Inter-Domain Routing: BGP

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(drawn mostly from lecture notes
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CS 3035/GZ01

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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?

- Scaling challenge:
  - millions 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
  - 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: Hierarchical Addressing

- Divide 32-bit IP address hierarchically
  - e.g., 128.16.64.200 is host at UCL
  - e.g., 128.16.64 prefix is UCL CS dept
  - e.g., 128.16 prefix is all of UCL
  - destination is a prefix
  - writing prefixes:
    - 128.16/16 means "high 16 bits of 128.16.x.y"
    - netmask 255.255.0.0 means "to find prefix of 32-bit address, bit-wise AND 255.255.0.0 with it"
  - prefixes need not be multiples of 8 bits long

Hierarchical Addressing: Pro

- Routing protocols generally incur cost that increases with number of destinations
  - Hierarchical addresses aggregate
  - Outside UCL, single prefix 128.16 can represent thousands of hosts on UCL network
  - End result: "reduces" number of destinations in global Internet routing system
- Centralized address allocation easier for smaller user/host population
  - Hierarchical addresses assure global uniqueness with only local coordination
  - Inside UCL, local authority can allocate low-order 16 bits of host IP addresses under 128.16 prefix
  - End result: decentralized unique address allocation

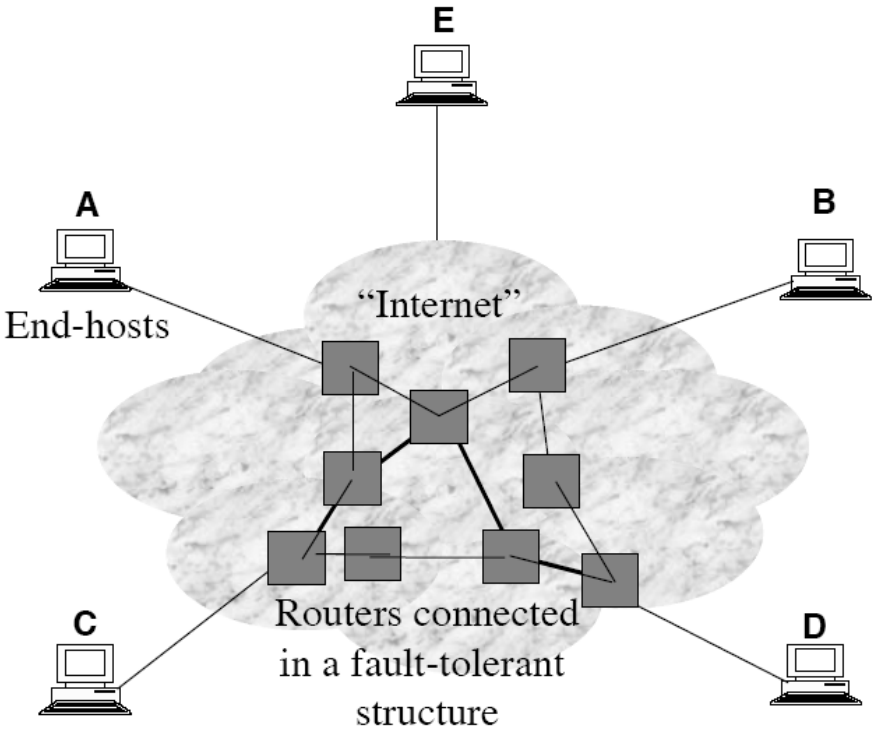
Hierarchical Addressing: Con

- Inherent loss of information from global routing protocol → less optimal routes
  - Nodes outside UCL know nothing about UCL internal topology
  - UCL host in Antarctica has 128.16 prefix → all traffic to it must be routed via London
- Host addresses indicate both host identity **and** network attachment point
  - Suppose move my UCL laptop to Berkeley
  - IP address must change to Berkeley one, so aggregates under Berkeley IP prefix!

Context: Autonomous Systems

- A routing domain is 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 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

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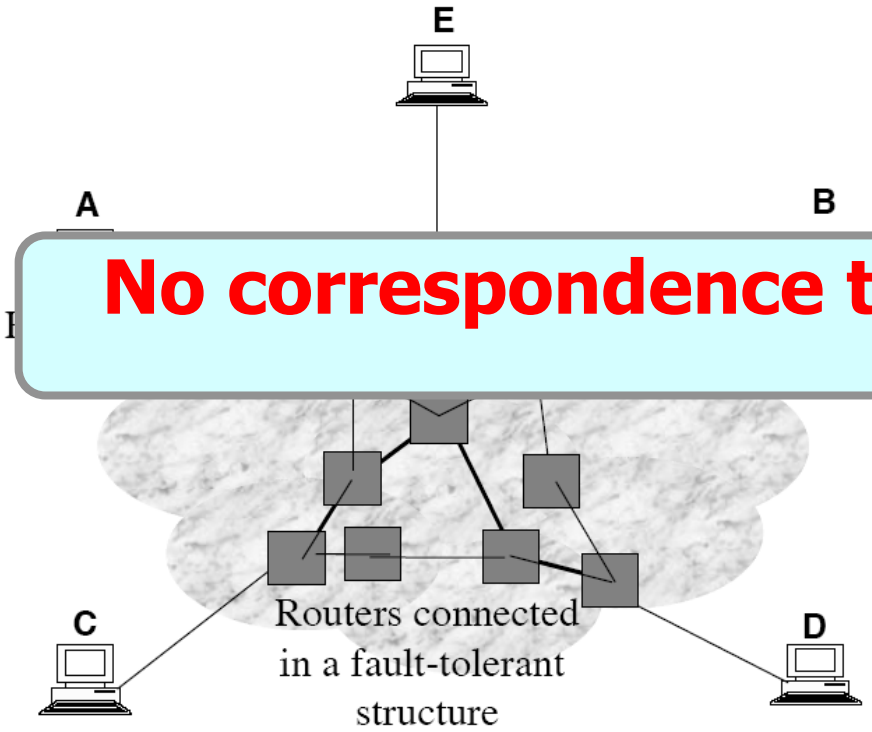


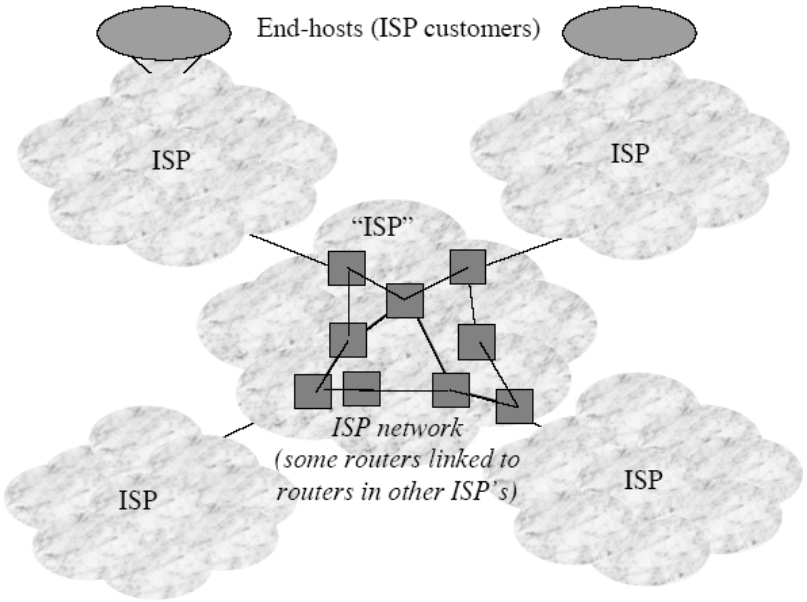
- Find globally shortest paths

No correspondence to reality!

redundant paths

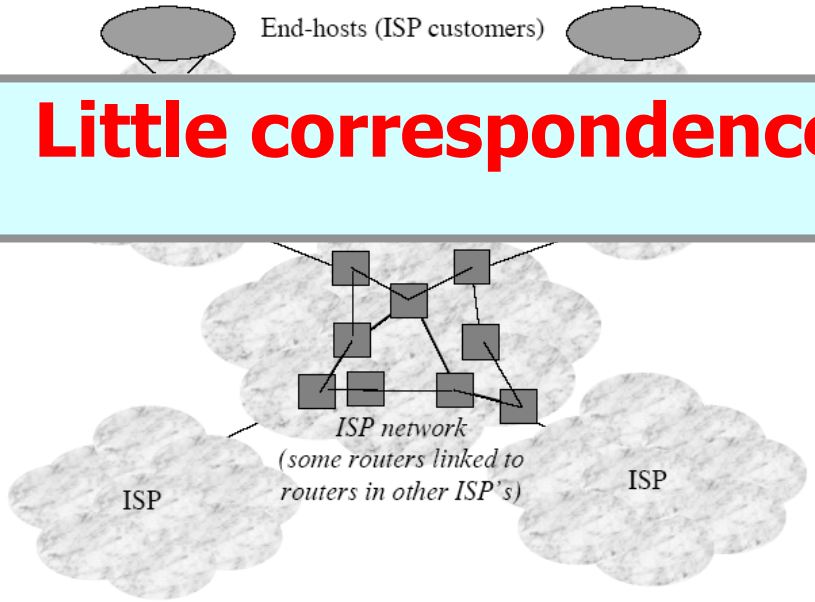
- Route traffic cooperatively onto lightly loaded paths

Global Internet Routing, Socialist Style



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

Global Internet Routing, Socialist Style



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Little correspondence to reality!

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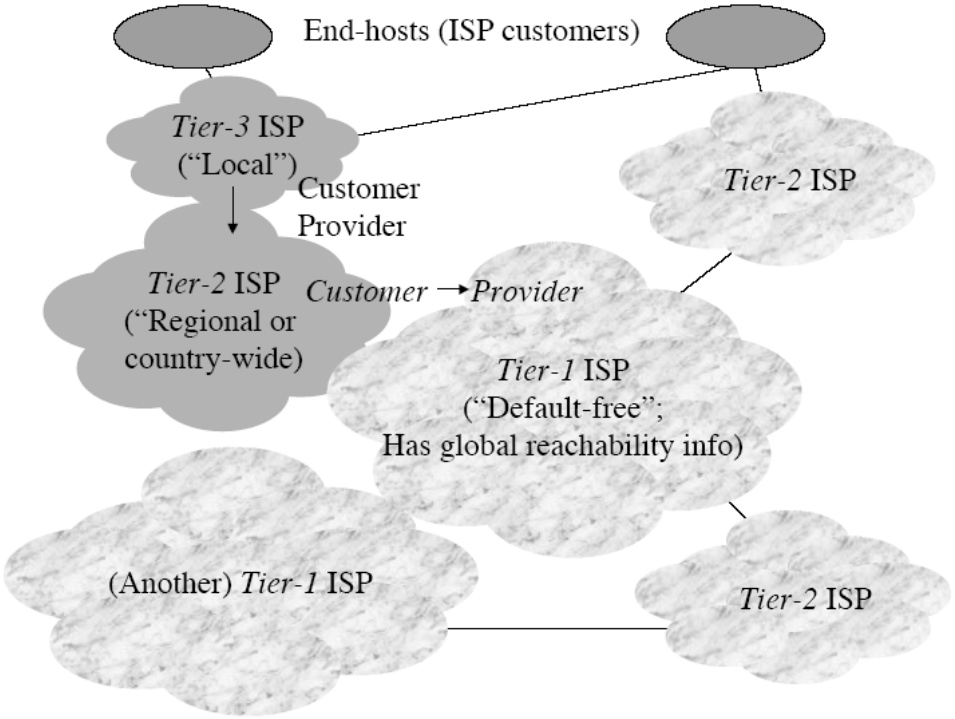
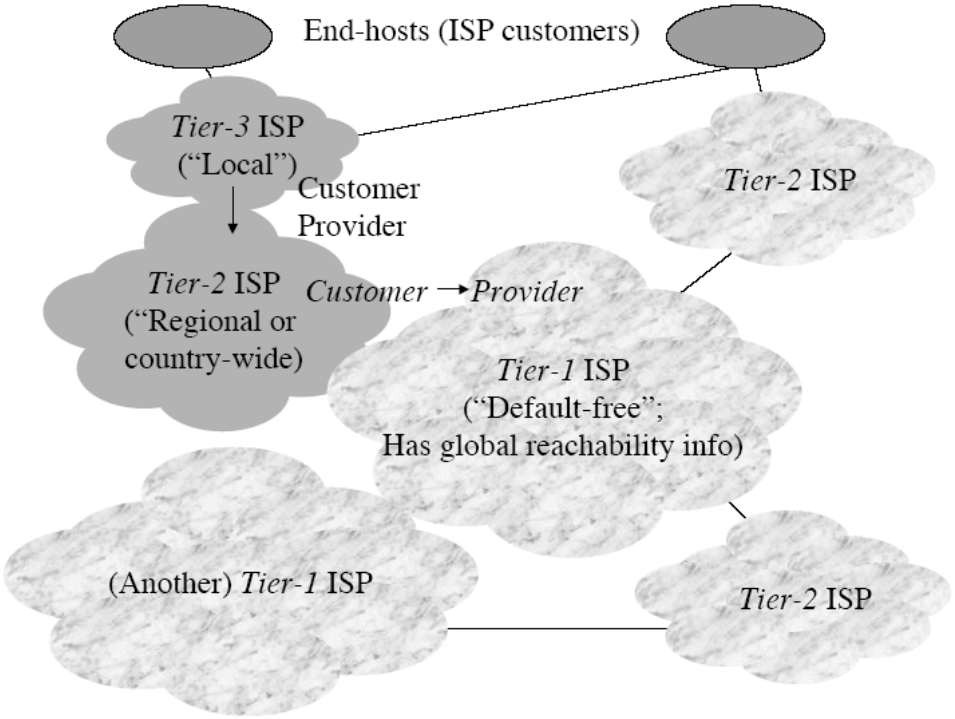
Global Internet Routing: Capitalist Style



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

Global Internet Routing: Capitalist Style



Reality!

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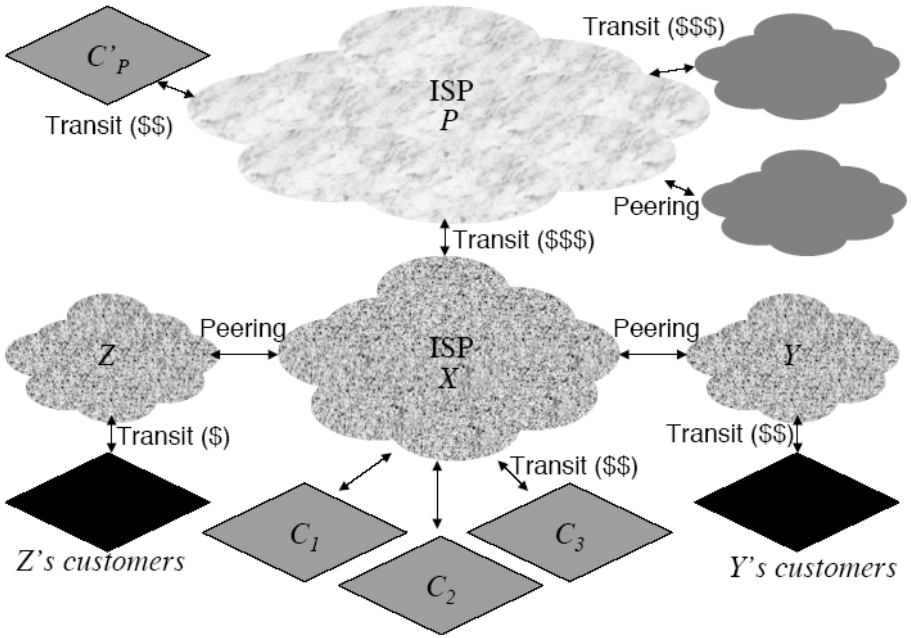
AS-AS Relationships: Customers and Providers

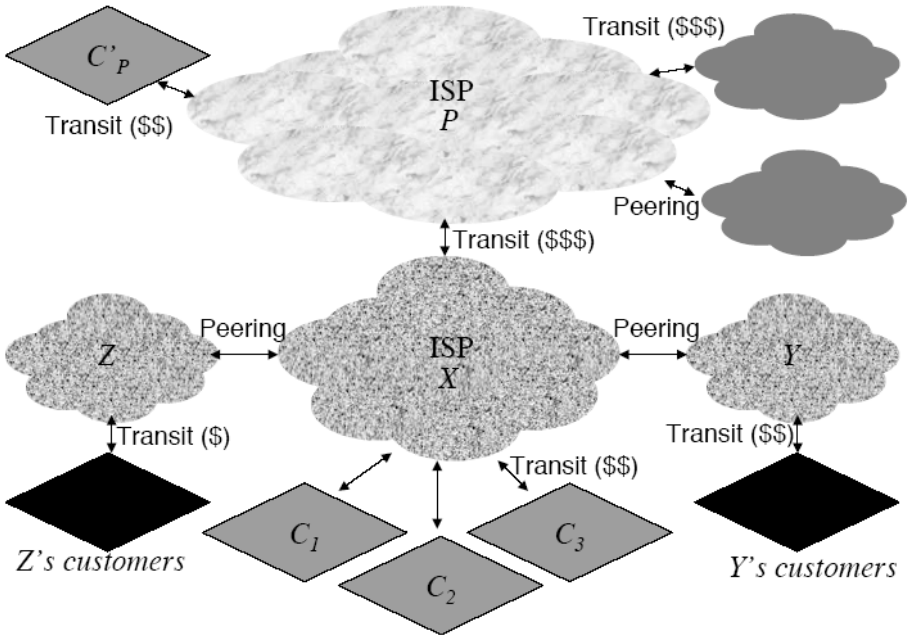
- Smaller ASes (corporations, universities) typically purchase connectivity from ISPs
- Regional ISPs typically purchase connectivity from global ISPs
- Each such connection has two roles:
  - Customer: smaller AS paying for connectivity
  - Provider: larger AS being paid for connectivity
- Other possibility: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

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

AS-AS Relationship: Peering



- **Peering:** two ASes (usually ISPs) mutually allow one another to route to some of the destinations in their routing tables
- Typically these are their own customers (whom they provide transit)
- 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

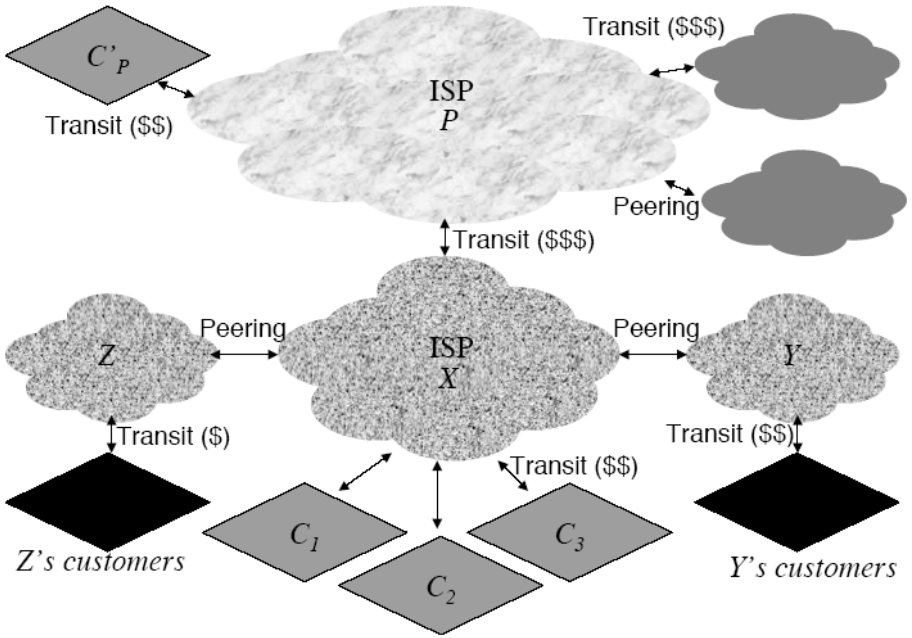
Advertising Routes for Transit Customers

- ISP motivated to advertise routes to 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

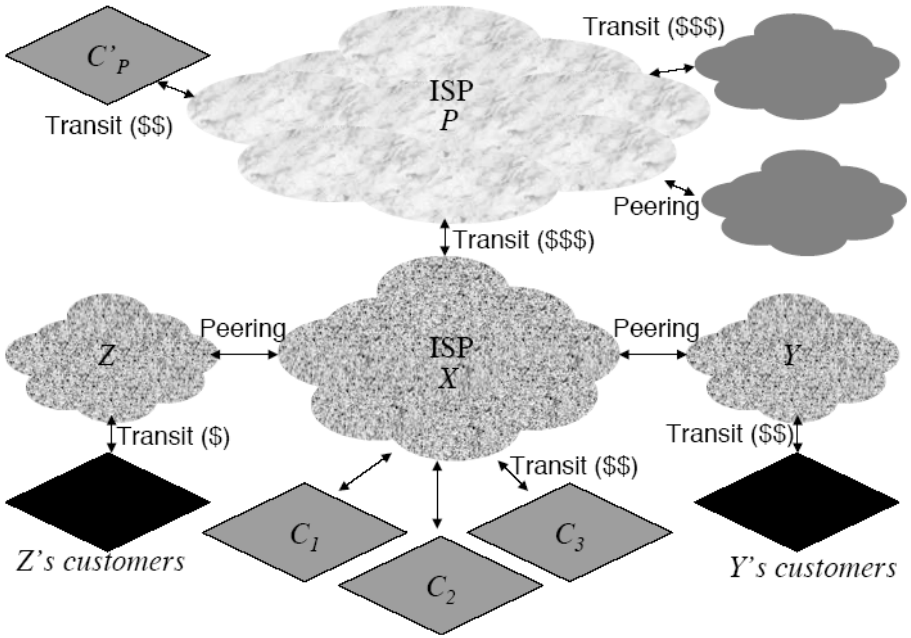


- ISP P announces route to C'_P, own customer, to X
- X doesn't announce C'_P to Y or Z; no revenue from peering
- X announces C'_P to C_i; they're paying to be able to reach everywhere

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] [...]