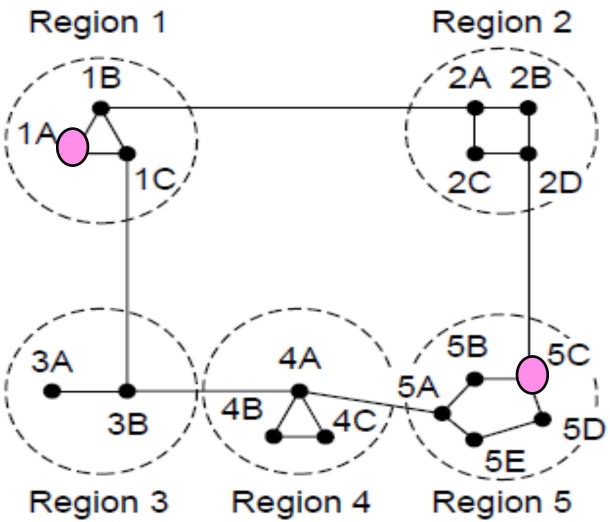
# Hierarchical Routing

- Introduce a larger routing unit
  - IP prefix (hosts) ← from one host
  - Region, e.g., ISP network
- Route first to the region, then to the IP prefix within the region
  - Hide details within a region from outside of the region

# Hierarchical Routing (2)



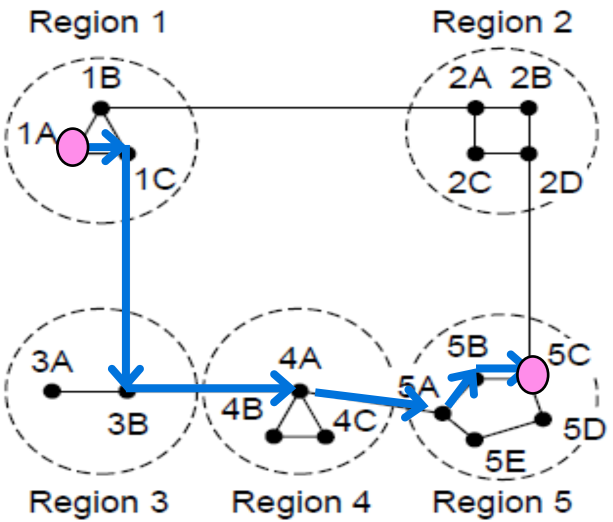

Full table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2A | 1B | 2 |
| 2B | 1B | 3 |
| 2C | 1B | 3 |
| 2D | 1B | 4 |
| 3A | 1C | 3 |
| 3B | 1C | 2 |
| 4A | 1C | 3 |
| 4B | 1C | 4 |
| 4C | 1C | 4 |
| 5A | 1C | 4 |
| 5B | 1C | 5 |
| 5C | 1B | 5 |
| 5D | 1C | 6 |
| 5E | 1C | 5 |

Hierarchical table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2 | 1B | 2 |
| 3 | 1C | 2 |
| 4 | 1C | 3 |
| 5 | 1C | 4 |

# Hierarchical Routing (3)




Full table for 1A

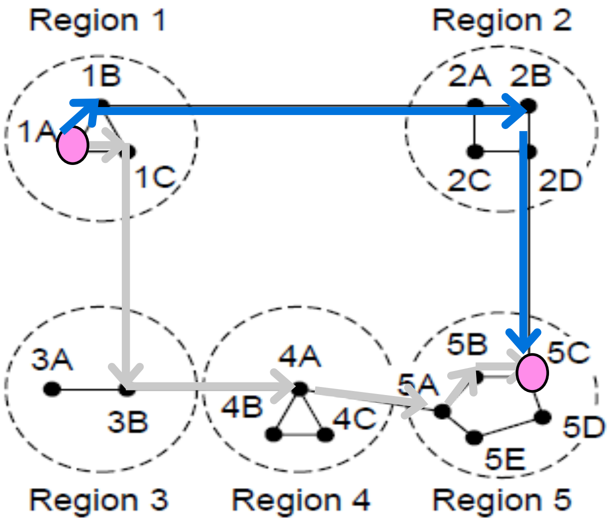
| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2A | 1B | 2 |
| 2B | 1B | 3 |
| 2C | 1B | 3 |
| 2D | 1B | 4 |
| 3A | 1C | 3 |
| 3B | 1C | 2 |
| 4A | 1C | 3 |
| 4B | 1C | 4 |
| 4C | 1C | 4 |
| 5A | 1C | 4 |
| 5B | 1C | 5 |
| 5C | 1B | 5 |
| 5D | 1C | 6 |
| 5E | 1C | 5 |

Hierarchical table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2 | 1B | 2 |
| 3 | 1C | 2 |
| 4 | 1C | 3 |
| 5 | 1C | 4 |

# Hierarchical Routing (4)

- Penalty is longer paths




Full table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2A | 1B | 2 |
| 2B | 1B | 3 |
| 2C | 1B | 3 |
| 2D | 1B | 4 |
| 3A | 1C | 3 |
| 3B | 1C | 2 |
| 4A | 1C | 3 |
| 4B | 1C | 4 |
| 4C | 1C | 4 |
| 5A | 1C | 4 |
| 5B | 1C | 5 |
| 5C | 1B | 5 |
| 5D | 1C | 6 |
| 5E | 1C | 5 |

Hierarchical table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2 | 1B | 2 |
| 3 | 1C | 2 |
| 4 | 1C | 3 |
| 5 | 1C | 4 |

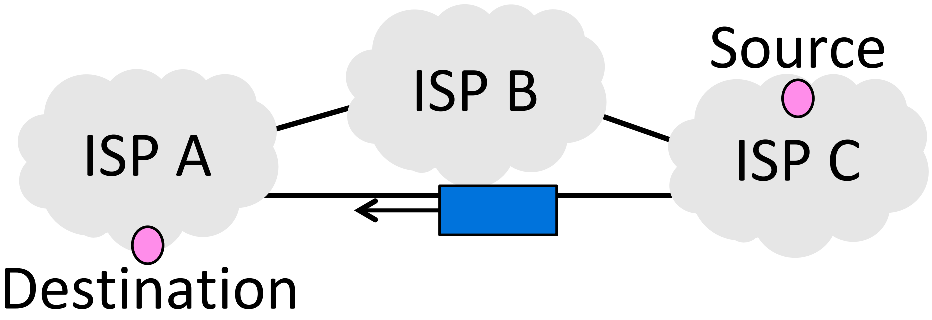
1C is best route to region 5, except for destination 5C

# Observations

- Outside a region, nodes have <u>one route</u> to all hosts within the region
  - This gives savings in table size, messages and computation
- However, each node may have a <u>different route</u> to an outside region
  - Routing decisions are still made by individual nodes; there is no single decision made by a region

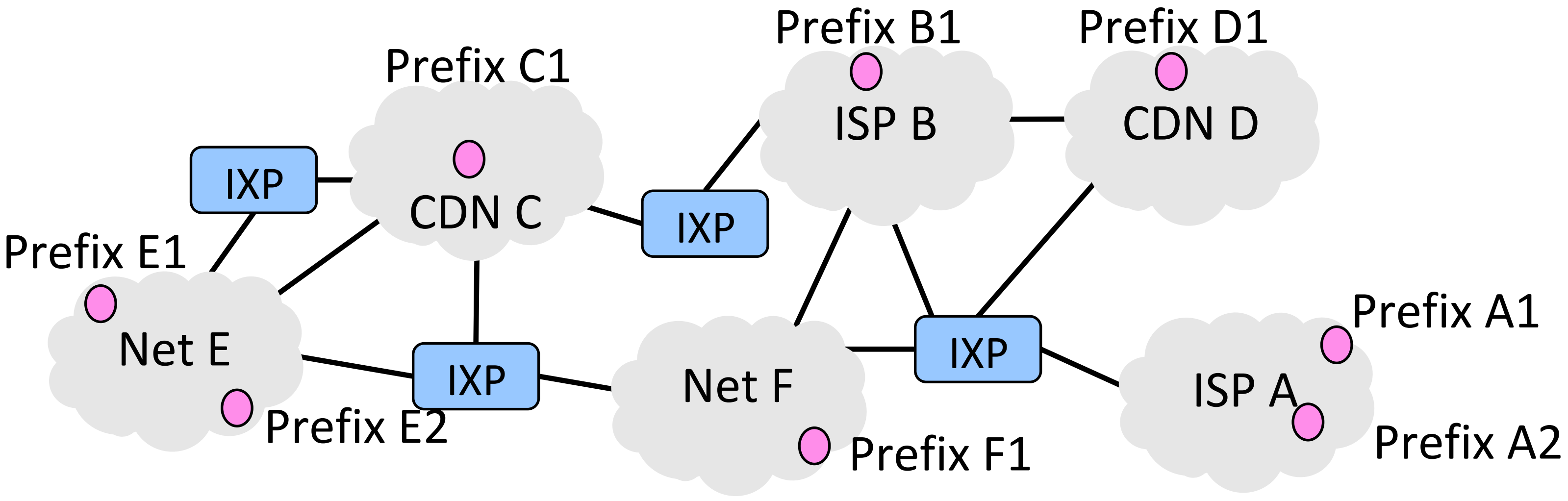
# Topic

- How to route with multiple parties, each with their own routing policies
  - This is Internet-wide BGP routing



# Structure of the Internet

- Networks (ISPs, CDNs, etc.) group hosts as IP prefixes
- Networks are richly interconnected, often using IXPs



# Internet-wide Routing Issues

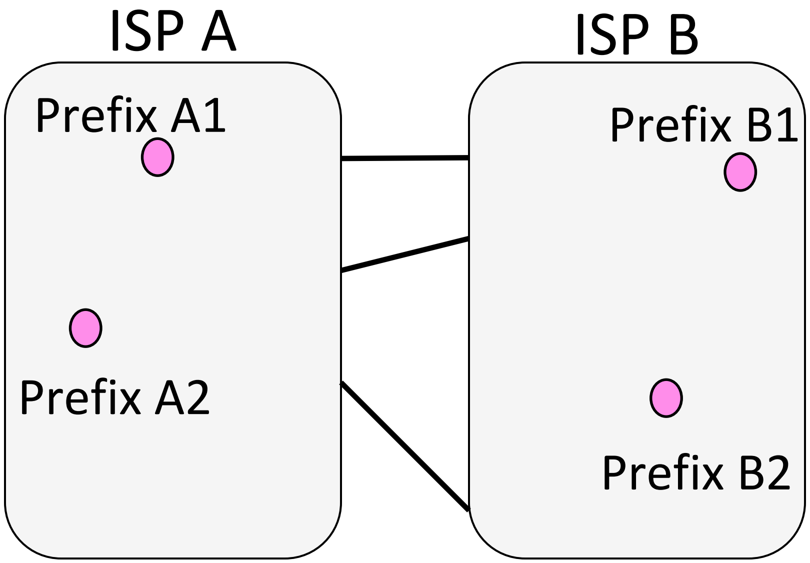
- Two problems beyond routing within an individual network

1. Scaling to very large networks
   - Techniques of IP prefixes, hierarchy, prefix aggregation
2. Incorporating policy decisions
   - Letting different parties choose their routes to suit their own needs

Yikes!

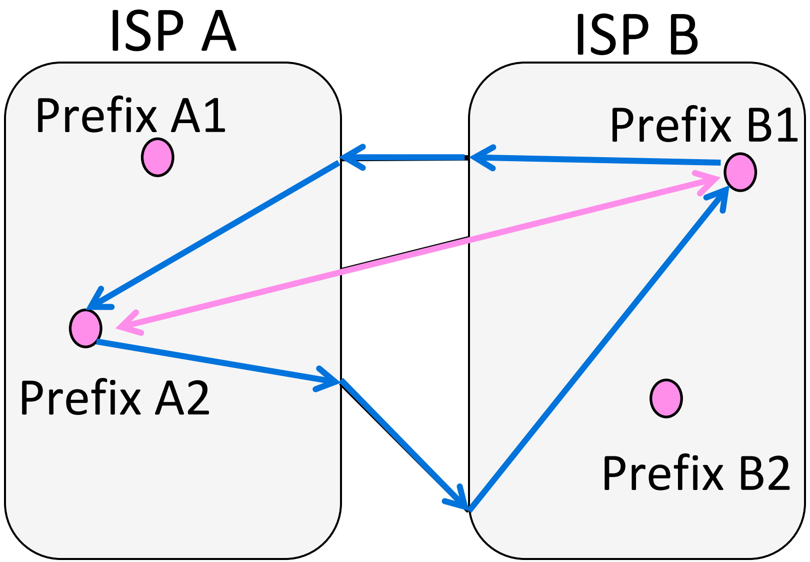
# Effects of Independent Parties

- Each party selects routes to suit its own interests
  - e.g, shortest path in ISP
- What path will be chosen for A2→B1 and B1→A2?
  - What is the best path?



# Effects of Independent Parties (2)

- Selected paths are longer than overall shortest path
  - And symmetric too!
- This is a consequence of independent goals and decisions, not hierarchy

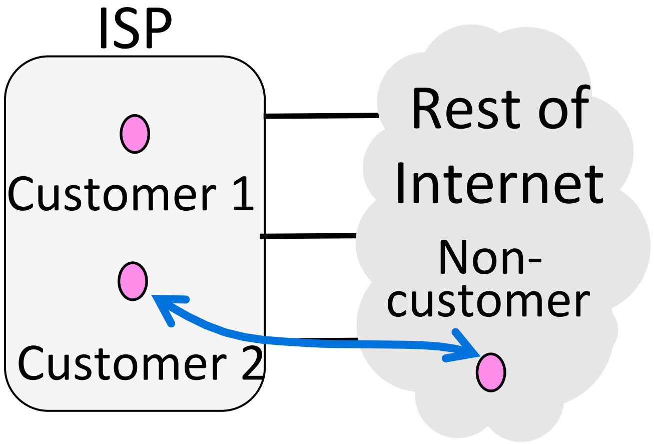


# Routing Policies

- Capture the goals of different parties – could be anything
  - E.g., Internet2 only carries non-commercial traffic
- Common policies we'll look at:
  - ISPs give TRANSIT service to customers
  - ISPs give PEER service to each other

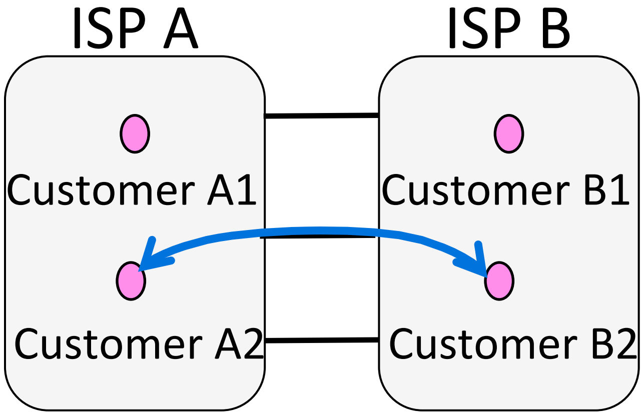
# Routing Policies – Transit

- One party (customer) gets TRANSIT service from another party (ISP)
  - ISP accepts traffic for customer from the rest of Internet
  - ISP sends traffic from customer to the rest of Internet
  - Customer pays ISP for the privilege



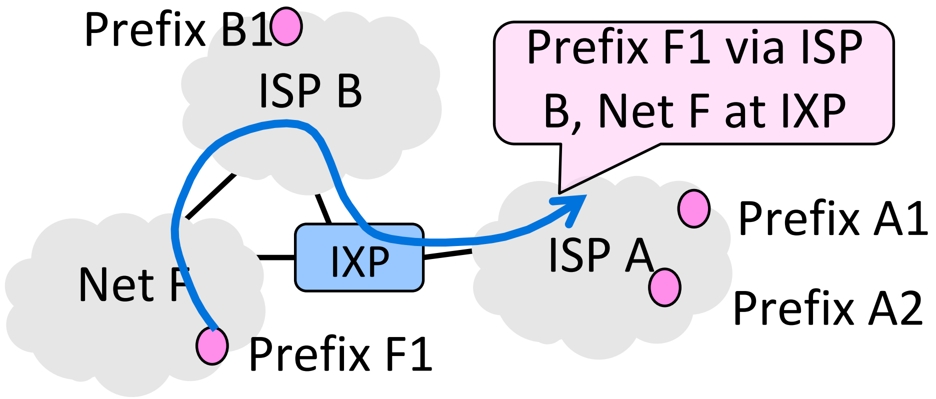
# Routing Policies – Peer

- Both party (ISPs in example) get PEER service from each other
  - Each ISP accepts traffic from the other ISP only for their customers
  - ISPs do not carry traffic to the rest of the Internet for each other
  - ISPs don’t pay each other



# Routing with BGP (Border Gateway Protocol)

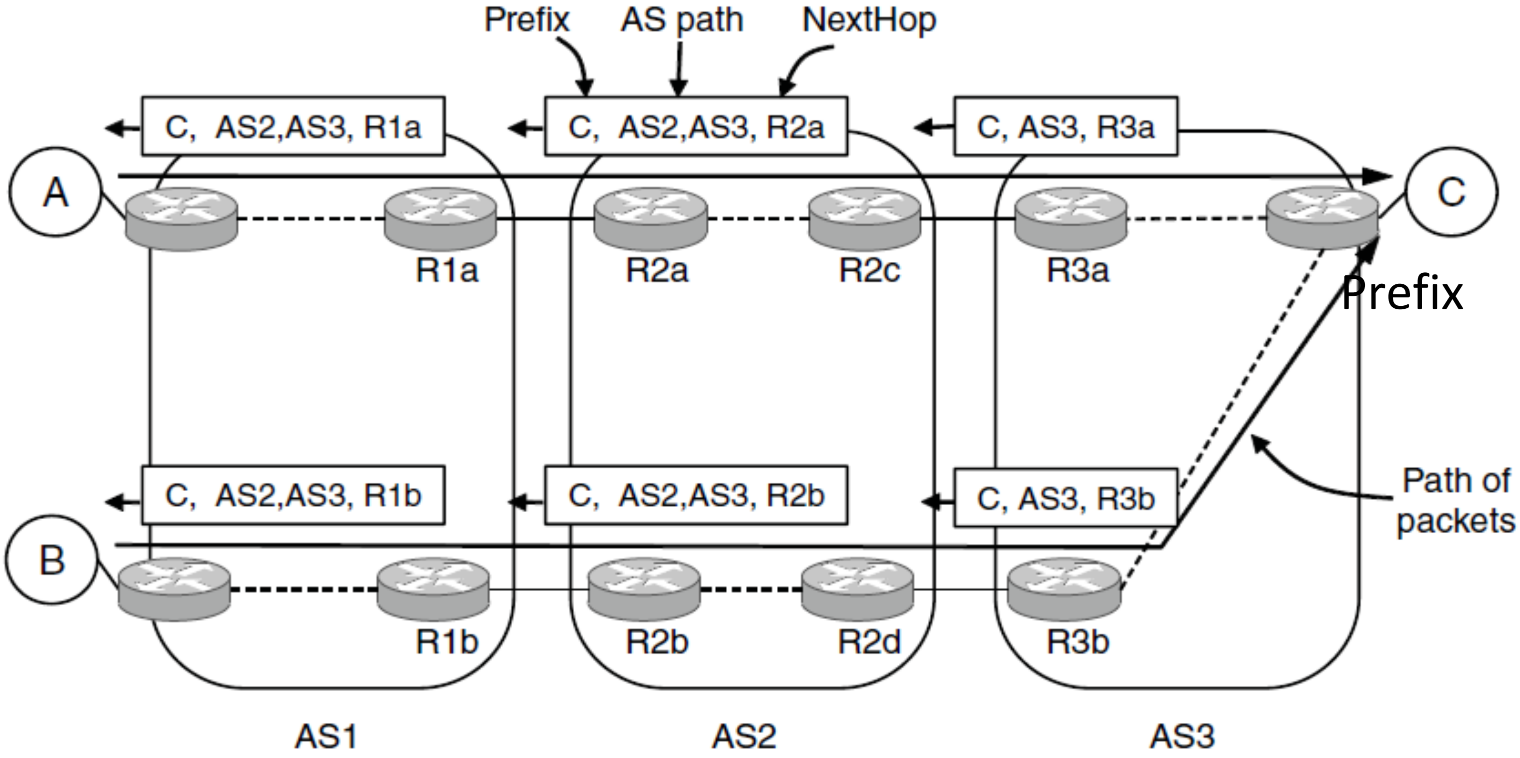
- BGP is the <u>interdomain</u> routing protocol used in the Internet
  - Path vector, a kind of distance vector



# Routing with BGP (2)

- Different parties like ISPs are called AS (Autonomous Systems)
- Border routers of ASes announce BGP routes to each other
- Route announcements contain an IP prefix, path vector, next hop
  - Path vector is list of ASes on the way to the prefix; list is to find loops
- Route announcements move in the opposite direction to traffic

# Routing with BGP (3)



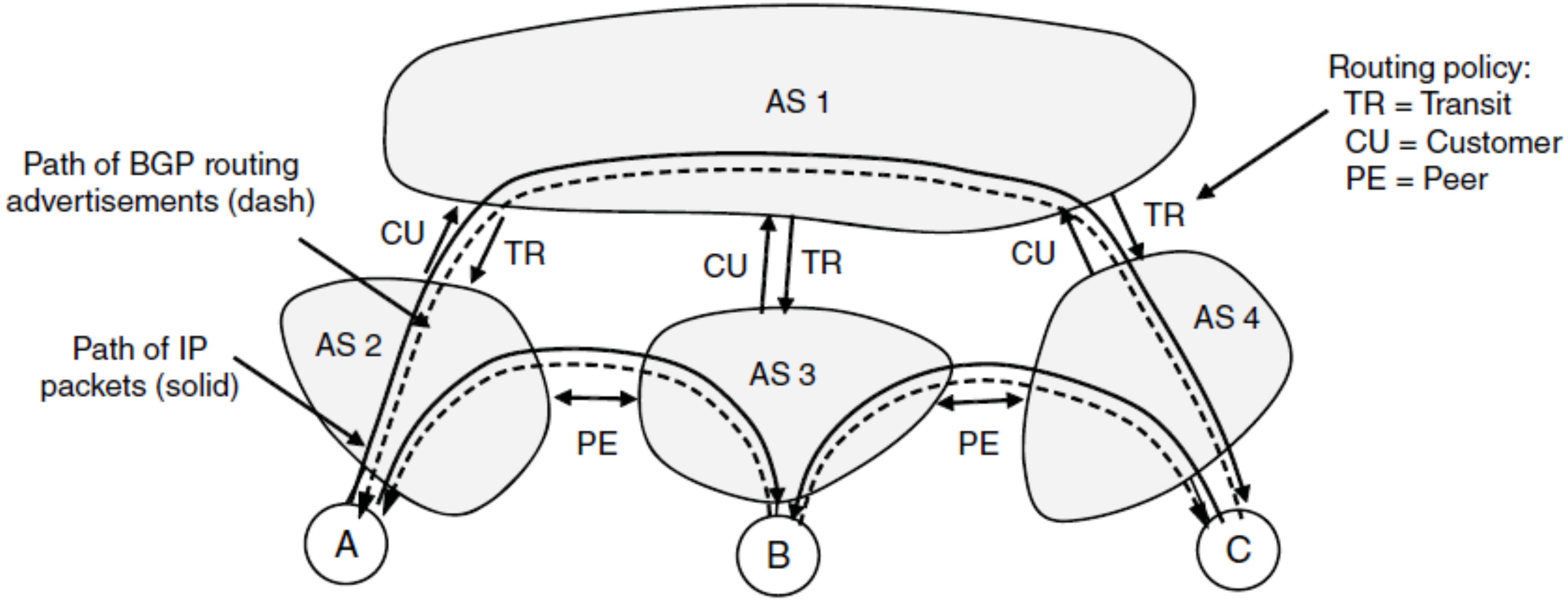
# Routing with BGP (4)

Policy is implemented in two ways:

1. Border routers of ISP announce paths only to other parties who may use those paths
   - Filter out paths others can't use
2. Border routers of ISP select the best path of the ones they hear in any, non-shortest way

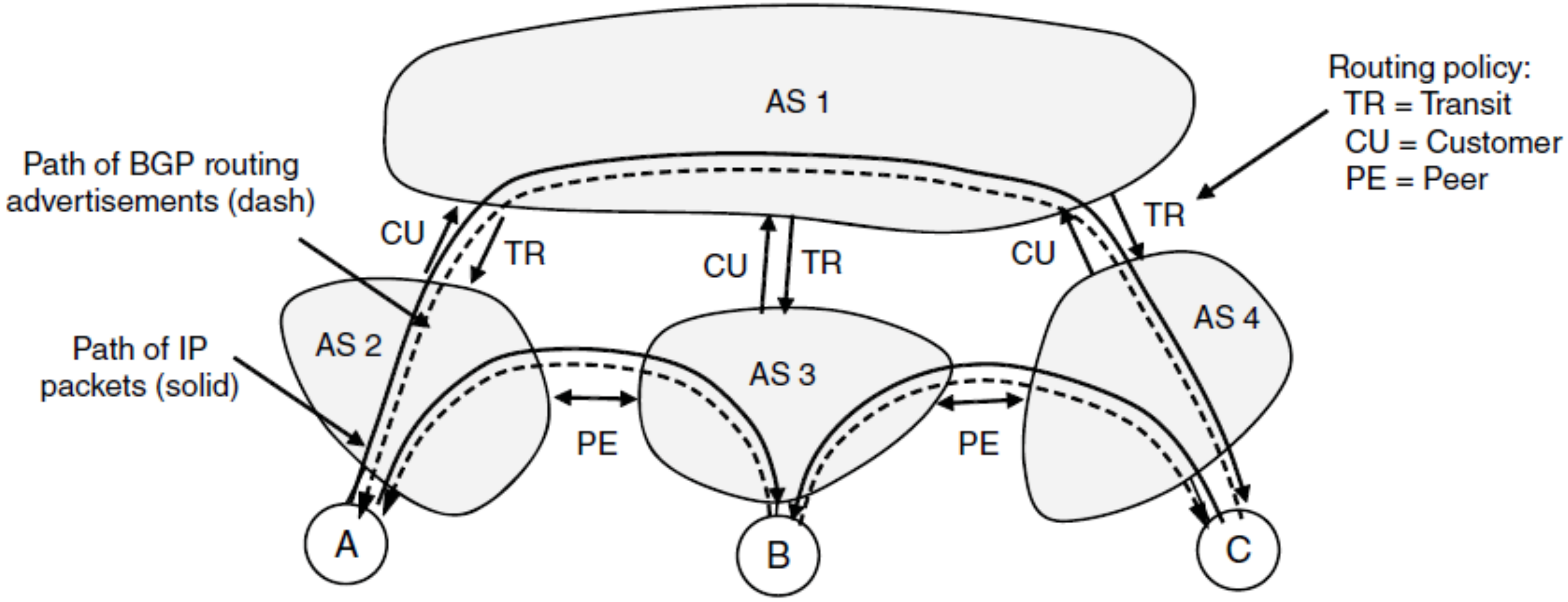
# Routing with BGP (5)

- TRANSIT: AS1 says [B, (AS1, AS3)], [C, (AS1, AS4)] to AS2



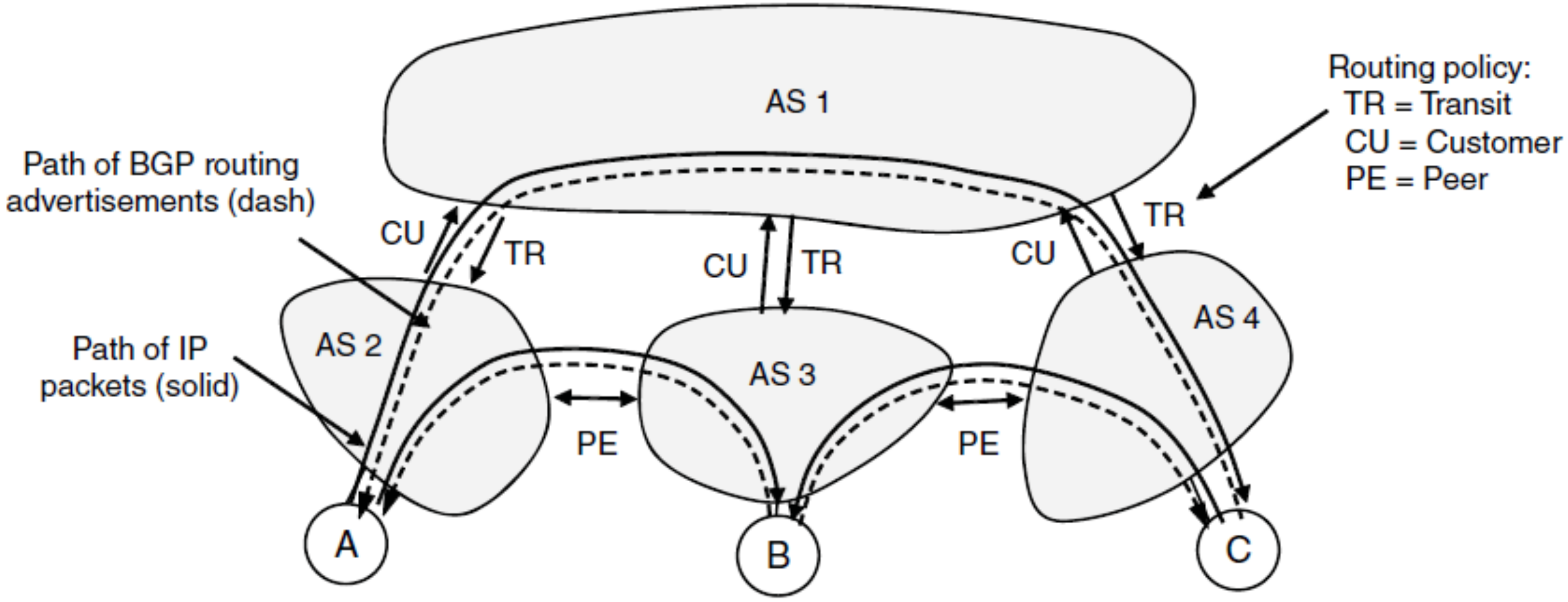
# Routing with BGP (6)

- CUSTOMER (other side of TRANSIT): AS2 says [A, (AS2)] to AS1



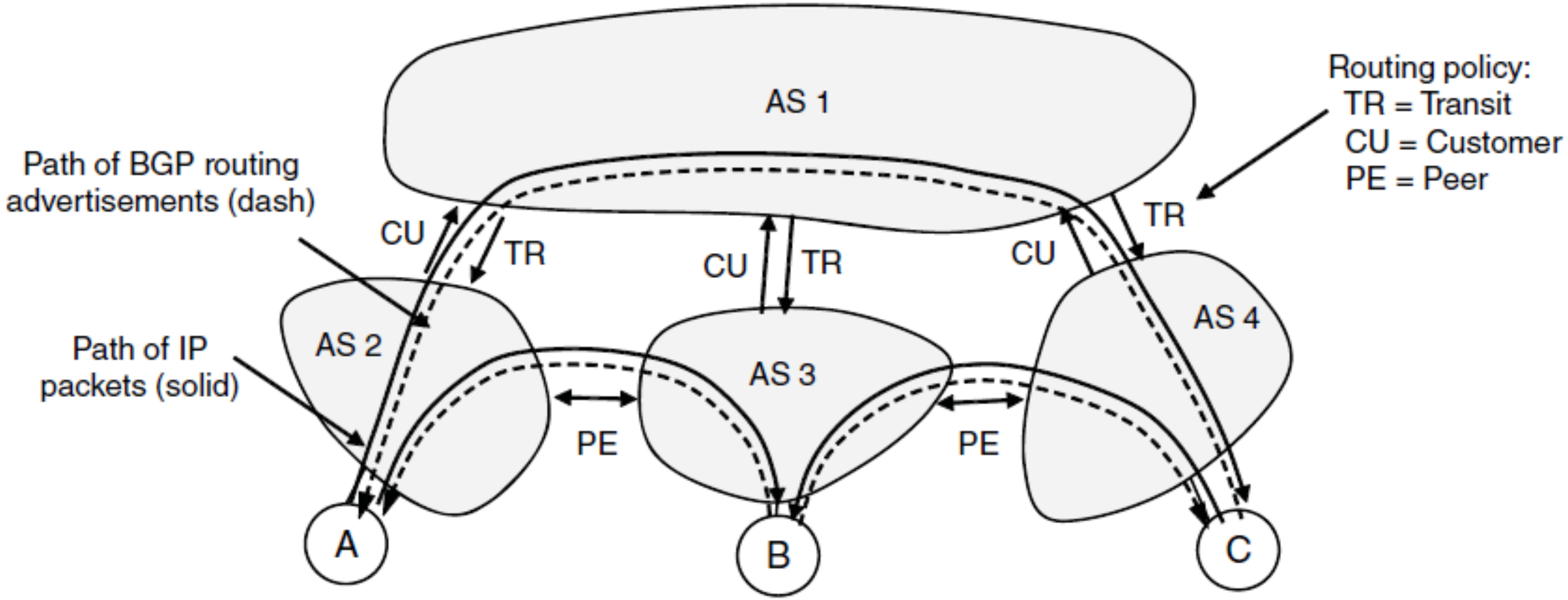
# Routing with BGP (7)

- PEER: AS2 says [A, (AS2)] to AS3, AS3 says [B, (AS3)] to AS2



# Routing with BGP (8)

- AS2 hears two routes to B (via AS1, AS3) and chooses AS3 (Free!)



# BGP Thoughts

- Much more beyond basics to explore!
- Policy is a substantial factor
  - Can we even be independent decisions will be sensible overall?
- Other important factors:
  - Convergence effects
  - How well it scales
  - Integration with intradomain routing
  - And more …