CS120: Computer Networks

Lecture 11. Routing 2

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Routing Protocols

- Routing Information Protocol (RIP)
  - Algorithm: Distance Vector
- Open Shortest Path First (OSPF)
  - Algorithm: Link State
- Border Gateway Protocol (BGP)

Intradomain Routing Protocol

Interdomain Routing Protocol

Link State Routing

- Network topology is known to all routers
  - Accomplished via broadcasting link state packets (LSP) to all routers
- Routing Algorithm: computes shortest paths from one node ('source') to all other nodes
  - Based on Dijkstra's Algorithm

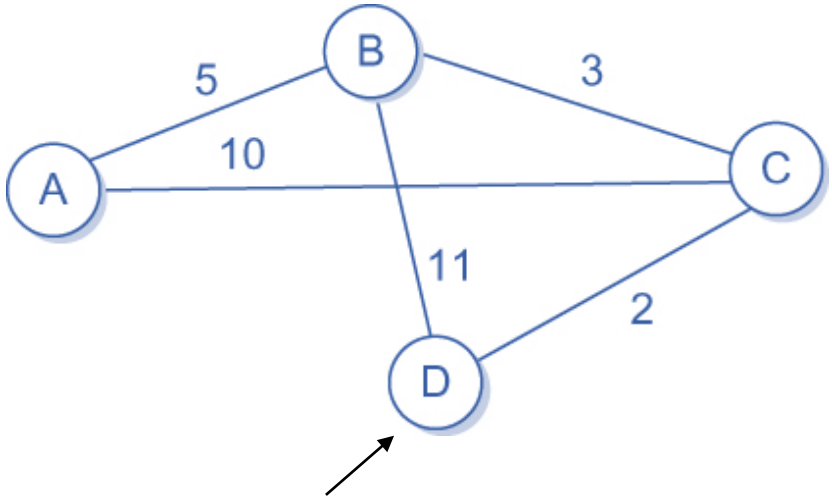
Dijkstra's Algorithm

Initialization:
M = {s}
for all nodes v
  if v adjacent to s
then $D_s(v) = c(u,v)$
else $D_s(v) = \inf$

Loop
  find w not in M such that $D_s(w)$ is a minimum
    add w to M
    update $D_s(v)$ for all v adjacent to w and not in M:
      $D_s(v) = \min(D_s(v), D_s(w) + c(w,v))$
until all nodes in M

- M: set of node processed
- S: node of the local router
- v: node of other routers
- $D_s(v)$ distance from s to v
- $c(u,v)$ link weight between node u and v

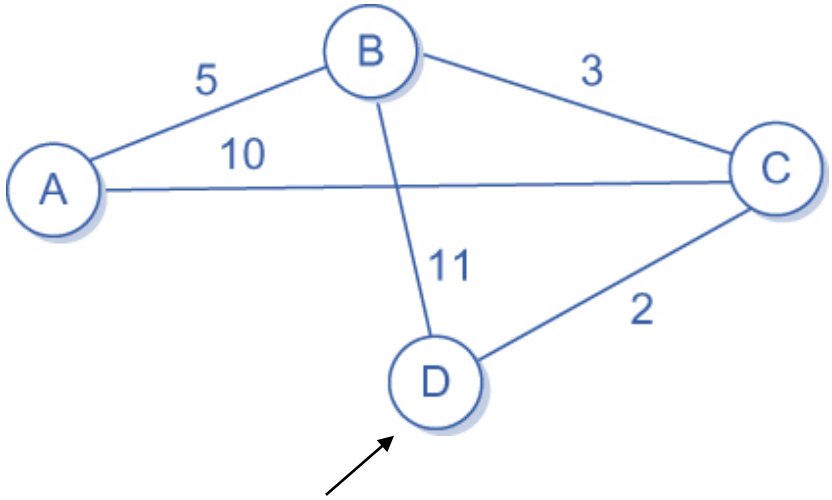
Dijkstra's Algorithm



Target Router

M	$D_D(A)$	$D_D(B)$	$D_D(C)$
{D}	Inf, from D	11, from D	2, from D

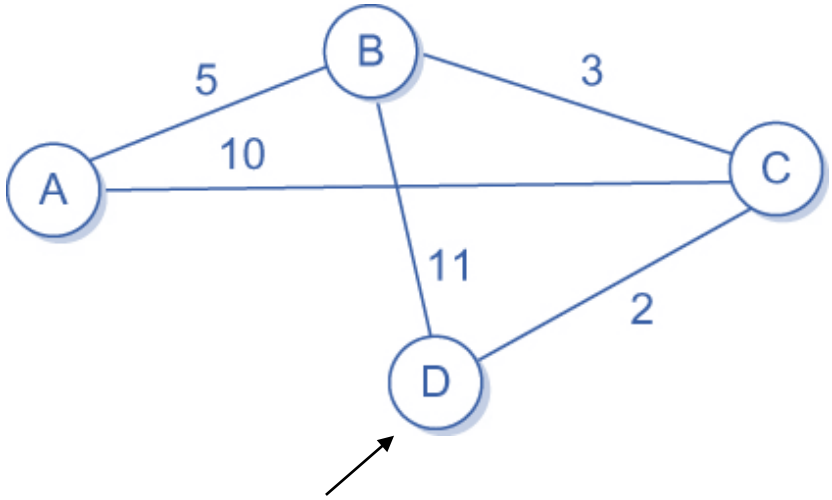
Dijkstra's Algorithm



Target Router

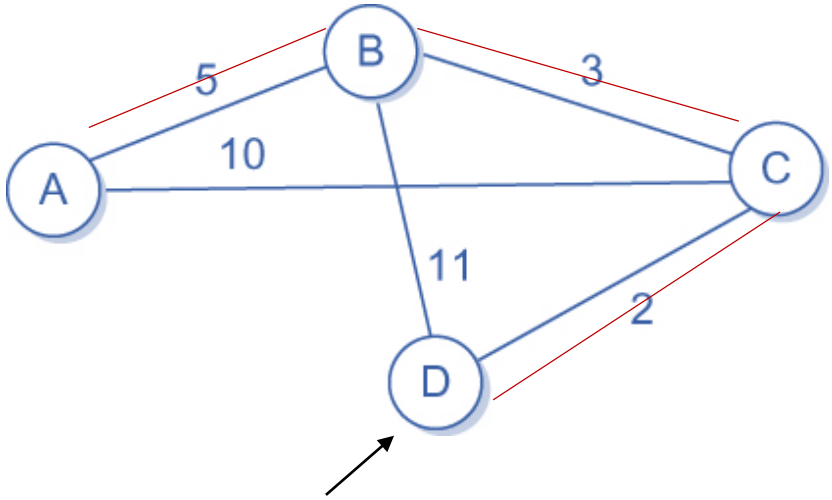
M	$D_D(A)$	$D_D(B)$	$D_D(C)$
{D}	Inf, from D	11, from D	2, from D
{D, C}	12, from C	5, from C	2, from D

Dijkstra's Algorithm



M	$D_D(A)$	$D_D(B)$	$D_D(C)$
{D}	Inf, from D	11, from D	2, from D
{D, C}	12, from C	5, from C	2, from D
{D, C, B}	10, from B	5, from C	2, from D

Dijkstra's Algorithm

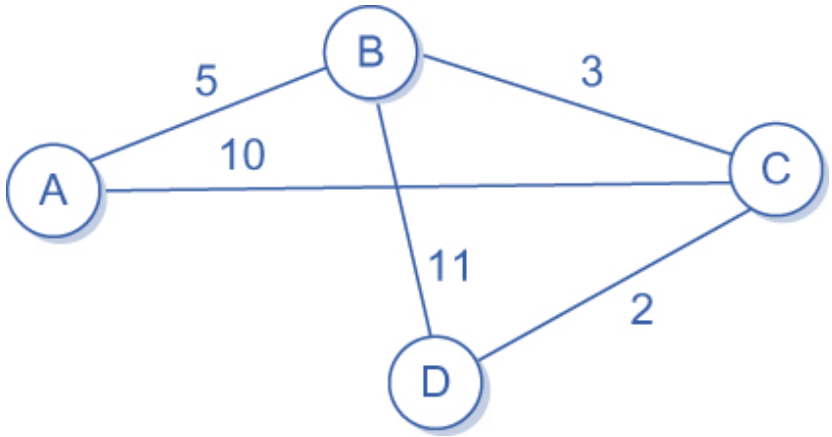


M	$D_D(A)$	$D_D(B)$	$D_D(C)$
{D}	Inf, from D	11, from D	2, from D
{D, C}	12, from C	5, from C	2, from D
{D, C, B}	10, from B	5, from C	2, from D

Dijkstra's Algorithm (Another notation)

- <Destination, Cost, Nexthop>

Step	Confirmed	Tentative
1	(D,0,–)	
2	(D,0,–)	(B,11,B) (C,2,C)
3	(D,0,–) (C,2,C)	(B,11,B)
4	(D,0,–) (C,2,C)	(B,5,C) (A,12,C)
5	(D,0,–) (C,2,C) (B,5,C)	(A,12,C)
6	(D,0,–) (C,2,C) (B,5,C)	(A,10,C)
7	(D,0,–) (C,2,C) (B,5,C) (A,10,C)	

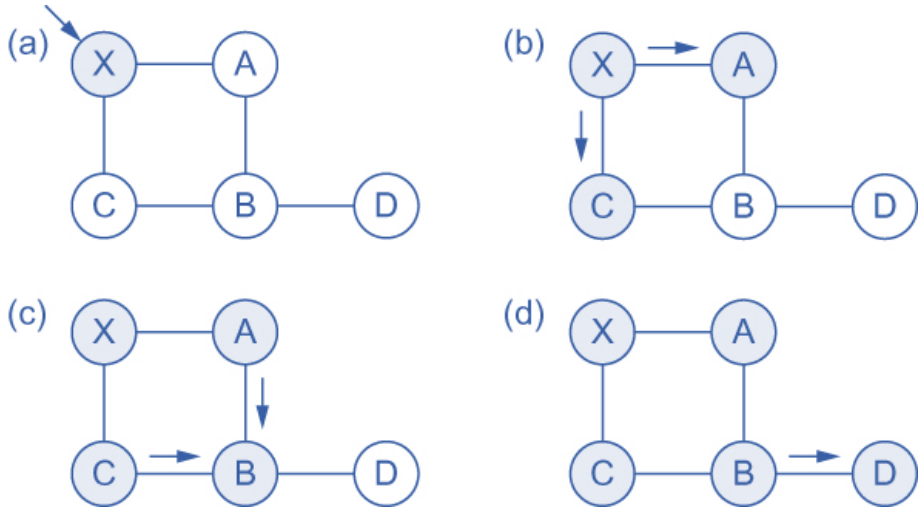


Link State Packet

- Contains key Information to describe the network topology
  - ID of the router
  - Neighbors of the router, and the cost to the neighbor
    - i.e., neighbor ID and connection weight
  - Sequence Number
  - Age

Link State Packet

- Reliably flood an LSP to all routers
  - Basic Flooding
    - Increase the seq number of the LSP
    - Transmit LSP to adjacent routers
    - Routers ACK the received LSP
  - Store LSP if
    - No such LSP
    - or Seq # Received LSP > Seq # stored LSP
  - Forward new LSP to adjacent routers
    - Do not forward to the router transmitted the LSP
  - Abandon old LSP
    - Increase age of forwarding LSP
    - Increase age of stored LSP
  - Keep LSP up to date
    - Generate new LSP when link states change
    - Periodically generate LSP to update age



Open Shortest Path First (OSPF)

- “Open”: nonproprietary standard created under Engineering Task Force (IETF).
- Security: all OSPF messages authenticated (to prevent malicious intrusion)
- Hierarchical routing: OSPF in large domains
- Load balancing: multiple same-cost paths allowed (only one path in RIP)

Routing Protocols

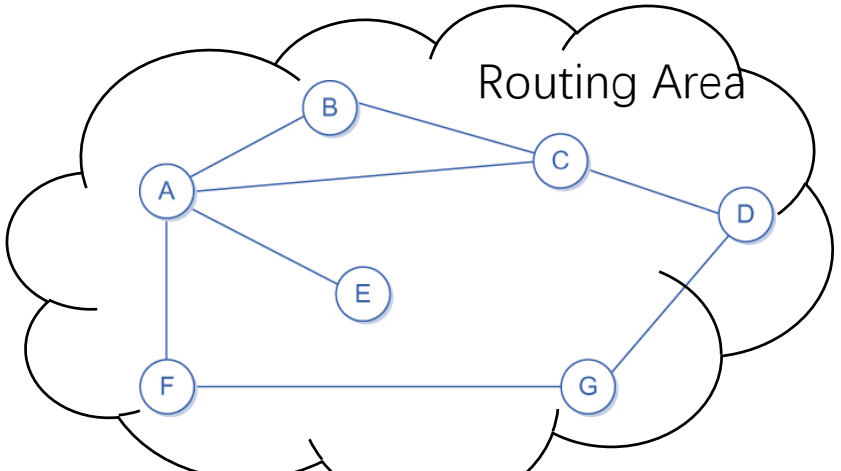
- Routing Information Protocol (RIP)
  - Algorithm: Distance Vector
- Open Shortest Path First (OSPF)
  - Algorithm: Link State
- Border Gateway Protocol (BGP)

Intradomain Routing Protocol

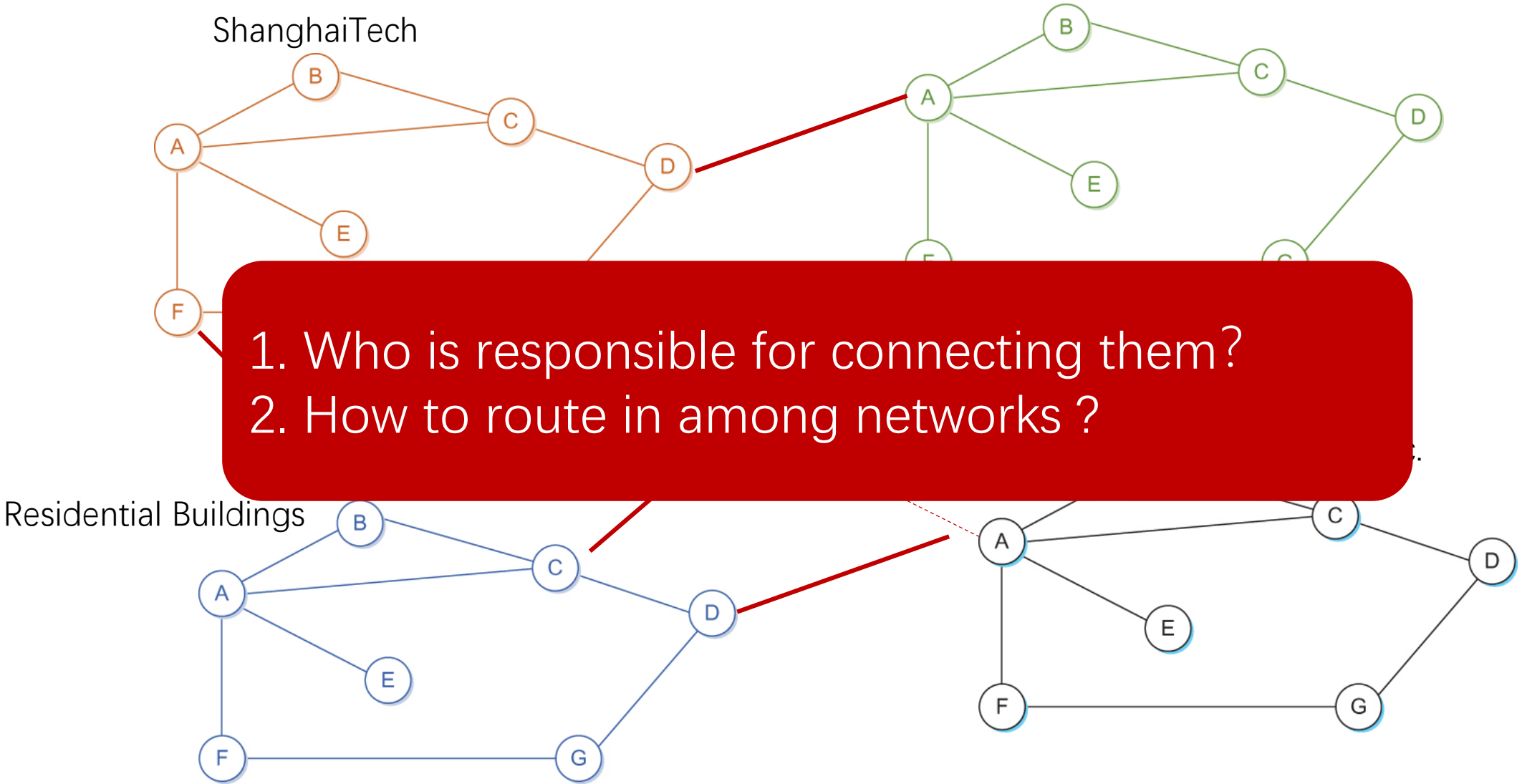
Interdomain Routing Protocol

The Discussion on Routing So Far …

- Routers in the network are managed by the same administrator
  - e.g. Residential building, Campus, Network of a same ISP, Network of a big company, etc.
- Routers running same routing protocol
  - OSPF, RIP, etc.
  - These routers have certain coverage, called the routing area (see next slides)



The Real Internet: Network of Network

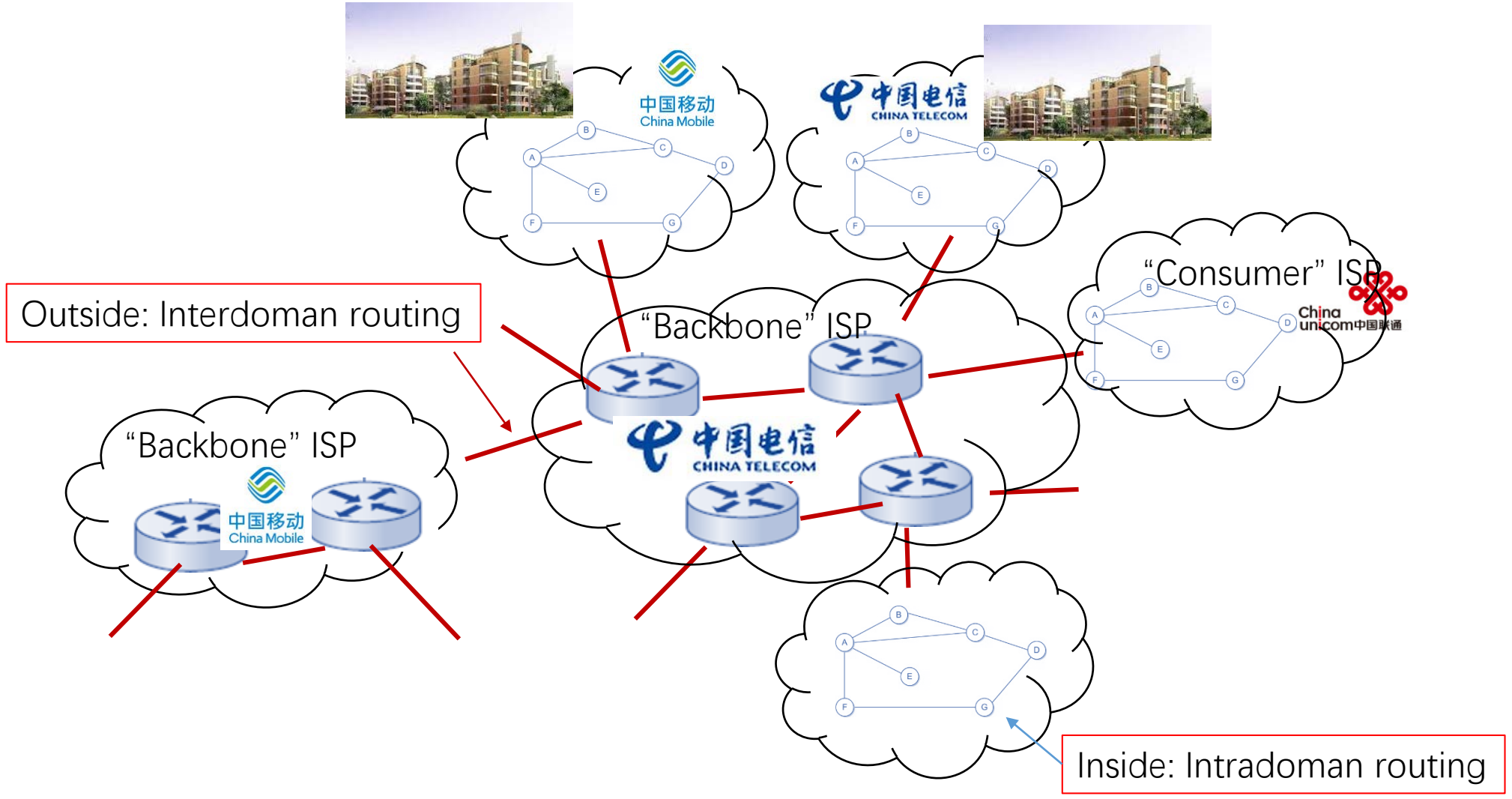


Internet Service Providers

- End systems connect to Internet via “Consumer” ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- “Consumer” ISPs are connected “Backbone” ISPs
  - Three Major Commercial ISPs in China

  - Other ISPs
    - e.g. cernet

The Real Internet: Network of Network

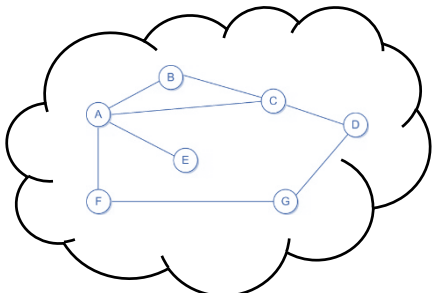


Interdomain Routing Problems

- Scalability: More than 600 million destinations
  - Storage
    - Routing Table
  - Calculation
    - Shortest Path
  - Communication
    - Exchanges Routing Information
- Routing Management: Complex Routing Polices

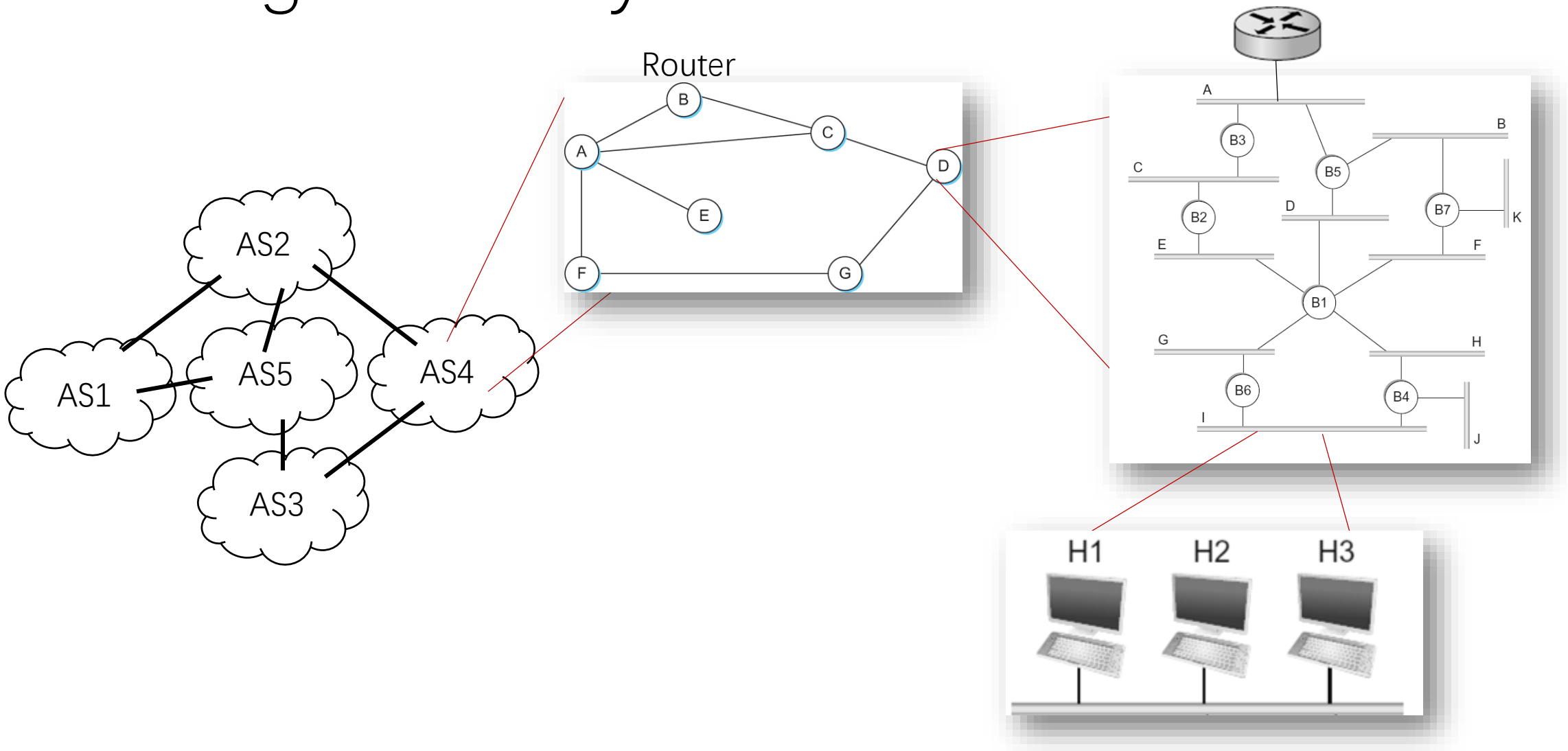
Interdomain Routing: New Hierarchy

- Aggregate Routers into Logical Areas: Autonomous System
- Autonomous System (AS)
  - Corresponds to an administrative domain
  - e.g. University, company, backbone network
- Routers in same AS run same intradomain routing protocol
  - RIP, OSPF, etc.
- Routers in different AS run intrerdomain routing protocol
  - BGP, EGP
- Interdomain routing element: AS



Autonomous System

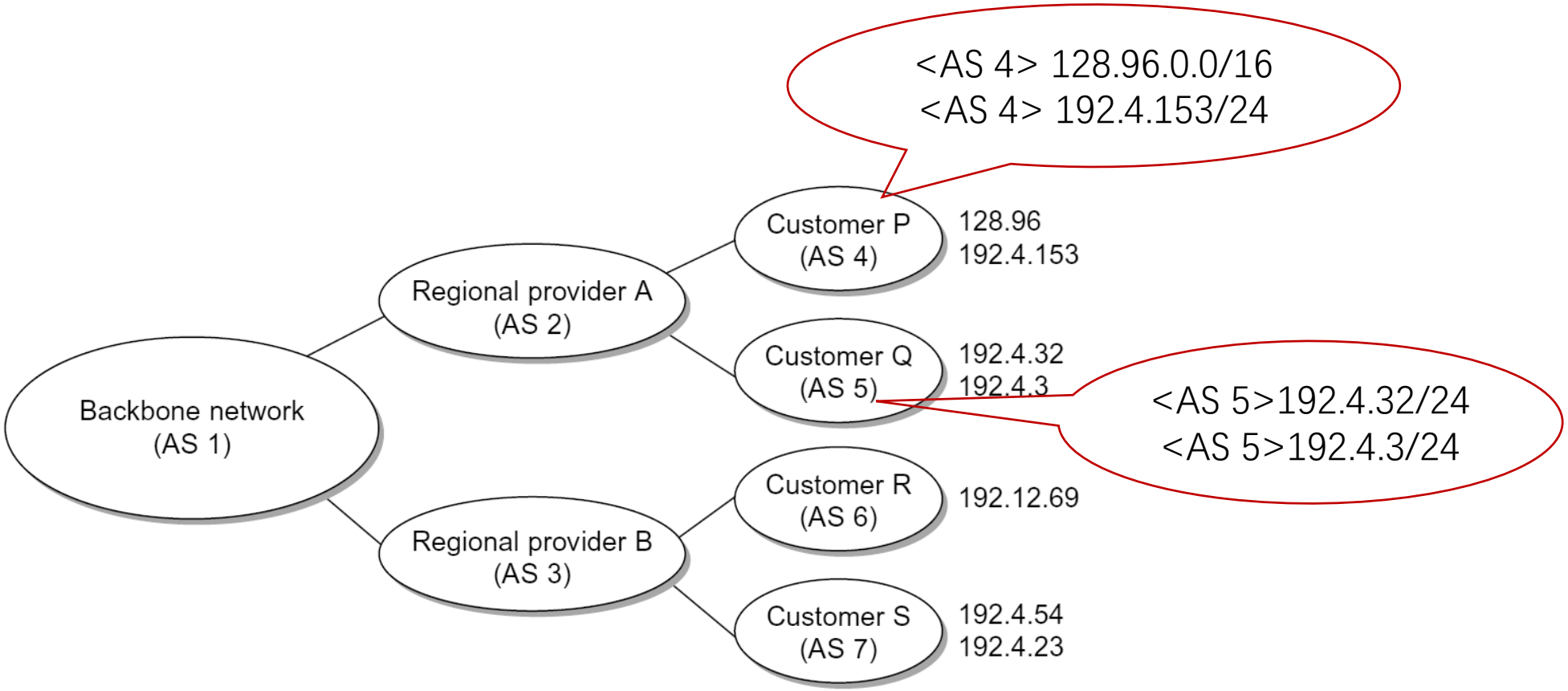
Routing Hierarchy



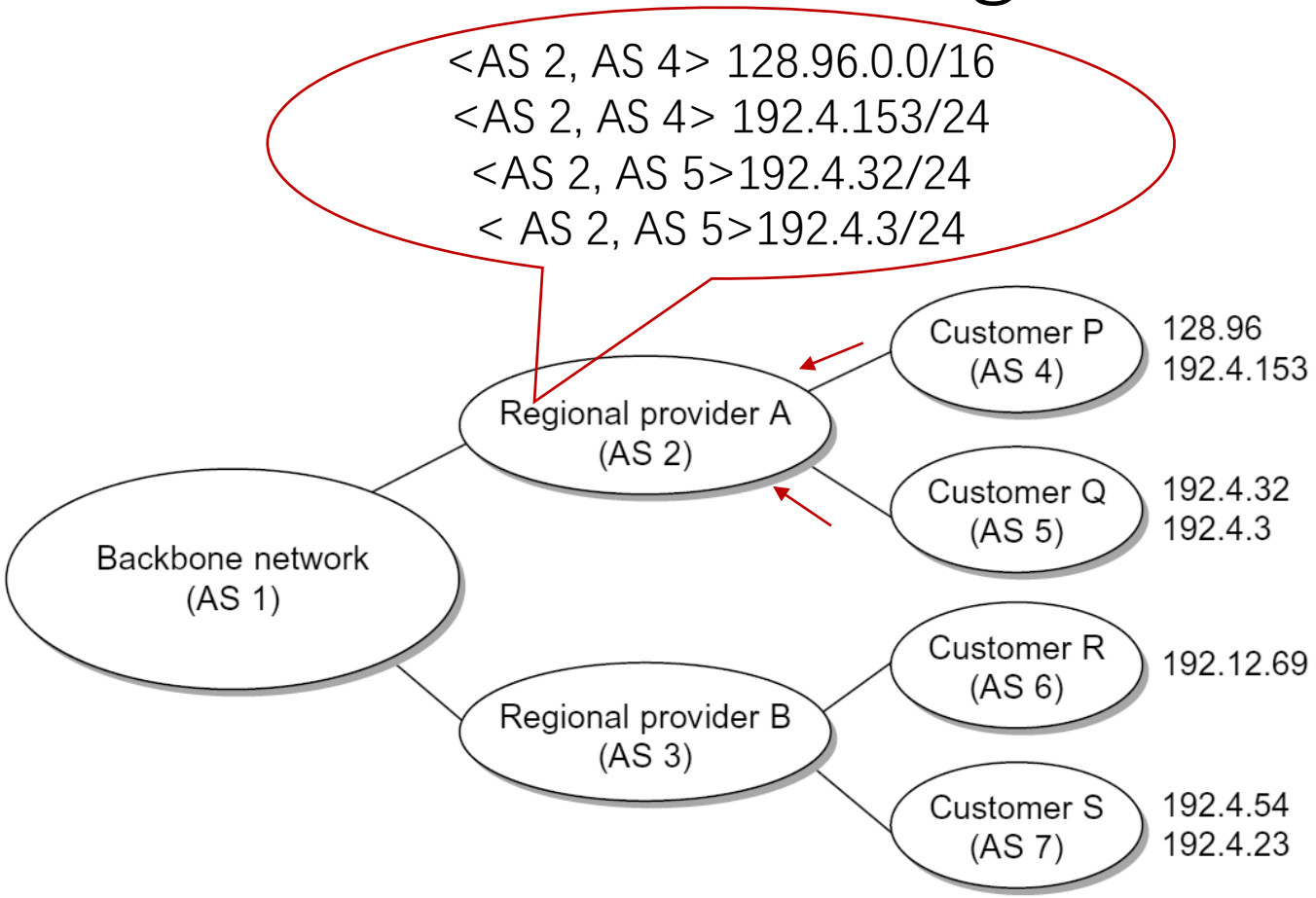
Border Gateway Protocol (BGP)

- Wildly Used Interdomain Routing Protocol
- Hardly be needed for small community or companies
- Routing Element: AS
- Routing Algorithm
  - Target on Reachability
    - Not “best” route
  - Avoid Loop

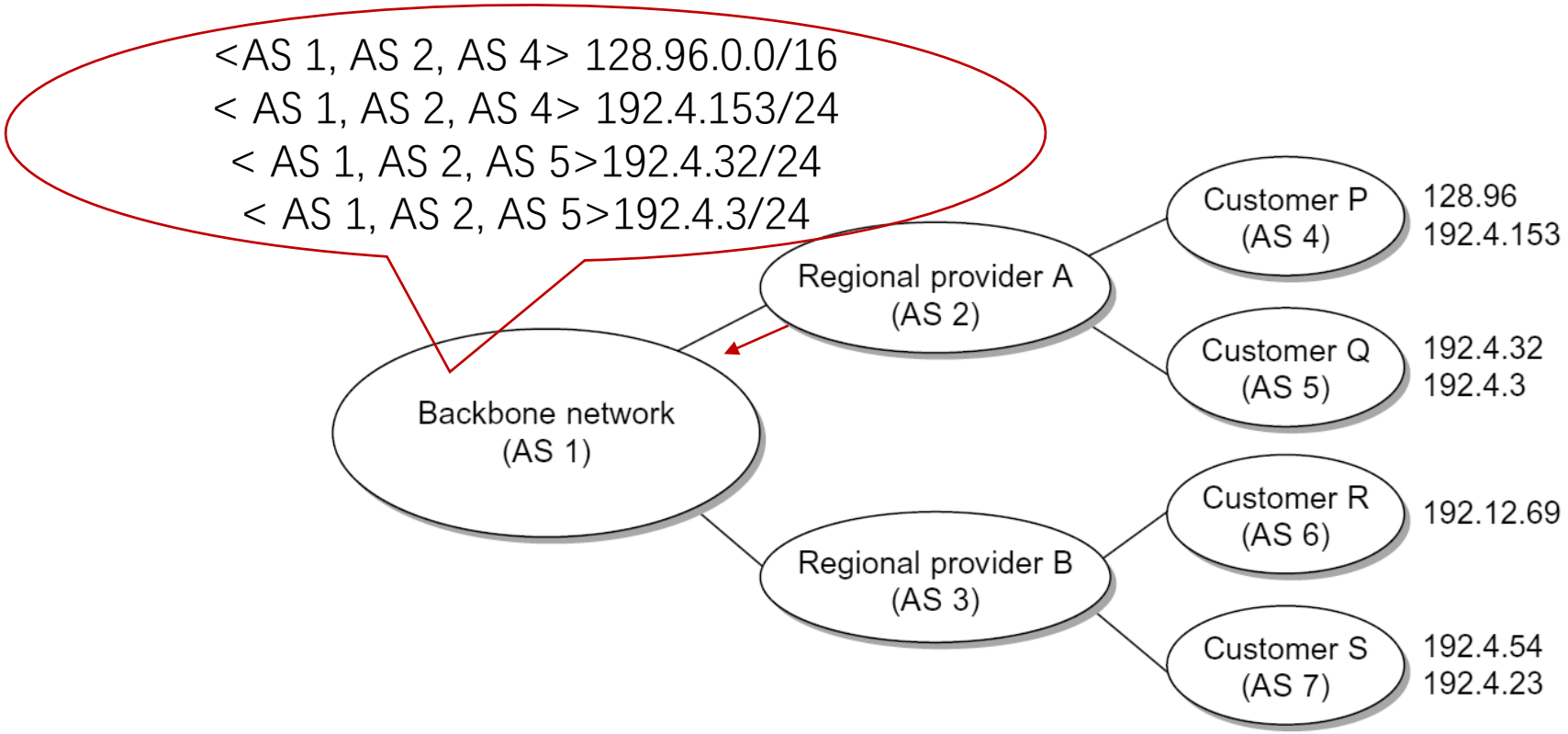
BGP: Path Vector Routing



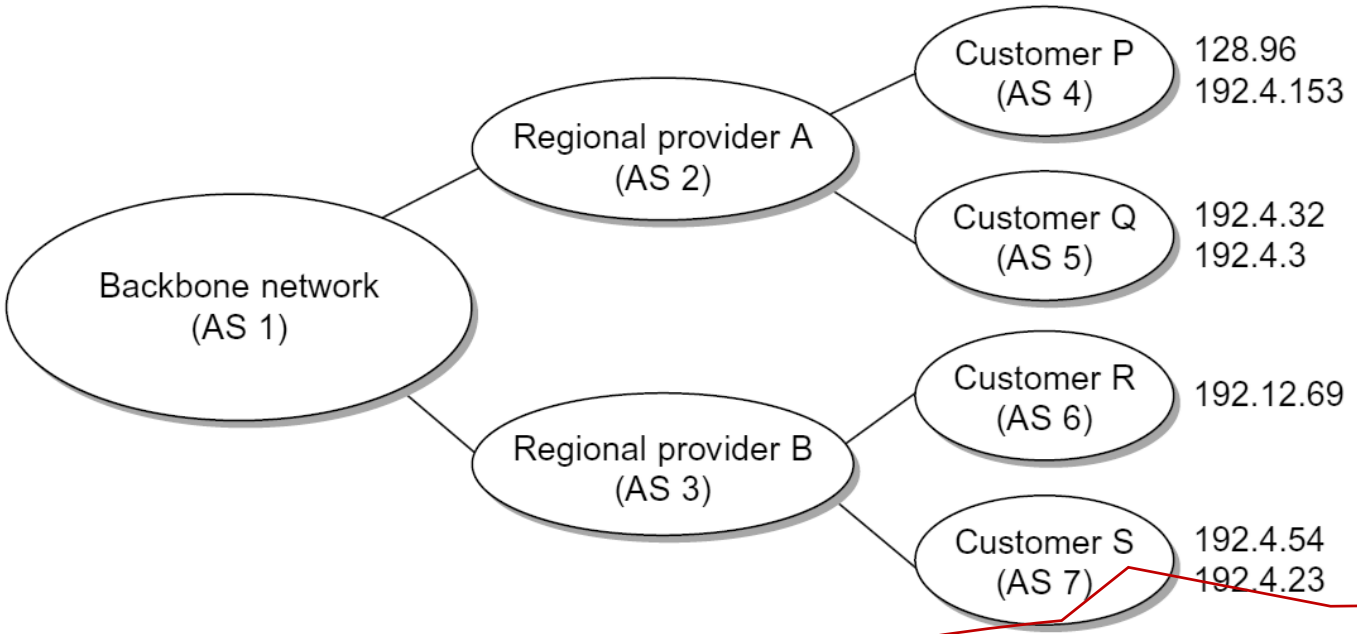
BGP: Path Vector Routing



BGP: Path Vector Routing

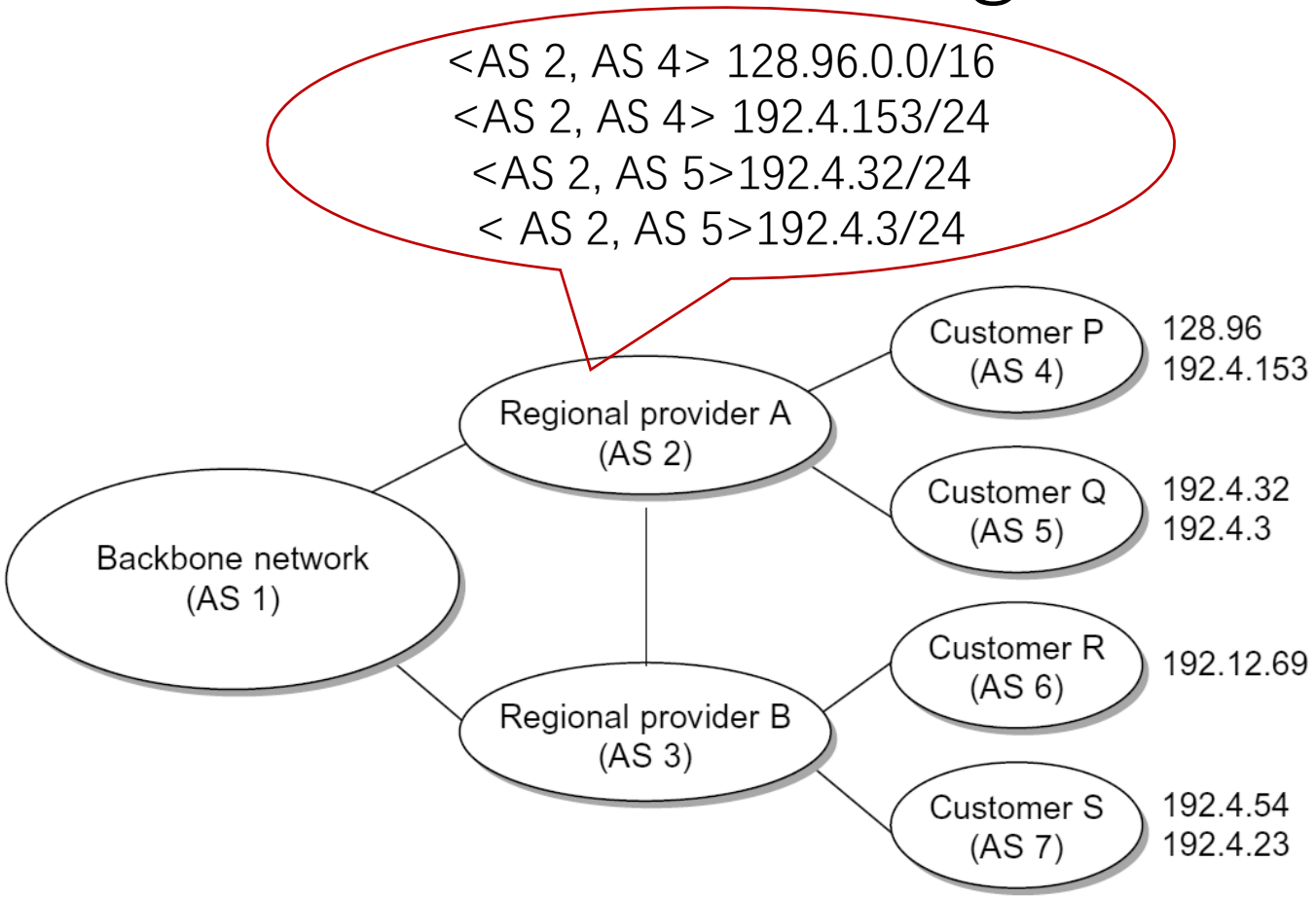


BGP: Path Vector Routing

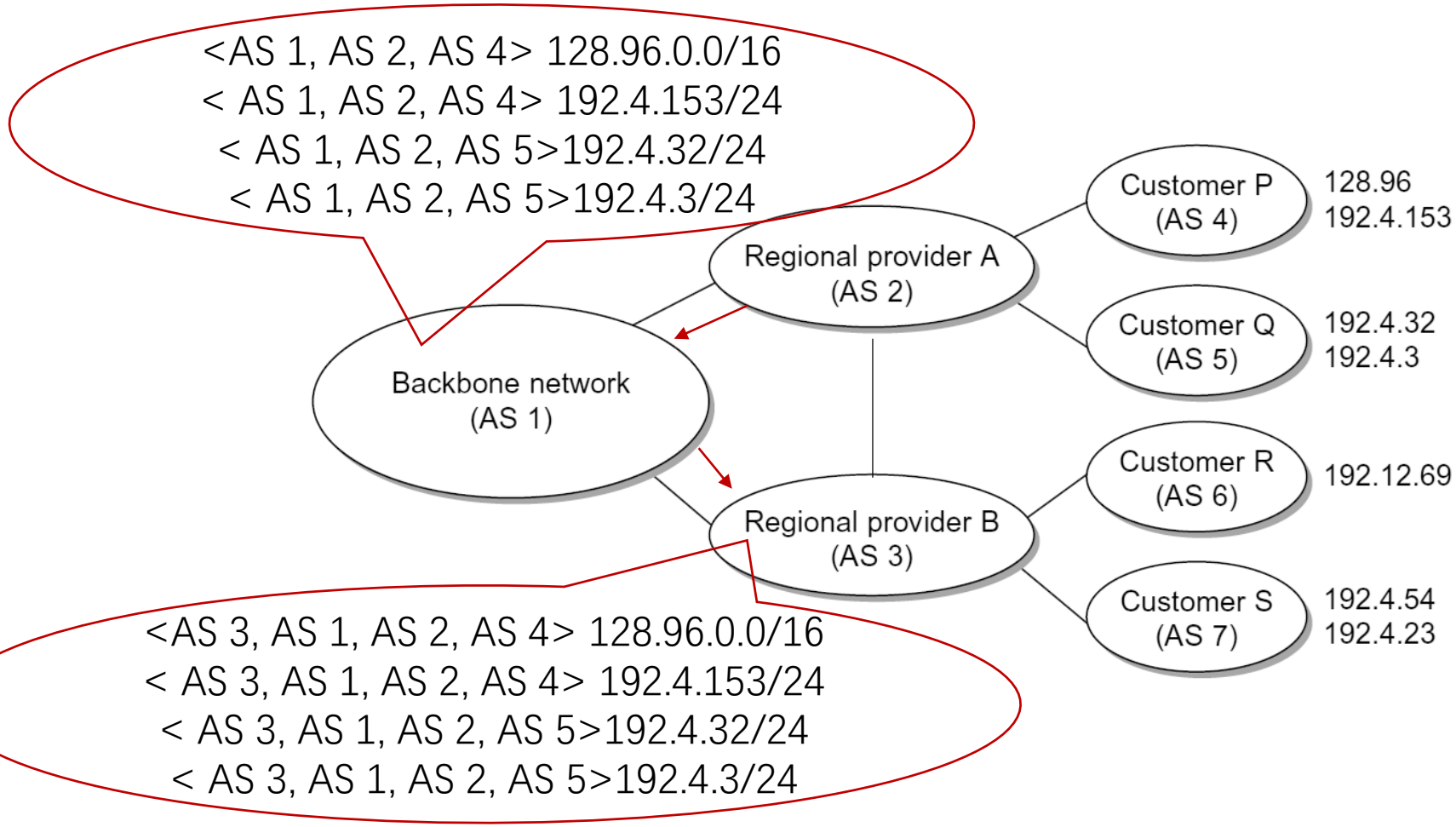


< AS 7, AS 3, AS 1, AS 2, AS 4> 128.96.0.0/16
< AS 7, AS 3, AS 1, AS 2, AS 4> 192.4.153/24
< AS 7, AS 3, AS 1, AS 2, AS 5>192.4.32/24
< AS 7, AS 3, AS 1, AS 2, AS 5>192.4.3/24

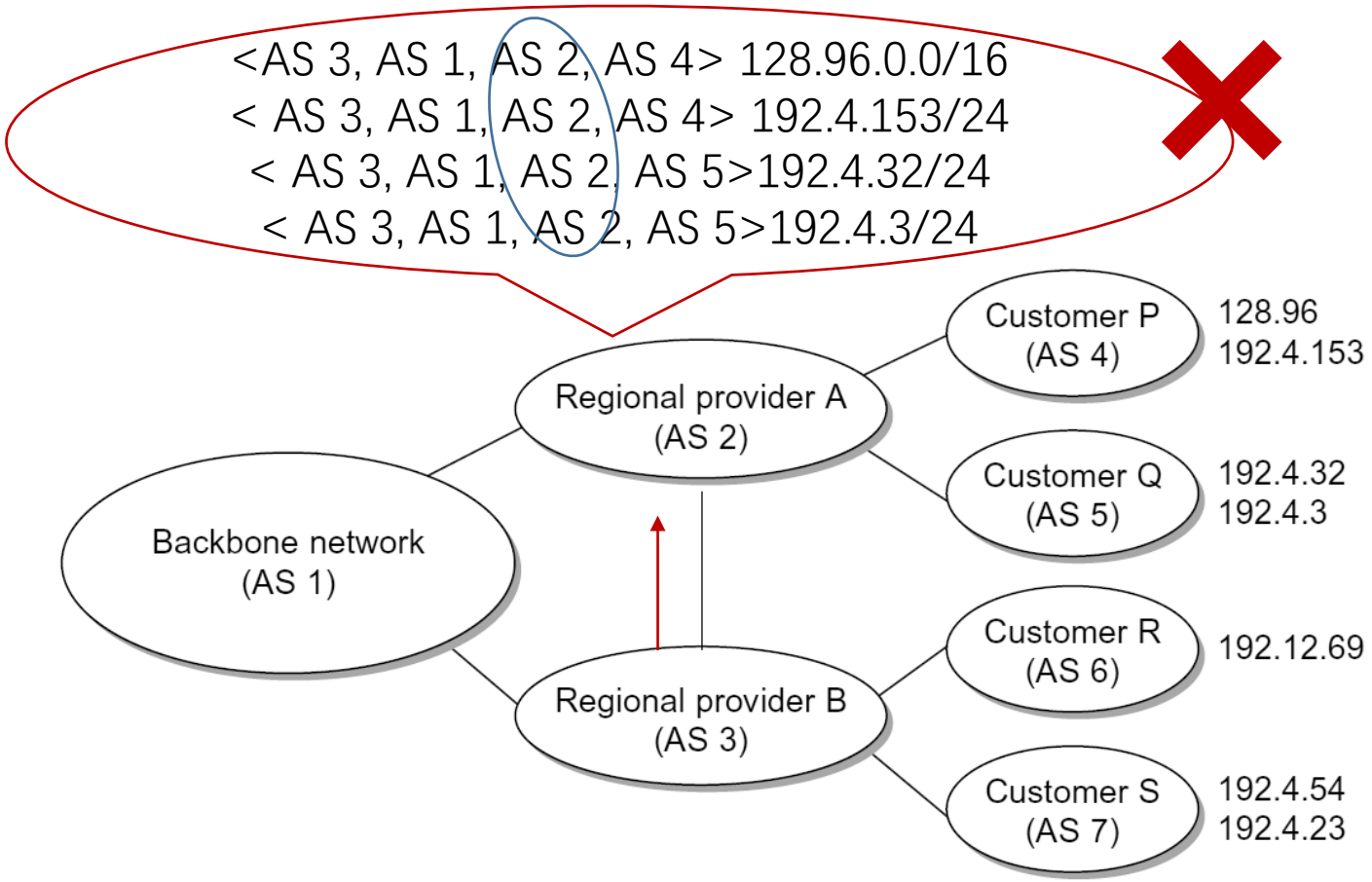
BGP: Path Vector Routing



BGP: Path Vector Routing



BGP: Path Vector Routing

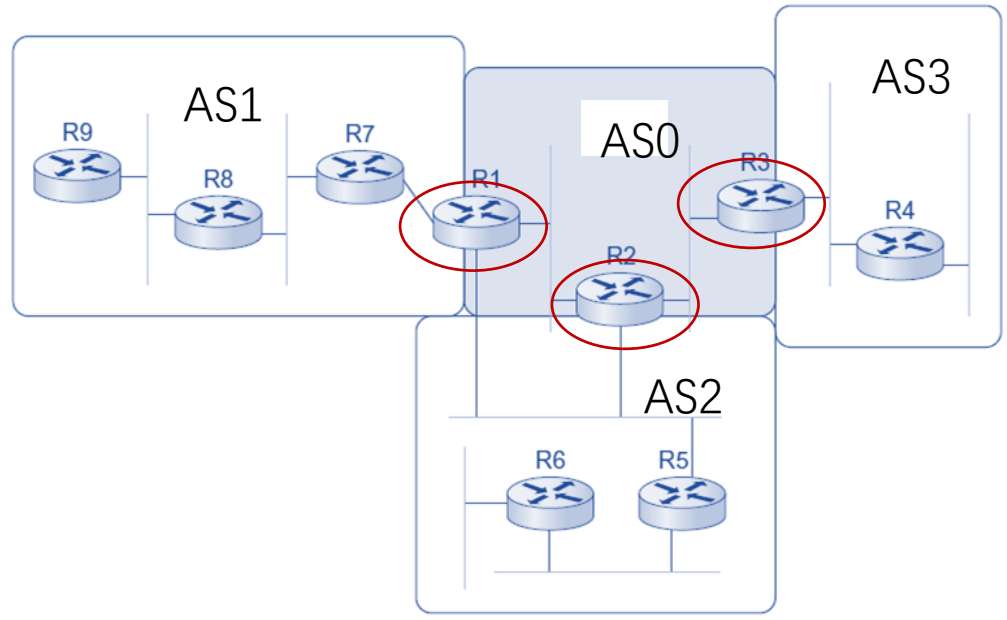


Demo

- BGP Entries
  - http://bgp.potaroo.net/as2.0/bgp-active.html
- BGP Looking Glass
  - eg: https://lg.telia.net/
- AS Number Look Up
  - eg: https://www.ultratools.com/tools/asnInfo

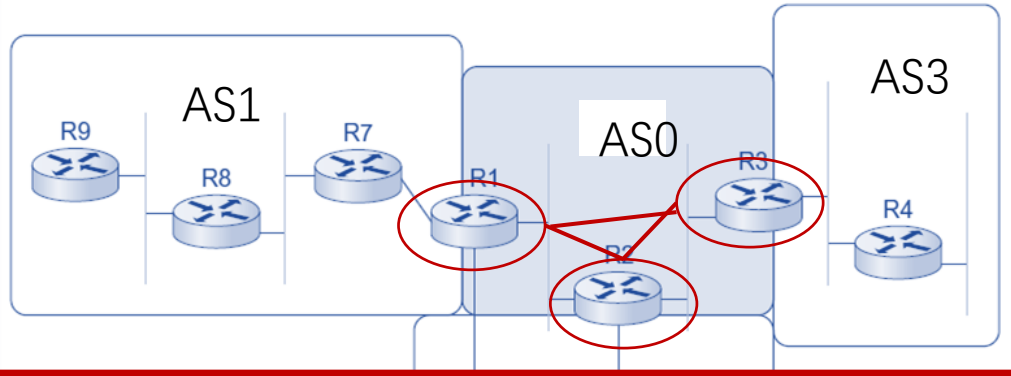
BGP: Integrate with Intradomain Routing

- Boarder Routers: connecting more than one ASs



BGP: Integrate with Intradomain Routing

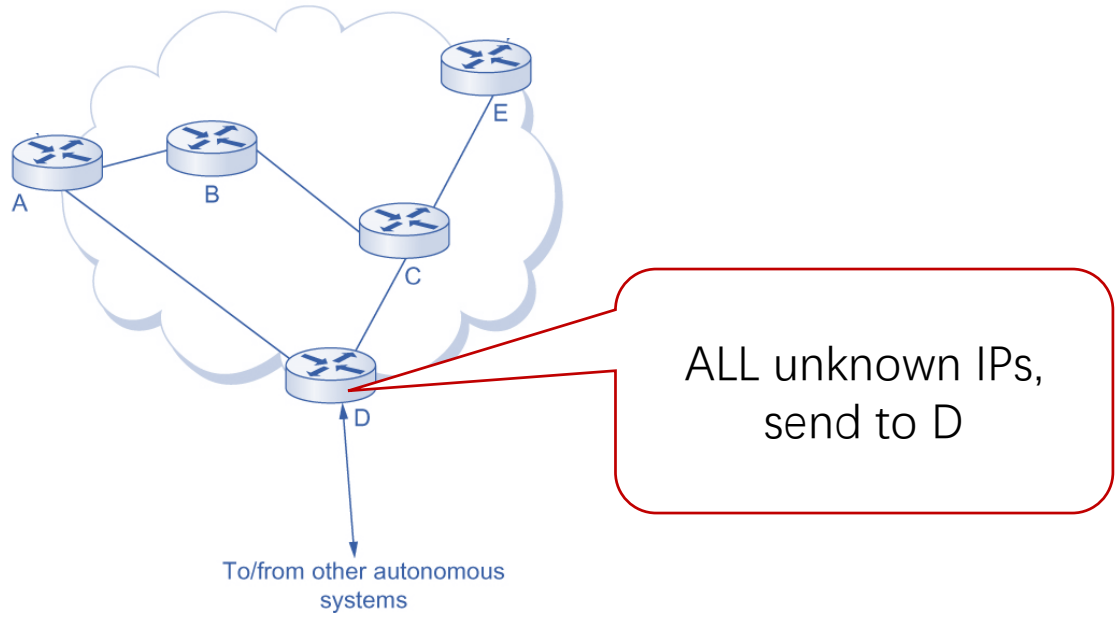
- Boarder Routers: connecting more than one ASs
  - Select and configured by AS administrators
  - Routing entries exchanged with other Boarder Routers through exterior BGP (eBGP)
    - Through TCP connection



How to inject BGP routing entries into routers inside the AS ?

BGP: Integrate with Intradomain Routing

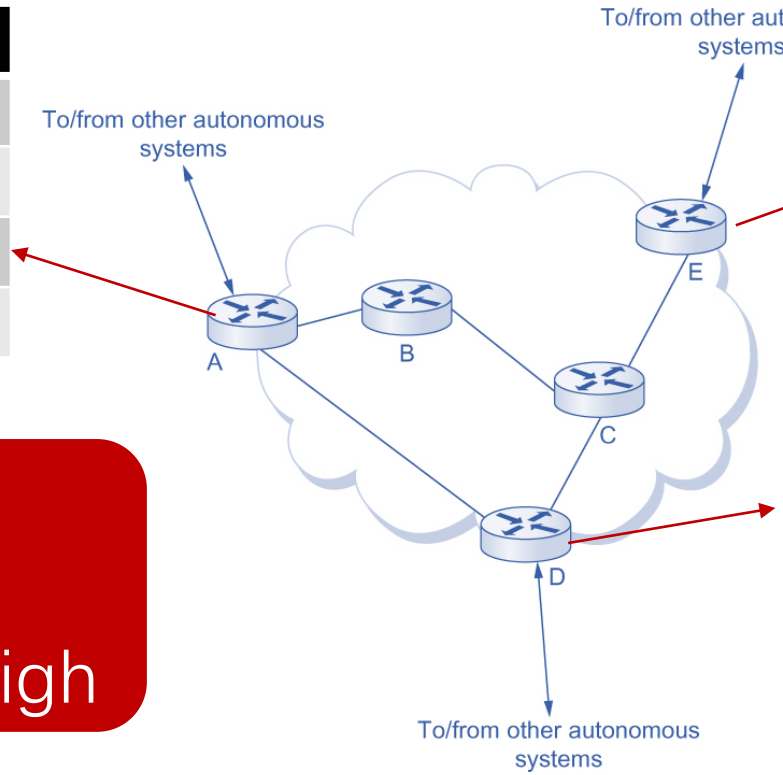
- Method 1: Default Router (Static Method)
  - Inject a default router entry into all routers in the AS through intradomain routing protocol



BGP: Integrate with Intradomain Routing

- Method 2: Entry Translation
  - Translate and broadcast BGP entries in the AS through intradomain routing protocol

Prefix	cost
18.0.0.0/16	10
12.5.5.0/24	1
128.34.0.0/16	13
128.69.0.0/16	8



Prefix	cost
18.0.0.0/16	3
12.5.5.0/24	15
128.34.0.0/16	4
128.69.0.0/16	2

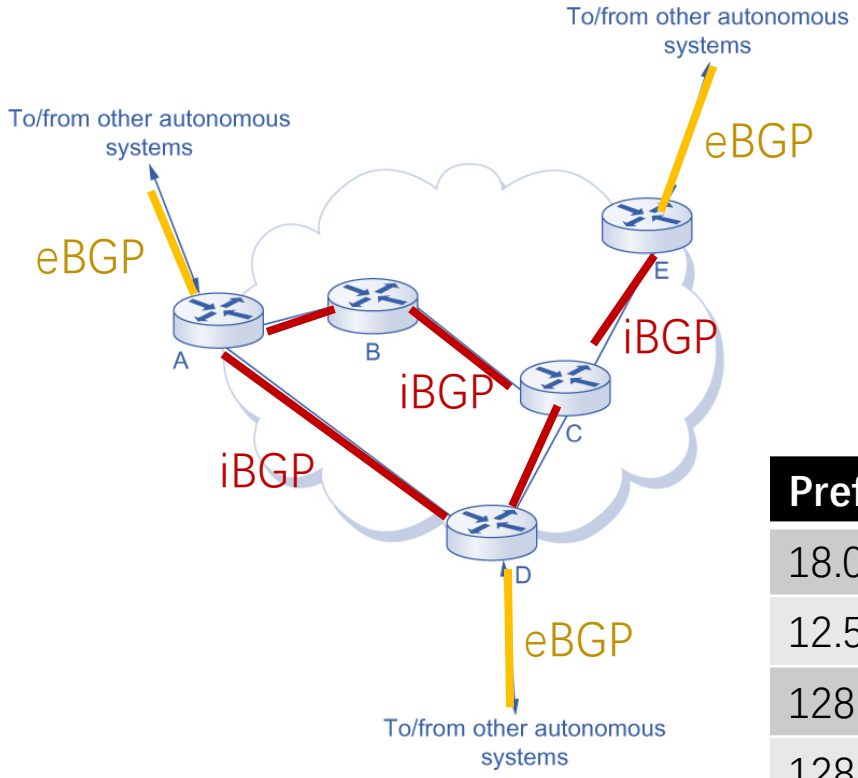
Prefix	cost
18.0.0.0/16	7
12.5.5.0/24	11
128.34.0.0/16	1
128.69.0.0/16	6

Overhead for Intradomain Routing is very High

BGP: Integrate with Intradomain Routing

- Method 3: interior BGP (iBGP)
  - Broadcast BGP entries in the AS through iBGP

Prefix	cost
18.0.0.0/16	10
12.5.5.0/24	1
128.34.0.0/16	13
128.69.0.0/16	2



Prefix	cost
18.0.0.0/16	3
12.5.5.0/24	15
128.34.0.0/16	4
128.69.0.0/16	12

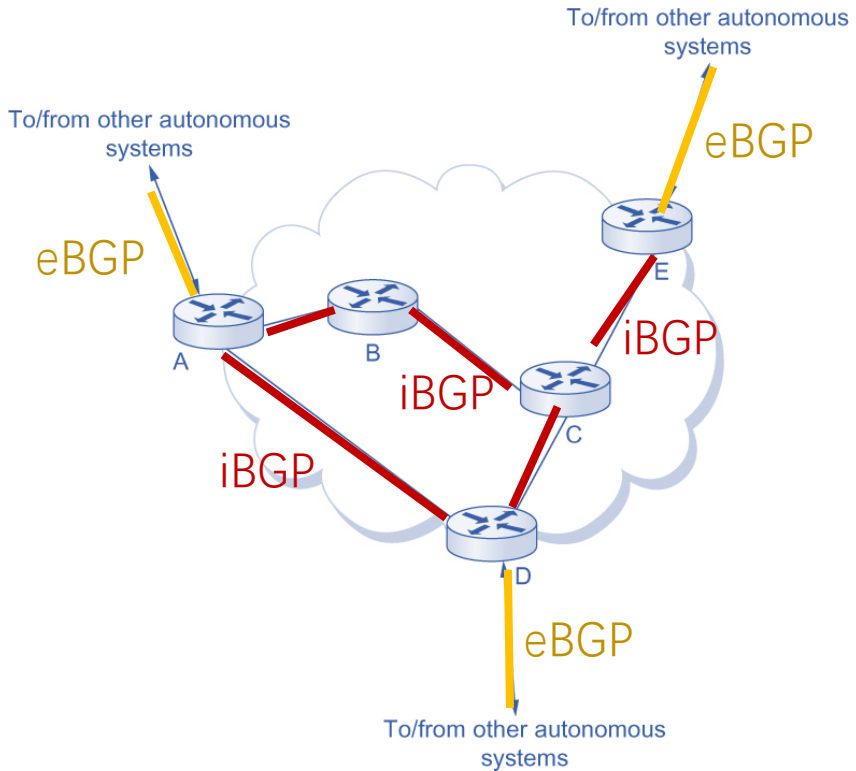
Prefix	cost
18.0.0.0/16	7
12.5.5.0/24	11
128.34.0.0/16	1
128.69.0.0/16	6

BGP: Integrate with Intradomain Routing

- Method 3: interior BGP (iBGP)
  - Broadcast BGP entries in the AS through iBGP
  - Roughly determine the best boarder router for certain prefix

Prefix	Cost	Out
18.0.0.0/16	3	E
12.5.5.0/24	1	A
128.34.0.0/16	1	D
128.69.0.0/16	2	A

BGP Table for the AS



BGP: Integrate with Intradomain Routing

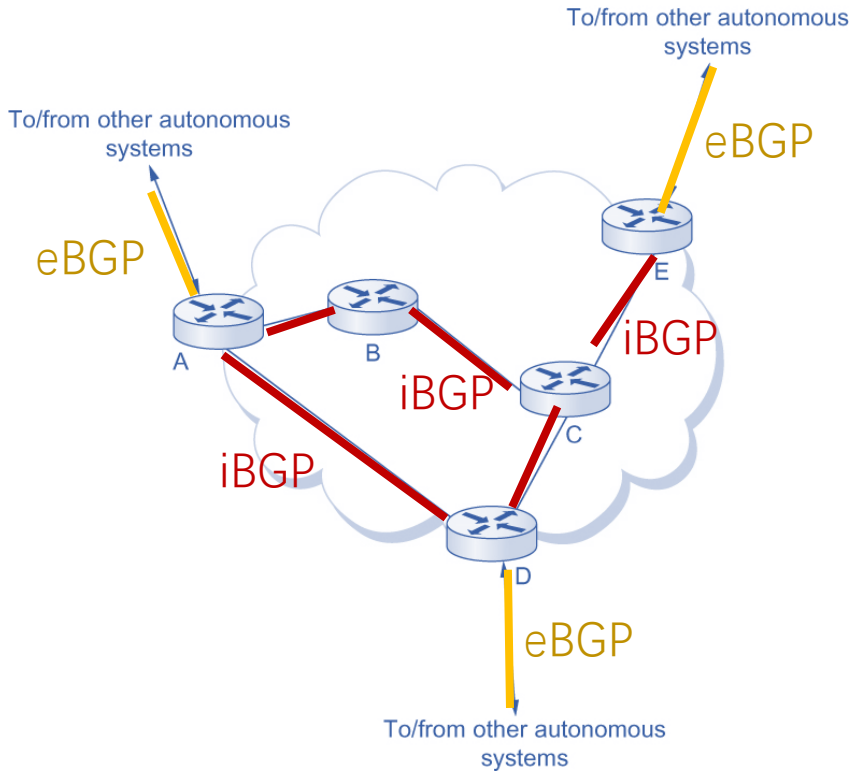
- Method 3: interior BGP (iBGP)
  - Broadcast BGP entries in the AS through iBGP
  - Roughly determine the best boarder router for certain prefix

Prefix	Cost	Out
18.0.0.0/16	3	E
12.5.5.0/24	1	A
128.34.0.0/16	1	D
128.69.0.0/16	2	A

BGP Table for the AS

Dest	Next
A	A
C	C
D	C
E	C

Routing Table of B



Prefix	Next
18.0.0.0/16	C
12.5.5.0/24	A
128.34.0.0/16	C
128.69.0.0/16	A

Combined Table for B

Reference

- Textbook 3.3
- Textbook 4.1
- http://www.ciscopress.com/articles/article.asp?p=24090