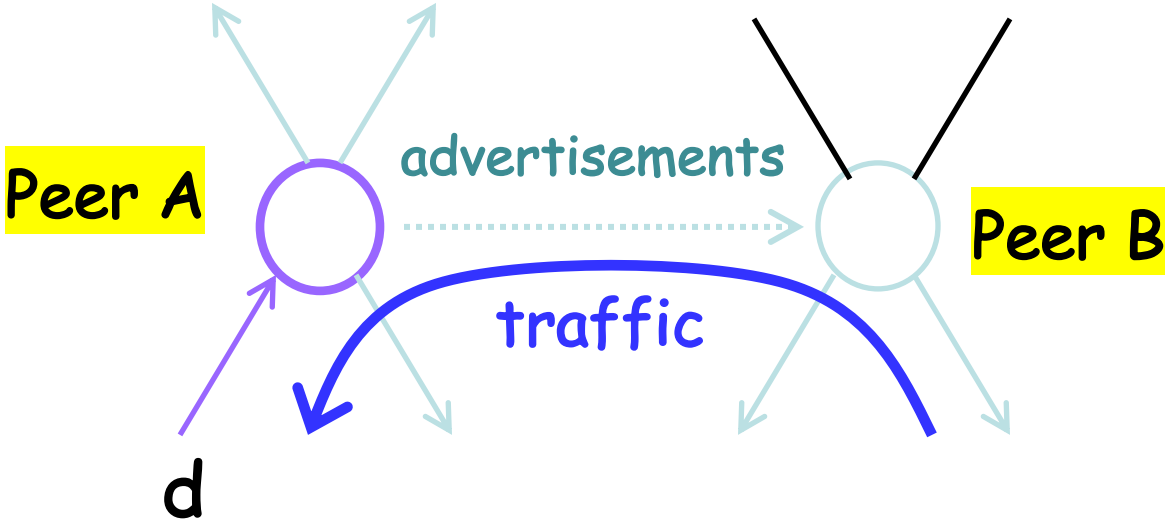
Traffic from customer



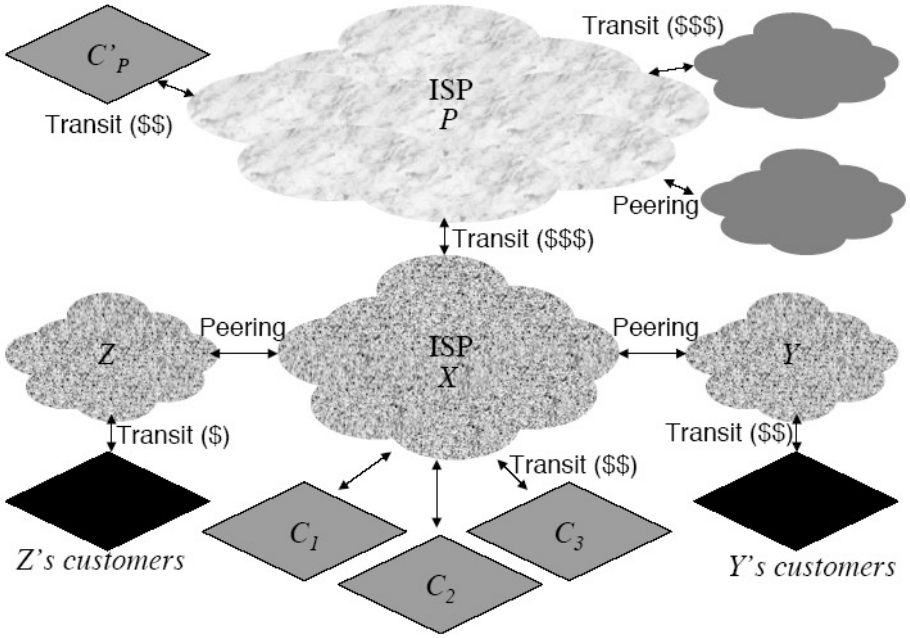
Peer-Peer Relationship

- Peers exchange traffic between their customers
  - AS exports **only customer** routes to a peer AS
  - AS exports a peer AS's routes <u>only</u> to **its customers**

Traffic to/from the peer and its customers



Peer-Peer Relationship: Financials



- By contract, but usually no money changes hands, so long as traffic ratio is narrower than, e.g., 4:1

Financial Motives: Peering and Transit

- Peering relationship often between competing ISPs
- Incentives to peer:
  - Typically, two ISPs notice their own direct customers originate a lot of traffic for the other
  - Each can avoid paying transit costs to others for this traffic; shunt it directly to one another
  - Often better performance (shorter latency, lower loss rate) as avoid transit via another provider
  - Easier than stealing one another's customers
- Tier 1s must typically peer with one another to build complete, global routing tables

Financial Motives: Peering and Transit (cont'd)

- Disincentives to peer:
  - Economic disincentive: transit lets ISP charge customer; peering typically doesn't
  - Contracts must be renegotiated often
  - Need to agree on how to handle asymmetric traffic loads between peers

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The Meaning of Advertising Routes

- When AS A advertises a route for destination D to AS B, it effectively offers to forward all traffic from AS B to D
- Forwarding traffic costs bandwidth
- ASes strongly motivated to control which routes they advertise
  - no one wants to forward packets without being compensated to do so
  - e.g., when peering, only let neighboring AS send to specific own customer destinations enumerated peering contract

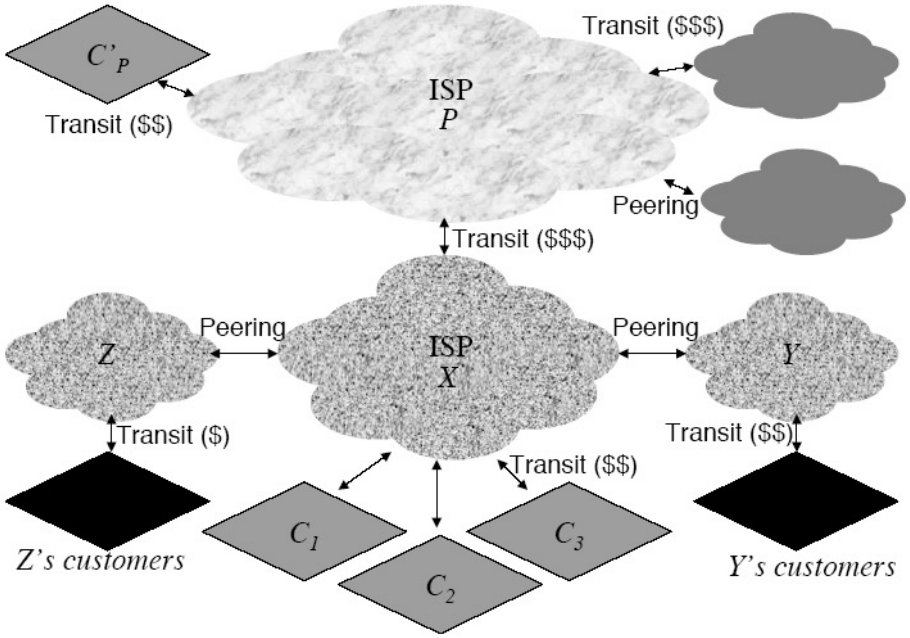
Advertising Routes for Transit Customers

- ISP motivated to advertise routes towards its own customers to its transit providers
  - Customers paying to be reachable from global Internet
  - More traffic to customer, faster link customer must buy
- If ISP hears route for its own customer from multiple neighbors, should favor advertisement from own customer

Routes Heard from Providers

- If ISP hears routes from its provider (via a transit relationship), to whom does it advertise them?
  - Not to ISPs with peering relationships; they don't pay, so no motivation to provide transit service for them!
  - To own customers, who pay to be able to reach global Internet

Example: Routes Heard from Providers

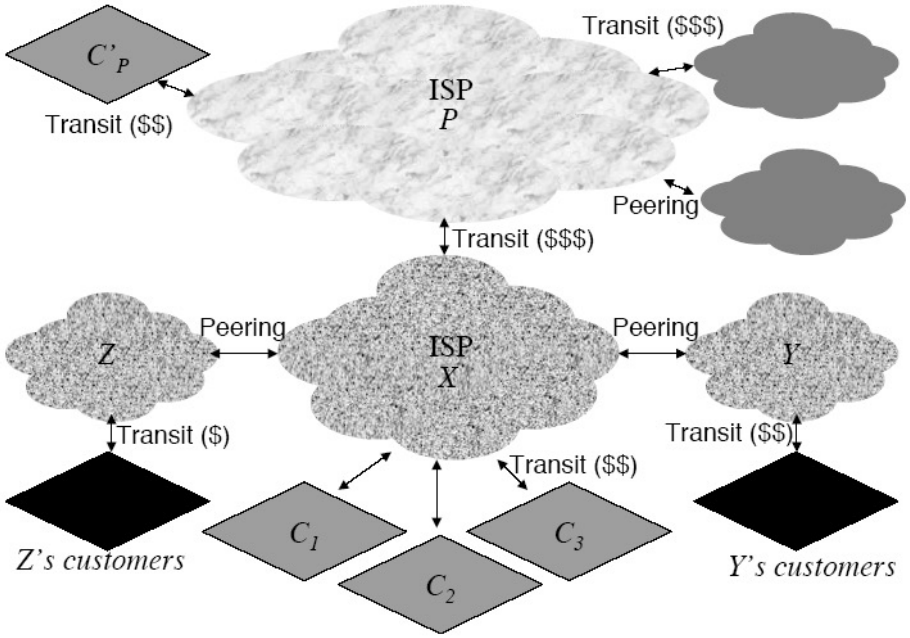


- ISP P announces route to C'_P, own customer, to X
- X doesn't announce C'_P to Y or Z; no revenue from peering
- X announces C'_P to C_i; they're paying to be able to reach everywhere

Routes Advertised to Peers

- Which routes should an ISP advertise to ASes with whom it has peering relationships?
  - Routes for all own downstream transit customers
  - Routes to ISP's own addresses
  - Not routes heard from upstream transit provider of ISP; peer might route via ISP for those destinations, but doesn't pay
  - Not routes heard from other peering relationships (same reason!)

Example: Routes Advertised to Peers



- ISP X announces C_i to Y and Z
- ISP X doesn't announce routes heard from ISP P to Y or Z
- ISP X doesn't announce routes heard from ISP Y to ISP Z, or vice-versa

Route Export: Summary

- ISPs typically provide selective transit
  - Full transit (export of all routes) for own transit customers in both directions
  - Some transit (export of routes between mutual customers) across peering relationship
  - Transit only for transit customers (export of routes to customers) to providers
- These decisions about what routes to advertise motivated by policy (money), not by optimality (e.g., shortest paths)

Route Import

- Router may hear many routes to same destination network
- Identity of advertiser very important
- Suppose router hears advertisement to own transit customer from other AS
  - Shouldn't route via other AS; longer path!
  - Customer routes higher priority than routes to same destination advertised by providers or peers
- Routes heard over peering higher priority than provider routes
  - Peering is free; you pay provider to forward via them
- customer > peer > provider

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Border Gateway Protocol (BGP): Design Goals

- Scalability in number of ASes
- Support for policy-based routing
  - tagging of routes with attributes
  - filtering of routes
- Cooperation under competitive pressure
  - BGP designed to run on successor to NSFnet, the former single, government-run backbone

BGP Protocol

- BGP runs over TCP, port 179
- Router connects to other router, sends OPEN message
- Both routers exchange all active routes in their tables (possibly minutes, depending on routing table sizes)
- In steady state, two main message types:
  - announcements: changes to existing routes or new routes
  - withdrawals: retraction of previously advertised route
- No periodic announcements needed; TCP provides reliable delivery

BGP Protocol (cont'd)

- BGP doesn't chiefly aim to compute shortest paths (or minimize other metric, as do DV, LS)
- Chief purpose of BGP is to announce reachability, and enable policy-based routing
- BGP announcement:
  - IP prefix: [Attribute 0] [Attribute1] [...]