BGP
Protocol & Configuration

AfNOG

Border Gateway Protocol (BGP4)

- Case Study 1, Exercise 1: Single upstream
- Part 6: BGP Protocol Basics
- Part 7: BGP Protocol - more detail
- Case Study 2, Exercise 2: Local peer
- Part 8: Routing Policy and Filtering
- Exercise 3: Filtering on AS-path
- Exercise 4: Filtering on prefix-list
- Part 9: More detail than you want
- Exercise 5: Interior BGP
- Part 10: BGP and Network Design

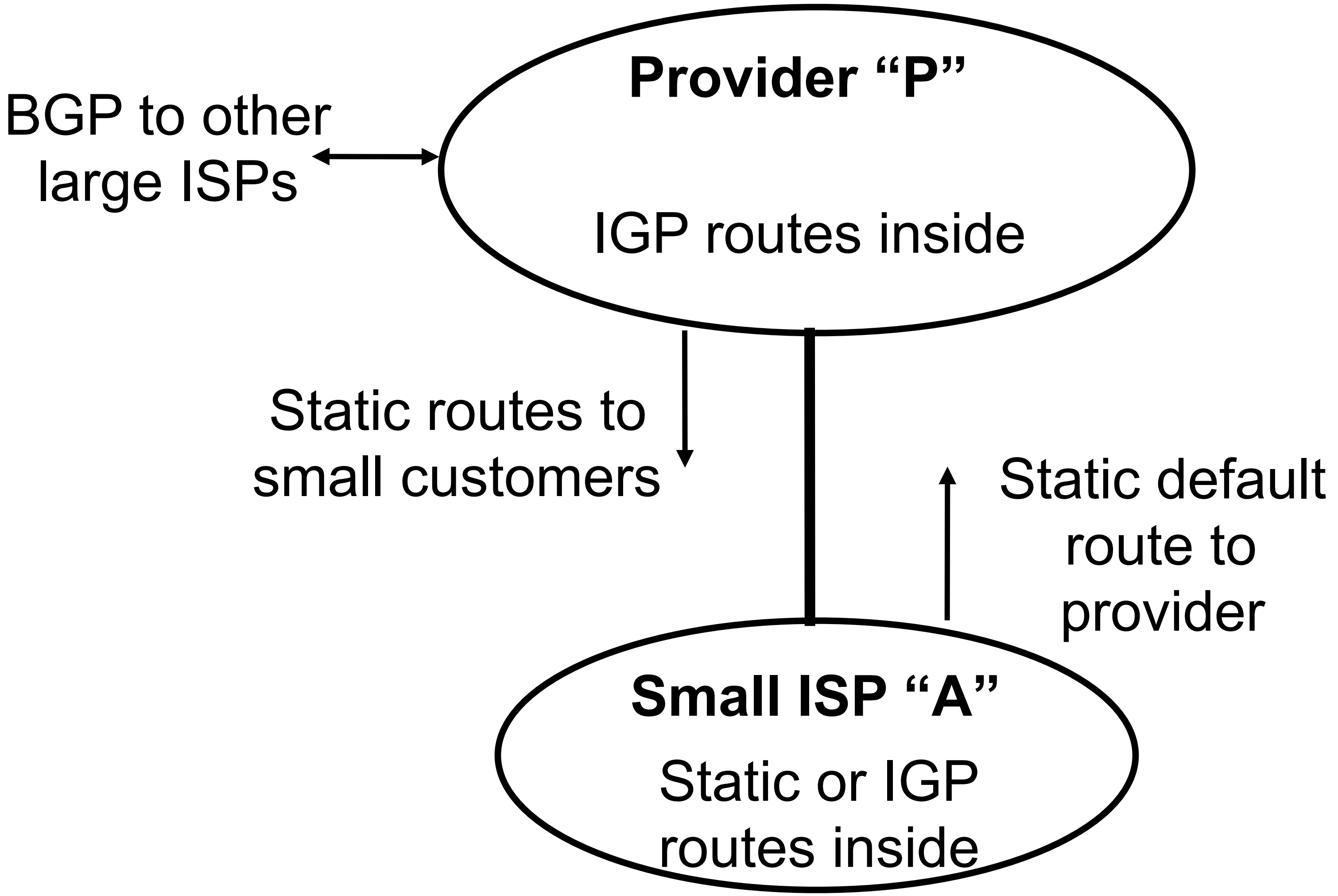
BGP Case Study 1 and Exercise 1

Small ISP with one upstream provider

Case Study 1: Small ISP with one upstream provider

- Local network
- May have multiple POPs
- Line to Internet
  - International line providing transit connectivity
  - Very, very expensive

Case Study 1: Small ISP with one upstream provider


BGP to other large ISPs
Provider "P"
IGP routes inside
Static routes to small customers
Static default route to provider
Small ISP "A"
Static or IGP routes inside

Case Study 1: Routing Protocols

- Static routes or IGP inside small ISP “A”
- Static default route from small ISP “A” to upstream provider “P”
- IGP inside upstream provider “P”
- The two IGPs do not know about each other
- BGP between upstream provider “P” and outside world

Case Study 1: BGP is not needed

- No need for BGP between small ISP “A” and upstream provider “P”
- The outside world does not need to care about the link between provider “P” and customer “A”
- Hiding that information from the outside world helps with scaling
- **We will do an exercise using BGP even though it is not needed**

Exercise 1: Upstream provider with small customers

- This is not a realistic exercise
- In reality, a single-homed network would not use BGP.
- Exercise 2 will be more realistic.

Exercise 1: BGP configuration

- Refer to "BGP cheat sheet"
- Connect cable to upstream provider
- "router bgp" for your AS number
- BGP "network" statement for your network
- BGP "neighbor" for upstream provider (IP address 196.200.220.xx, remote AS 100)
  - (Your workshop instructor will provide point to point link addresses)
- Do the same for IPv6

Exercise 1: Transit through upstream provider

- Instructors configure AS 100 to send you all routes to other classroom ASes, and a default route
  - You can send traffic through AS 100 to more distant destinations
  - In other words, AS 100 provides “transit” service to you

Exercise 1:
What you should see

- You should see routes to all other classroom networks
- Try:
  - “show ip route” to see IPv4 routing table
  - “show ipv6 route” to see IPv6 routing table
  - “show ip bgp” to see IPv4 BGP table
  - “show bgp ipv6” to see IPv6 BGP table
- Look at the “next hop” and “AS path”
- Try some pings and traceroutes.

Exercise 1: Did BGP "network" statement work?

- BGP "network" statement has no effect unless route exists in IGP (or static route)
- You might need to add a static route to make it work
  - IPv4: ip route x.x.x.x m.m.m.m Null0 250
  - IPv6: ipv6 route x:x::/60 Null0 250
- 250 is the administrative distance (cisco, not standardised)
  - Smaller is "most important"
  - Default for a static route is 1
  - 255 is "least important"

BGP Part 6

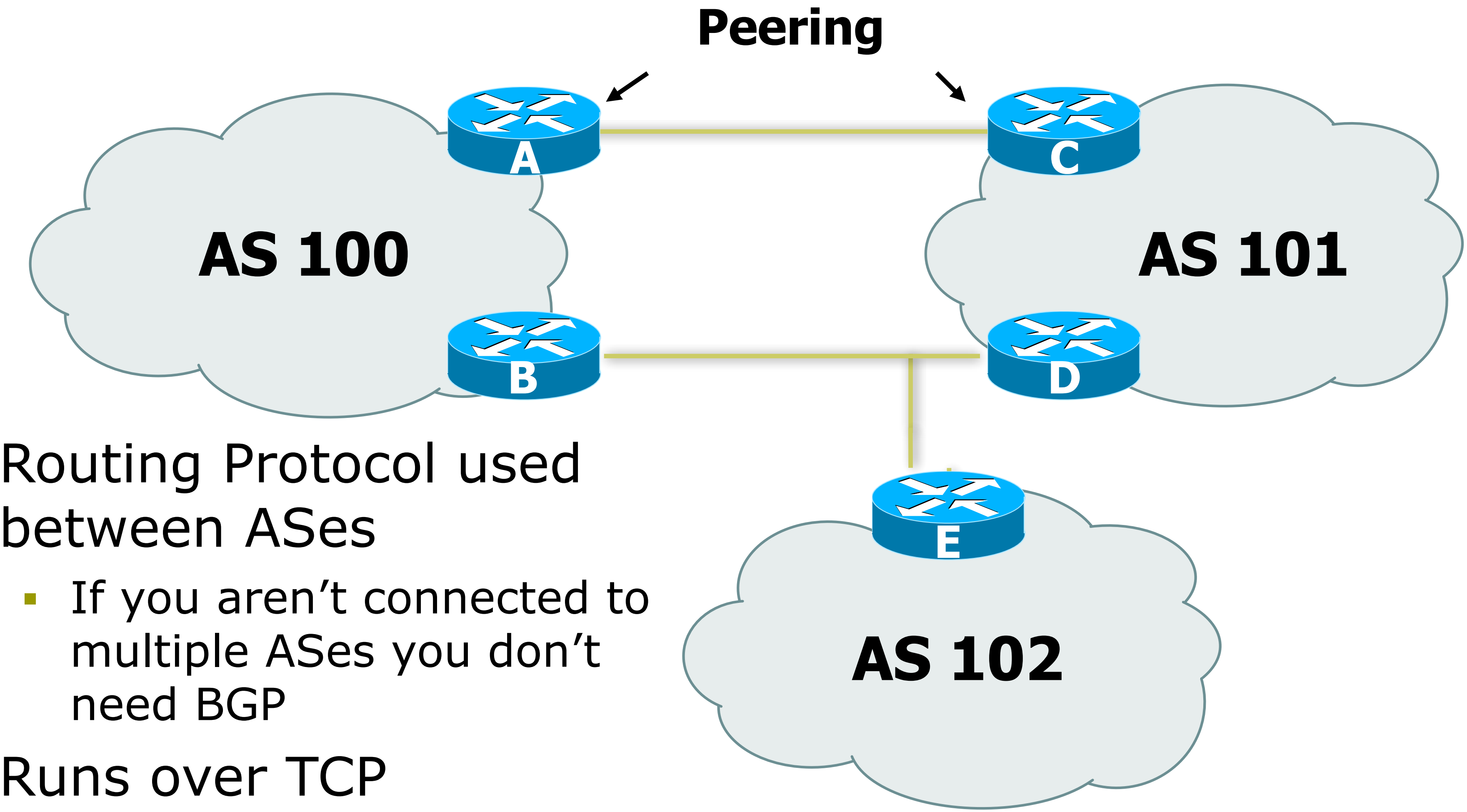
BGP Protocol Basics

Terminology

General Operation

Interior/Exterior BGP

BGP Protocol Basics



- Routing Protocol used between ASes
  - If you aren’t connected to multiple ASes you don’t need BGP
- Runs over TCP

BGP Protocol Basics

- Uses Incremental updates
  - sends one copy of the RIB at the beginning, then sends changes as they happen
- Path Vector protocol
  - keeps track of the AS path of routing information
- Many options for policy enforcement

Terminology

- Neighbour
  - Configured BGP peer
- NLRI/Prefix
  - NLRI – network layer reachability information
  - Reachability information for an IP address & mask
- Router-ID
  - 32 bit integer to uniquely identify router
  - Comes from Loopback or Highest IP address configured on the router
- Route/Path
  - NLRI advertised by a neighbour

Terminology

- Transit – carrying network traffic across a network, usually for a fee
- Peering – exchanging routing information and traffic
  - your customers and your peers' customers network information only.
  - not your peers' peers; not your peers' providers.
- Peering also has another meaning:
  - BGP neighbour, whether or not transit is provided
- Default – where to send traffic when there is no explicit route in the routing table

BGP Basics …

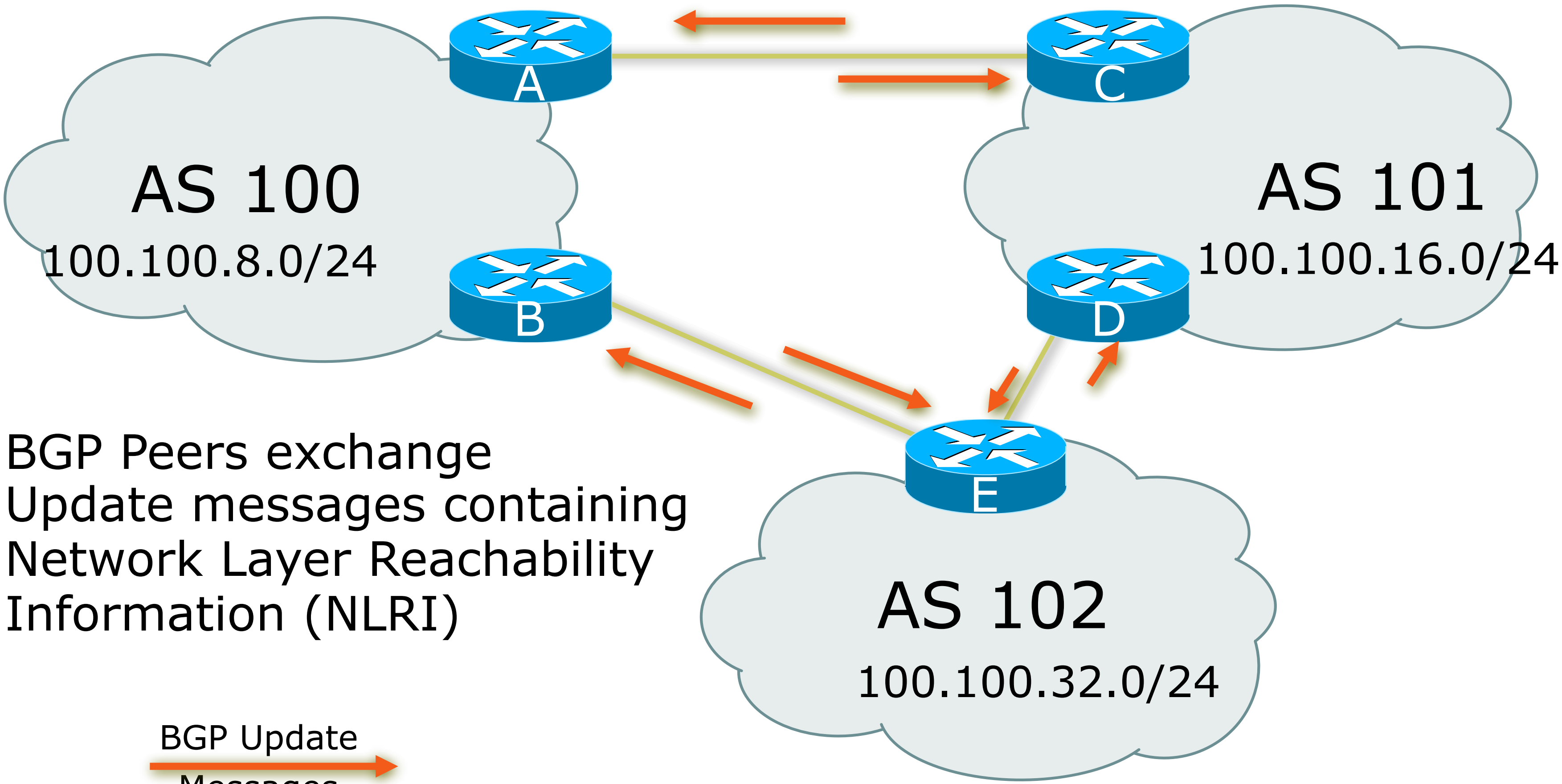
- Each AS originates a set of NLRI (routing announcements)
- NLRI is exchanged between BGP peers
- Can have multiple paths for a given prefix
- BGP picks the best path and installs in the IP forwarding table
- Policies applied (through attributes) influences BGP path selection

Interior BGP vs. Exterior BGP

- Interior BGP (iBGP)
  - Between routers in the same AS
  - Often between routers that are far apart
  - Should be a full mesh: every iBGP router talks to all other iBGP routers in the same AS

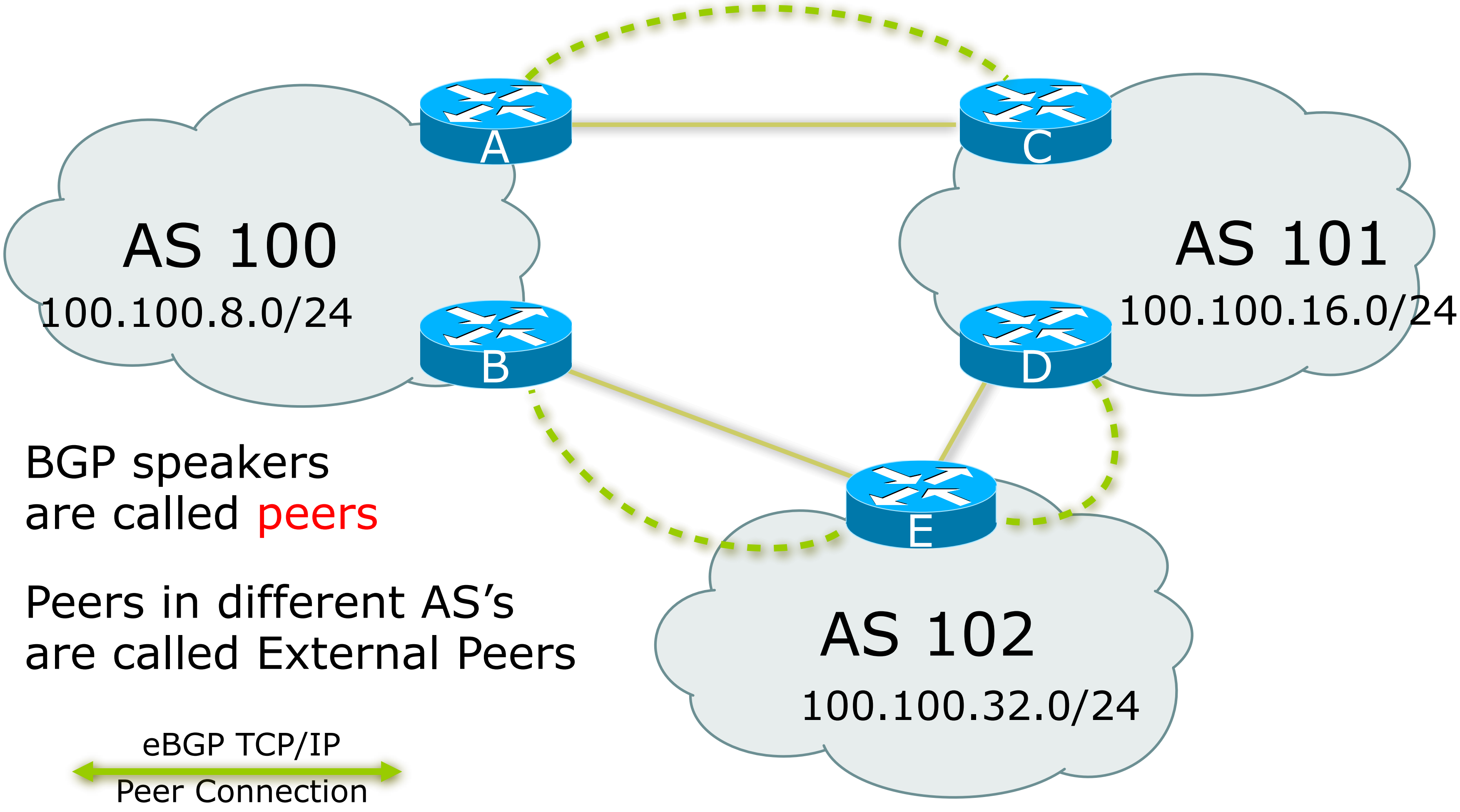
- Exterior BGP (eBGP)
  - Between routers in different ASes
  - Almost always between directly-connected routers (ethernet, serial line, etc.)

BGP Peers



BGP Peers exchange Update messages containing Network Layer Reachability Information (NLRI)

BGP Peers – External (eBGP)

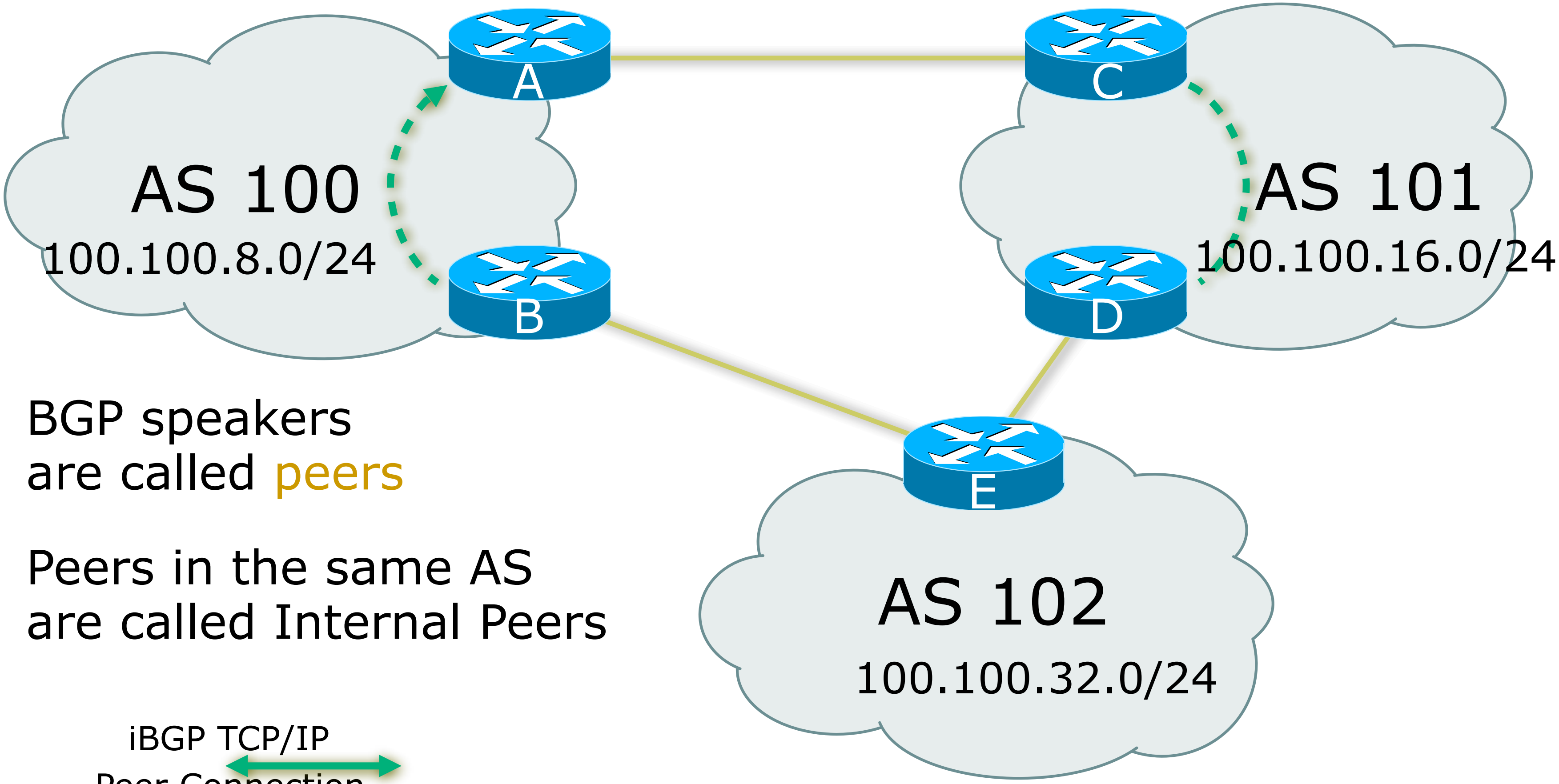


BGP speakers are called peers

Peers in different AS’s are called External Peers

Note: eBGP Peers normally should be directly connected.

BGP Peers – Internal (iBGP)



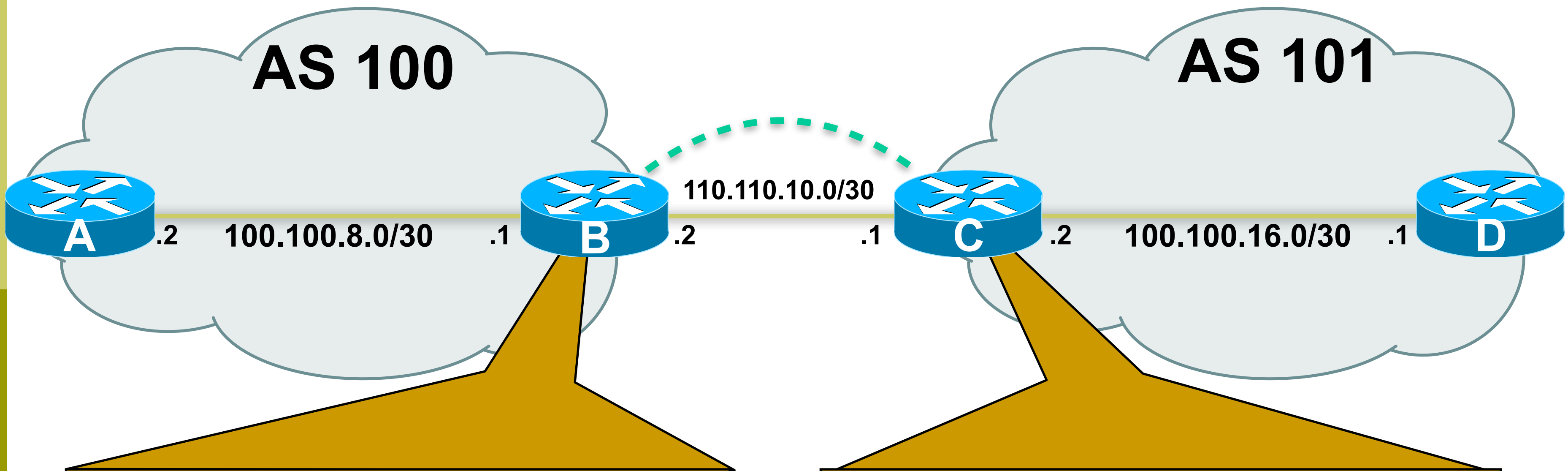
BGP speakers
are called peers

Peers in the same AS
are called Internal Peers

Note: iBGP Peers don’t have to be directly connected.

Configuring eBGP peers

- BGP peering sessions are established using the BGP “neighbor” command
  - eBGP is configured when AS numbers are different

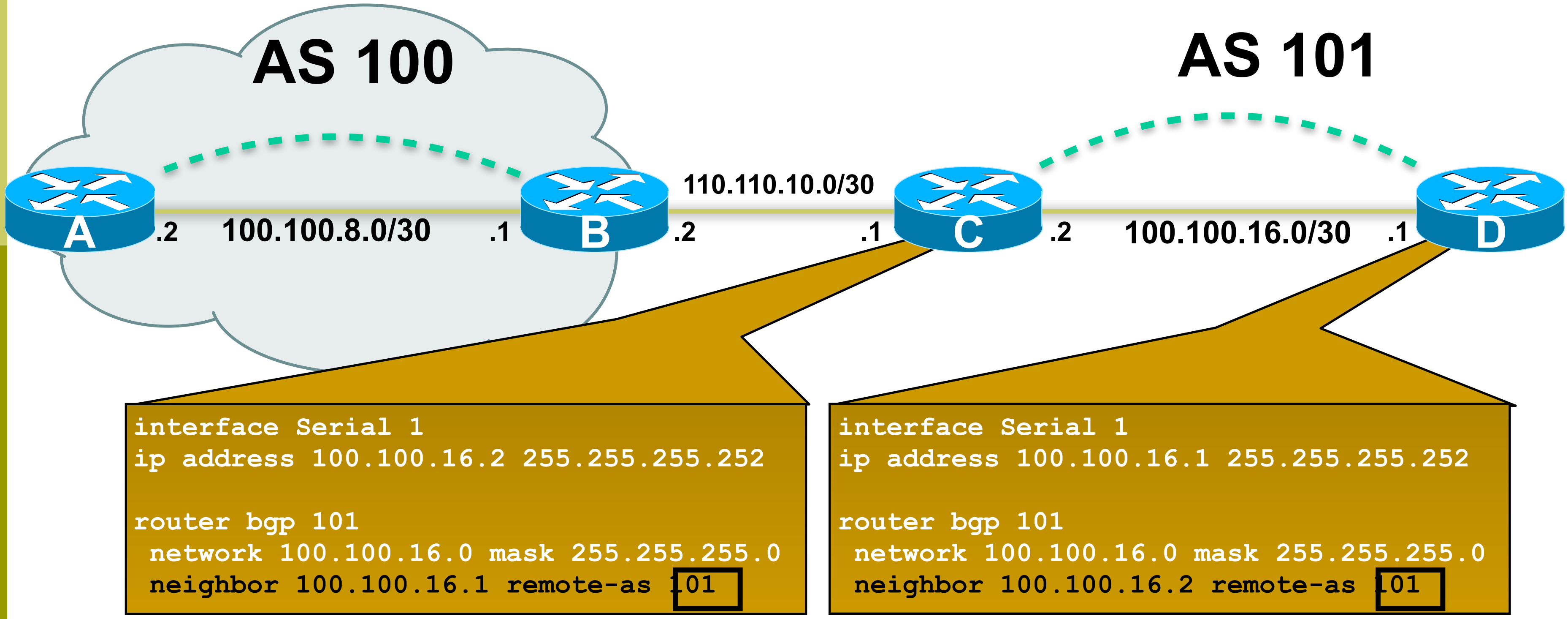


```
interface Serial 0
ip address 110.110.10.2 255.255.255.252

router bgp 100
 network 100.100.8.0 mask 255.255.255.0
 neighbor 110.110.10.1 remote-as 101
```

```
interface Serial 0
ip address 110.110.10.1 255.255.255.252

router bgp 101
 network 100.100.16.0 mask 255.255.255.0
 neighbor 110.110.10.2 remote-as 100
```

Configuring iBGP peers

- BGP peering sessions are established using the BGP “neighbor” command
  - iBGP is configured when AS numbers are the same

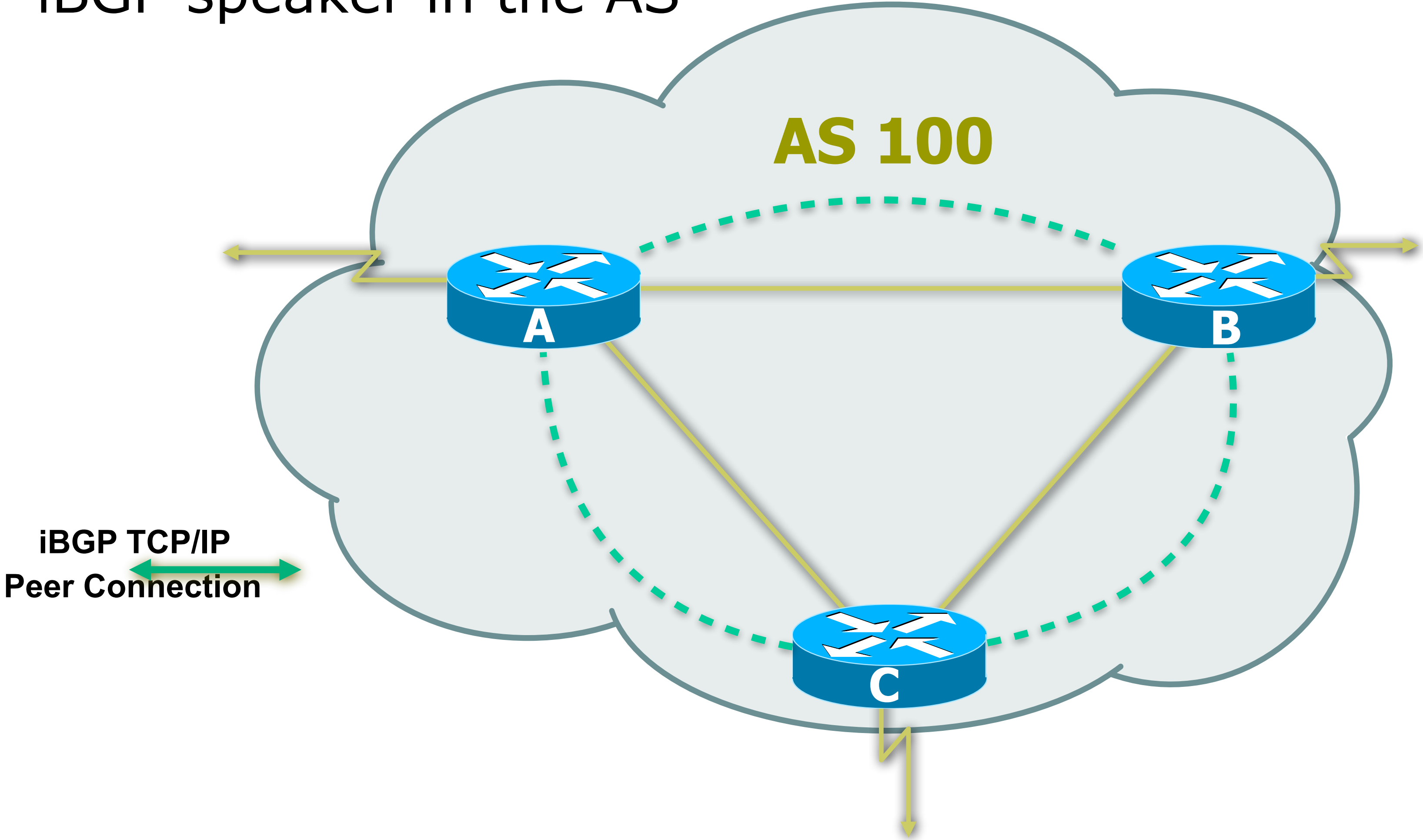


```
interface Serial 1
ip address 100.100.16.2 255.255.255.252

router bgp 101
 network 100.100.16.0 mask 255.255.255.0
 neighbor 100.100.16.1 remote-as 101
```

```
interface Serial 1
ip address 100.100.16.1 255.255.255.252

router bgp 101
 network 100.100.16.0 mask 255.255.255.0
 neighbor 100.100.16.2 remote-as 101
```

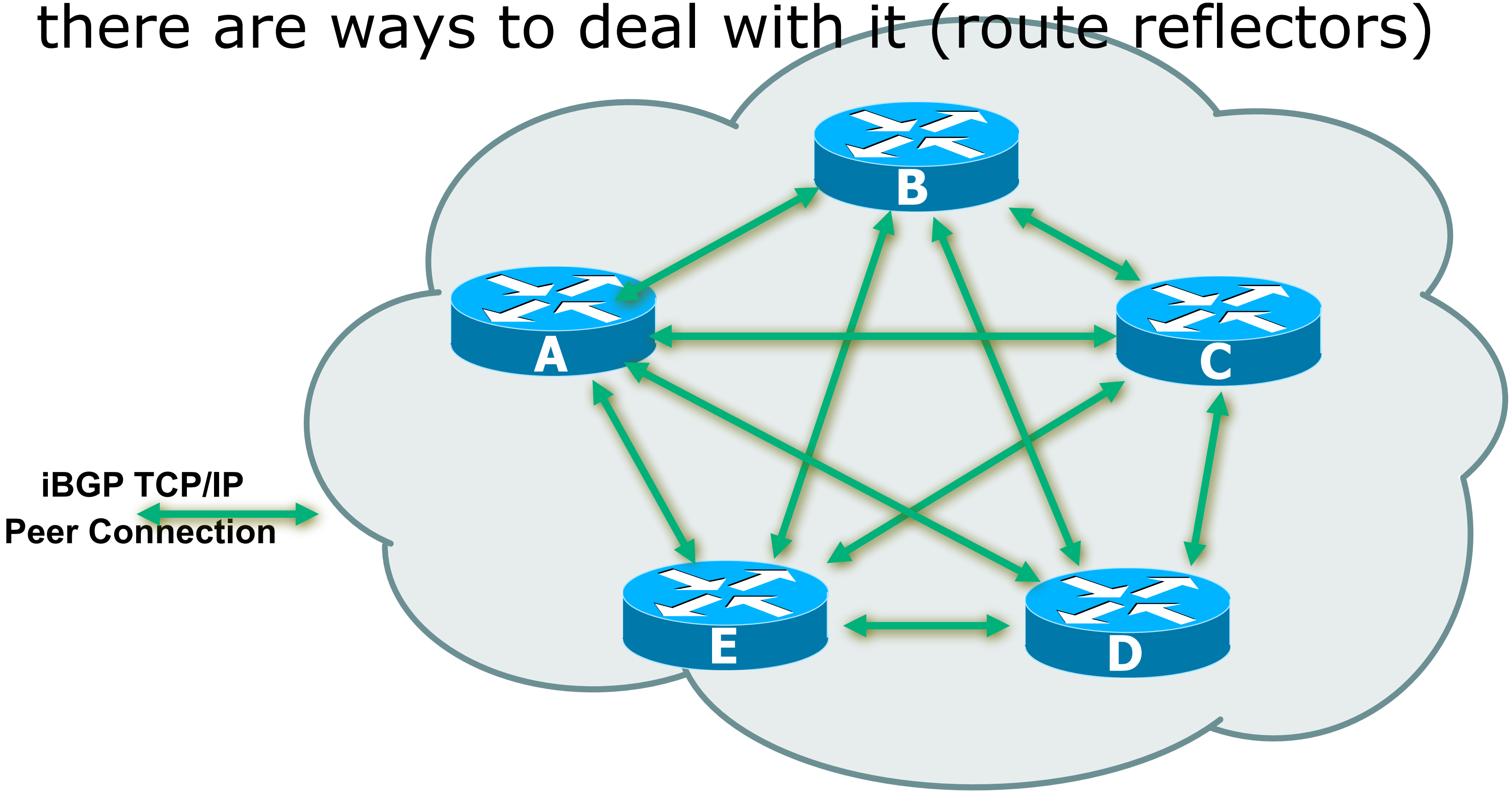
Configuring iBGP peers: Full mesh

- Each iBGP speaker must peer with every other iBGP speaker in the AS



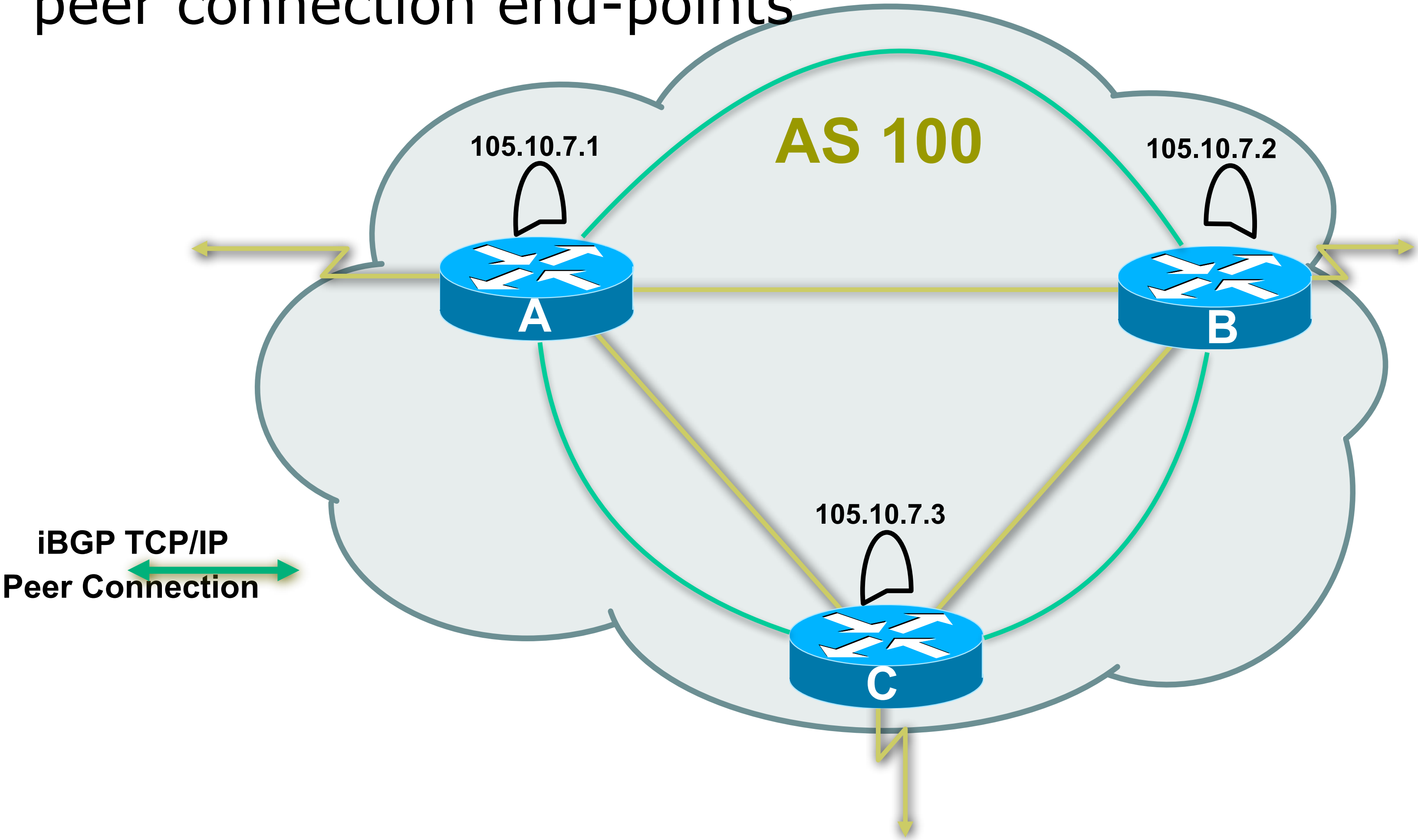
Configuring iBGP peers: Full mesh

- Each iBGP speaker must peer with every other iBGP speaker in the AS
- This can be a pain if there are many routers, but there are ways to deal with it (route reflectors)

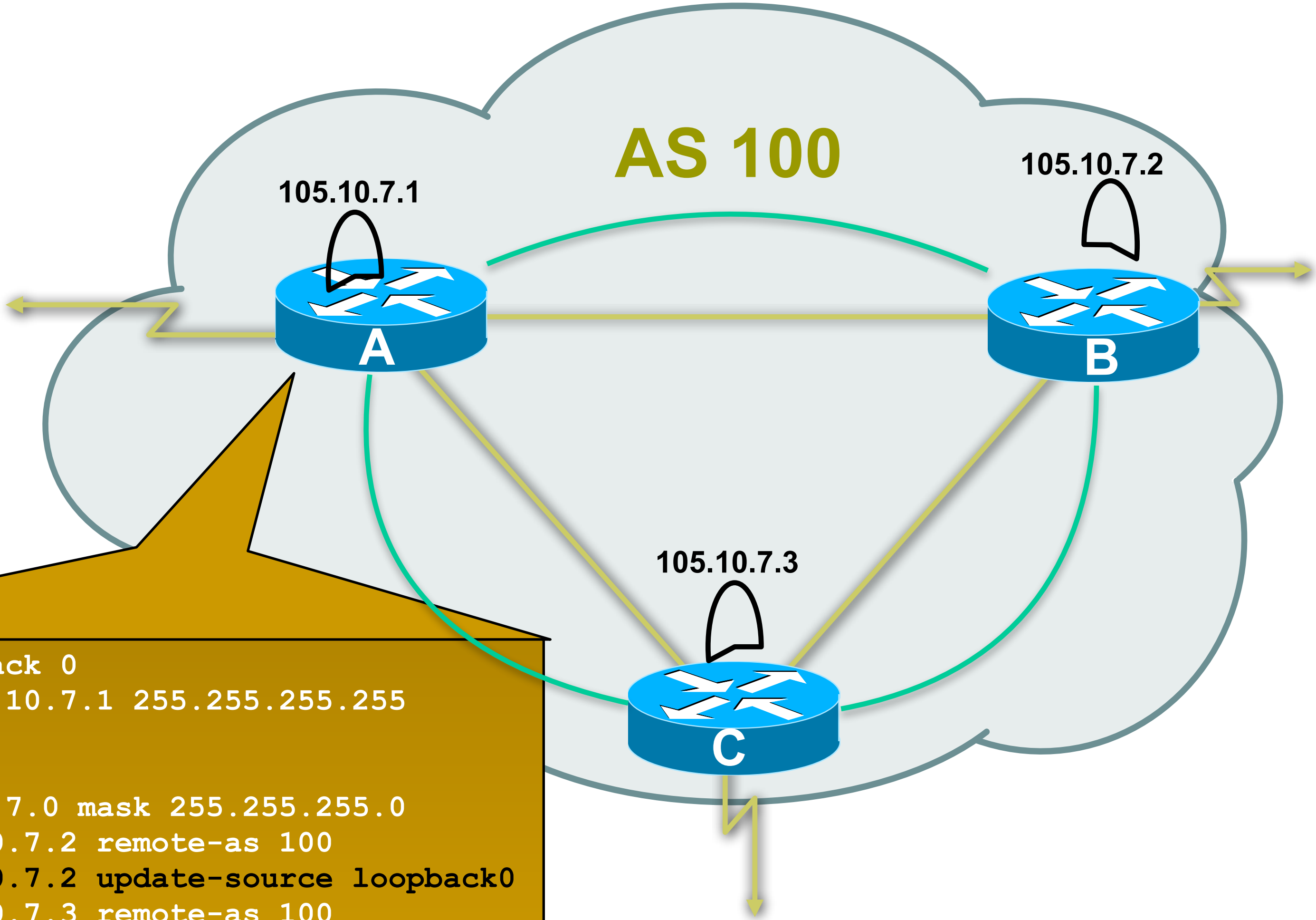


Configuring iBGP peers: Loopback interface

- Loopback interfaces are normally used as the iBGP peer connection end-points

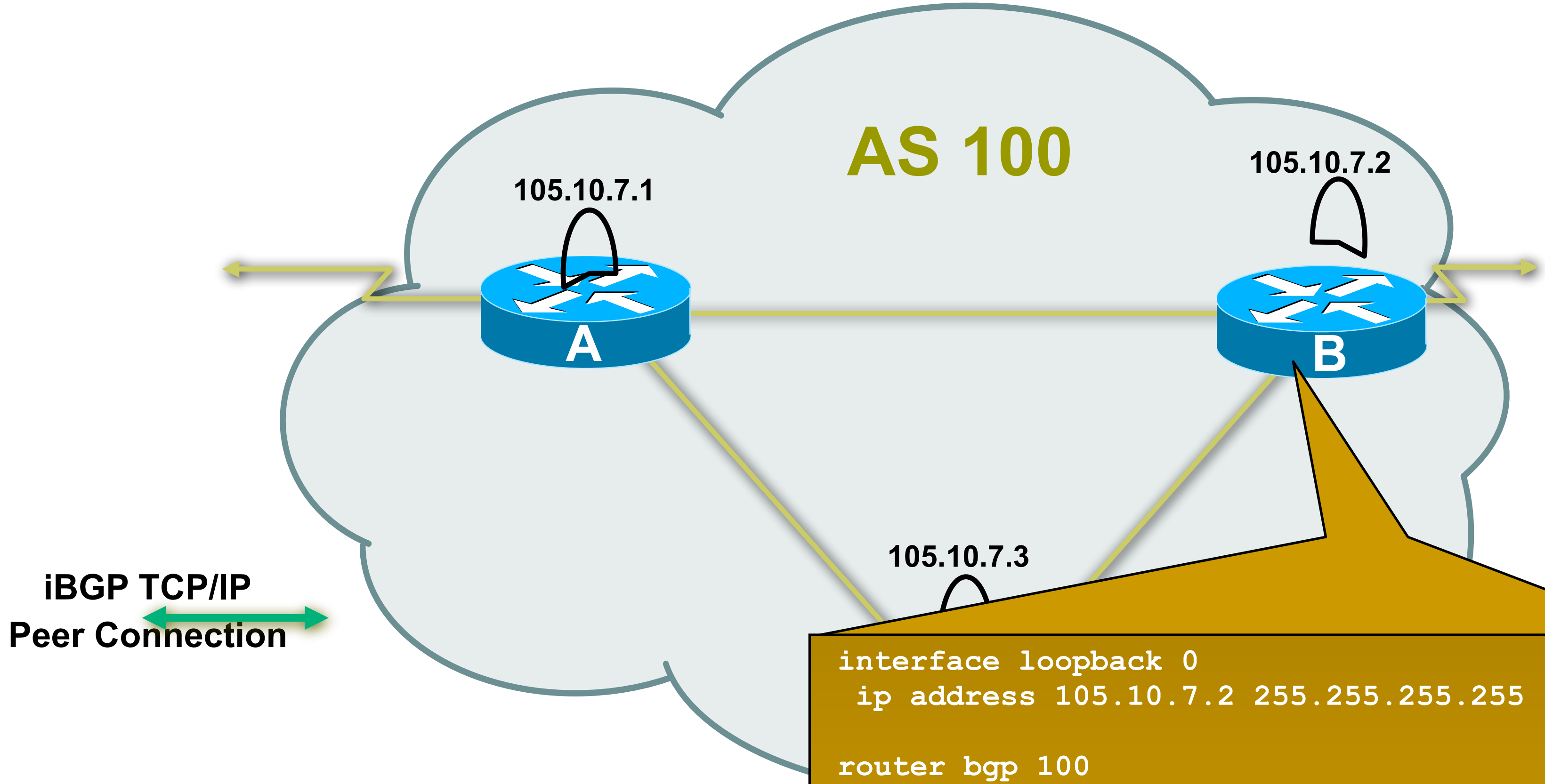


Configuring iBGP peers



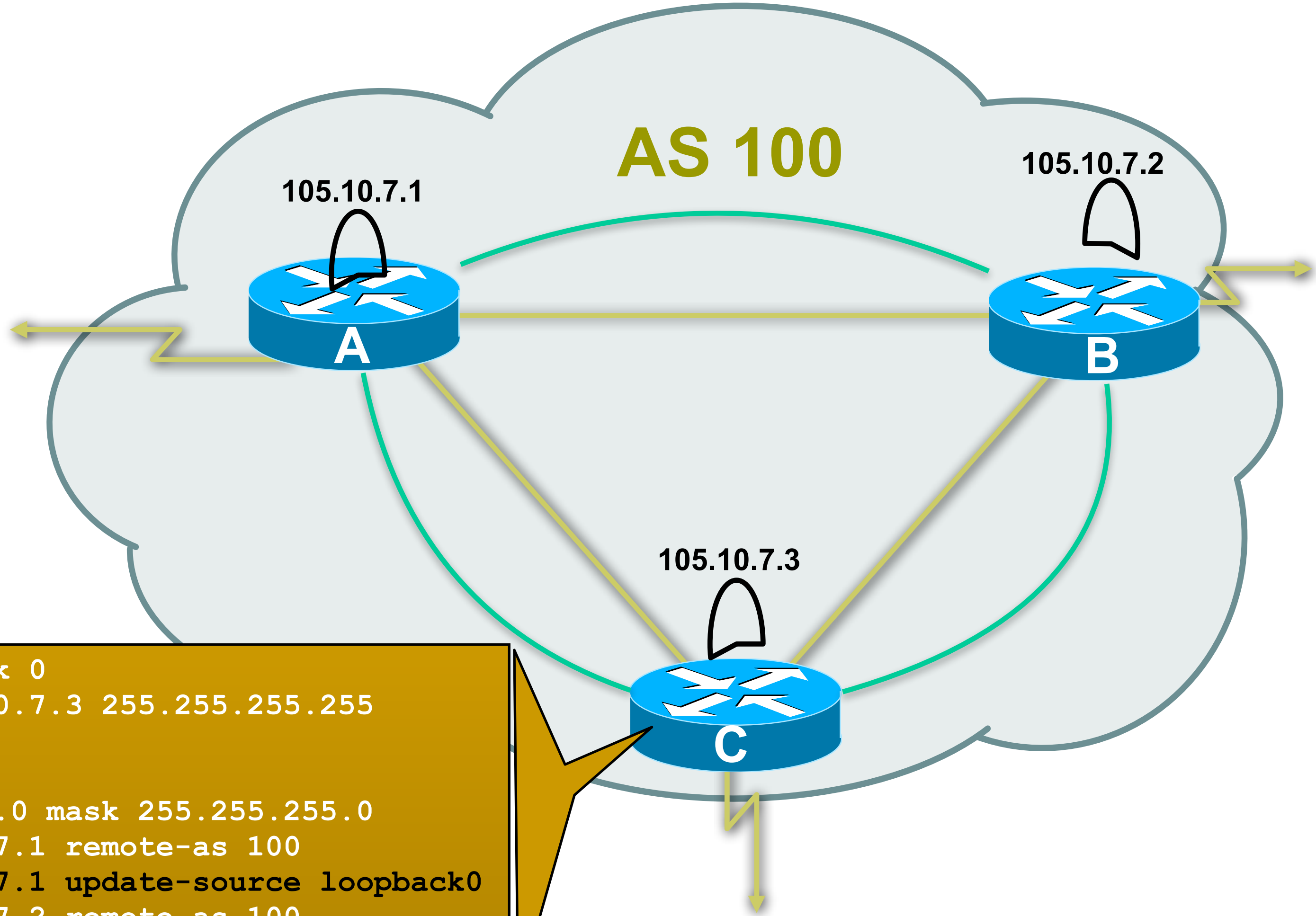
```
interface loopback 0
 ip address 105.10.7.1 255.255.255.255

router bgp 100
 network 105.10.7.0 mask 255.255.255.0
 neighbor 105.10.7.2 remote-as 100
 neighbor 105.10.7.2 update-source loopback0
 neighbor 105.10.7.3 remote-as 100
 neighbor 105.10.7.3 update-source loopback0
```

Configuring iBGP peers



```
interface loopback 0
 ip address 105.10.7.2 255.255.255.255

router bgp 100
 network 105.10.7.0 mask 255.255.255.0
 neighbor 105.10.7.1 remote-as 100
 neighbor 105.10.7.1 update-source loopback0
 neighbor 105.10.7.3 remote-as 100
 neighbor 105.10.7.3 update-source loopback0
```

Configuring iBGP peers



```
interface loopback 0
 ip address 105.10.7.3 255.255.255.255

router bgp 100
 network 105.10.7.0 mask 255.255.255.0
 neighbor 105.10.7.1 remote-as 100
 neighbor 105.10.7.1 update-source loopback0
 neighbor 105.10.7.2 remote-as 100
 neighbor 105.10.7.2 update-source loopback0
```

BGP Part 7

BGP Protocol – A little more detail

BGP Updates — NLRI

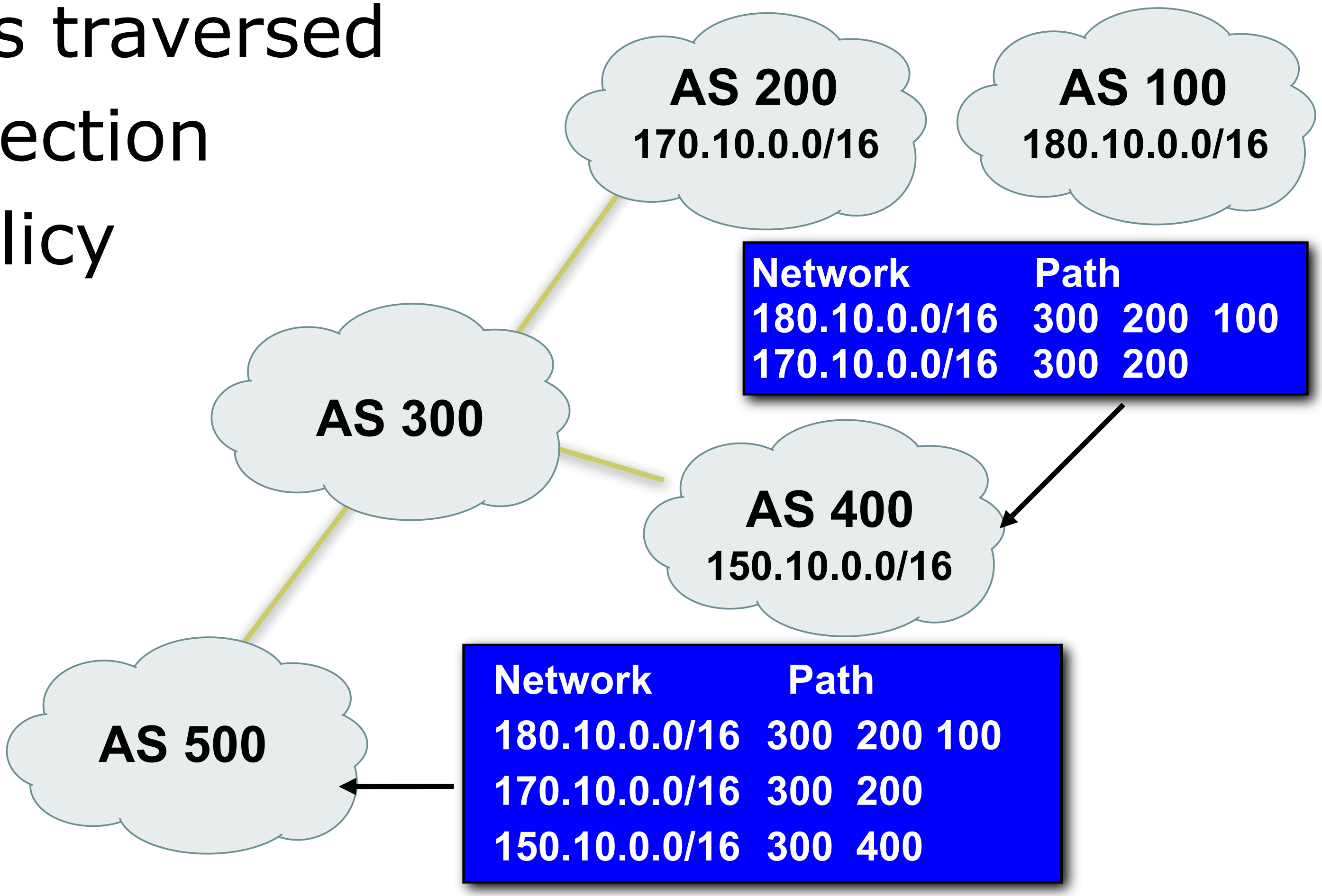
- Network Layer Reachability Information
- Used to advertise feasible routes
- Composed of:
  - Network Prefix
  - Mask Length
  - Attributes of the path between you and the destination

BGP Updates — Attributes

- Used to convey information associated with NLRI
  - AS path
  - Next hop
  - Local preference
  - Multi-Exit Discriminator (MED)
  - Community
  - Origin
  - Aggregator

AS-Path Attribute

- Sequence of ASes a route has traversed
- Loop detection
- Apply policy

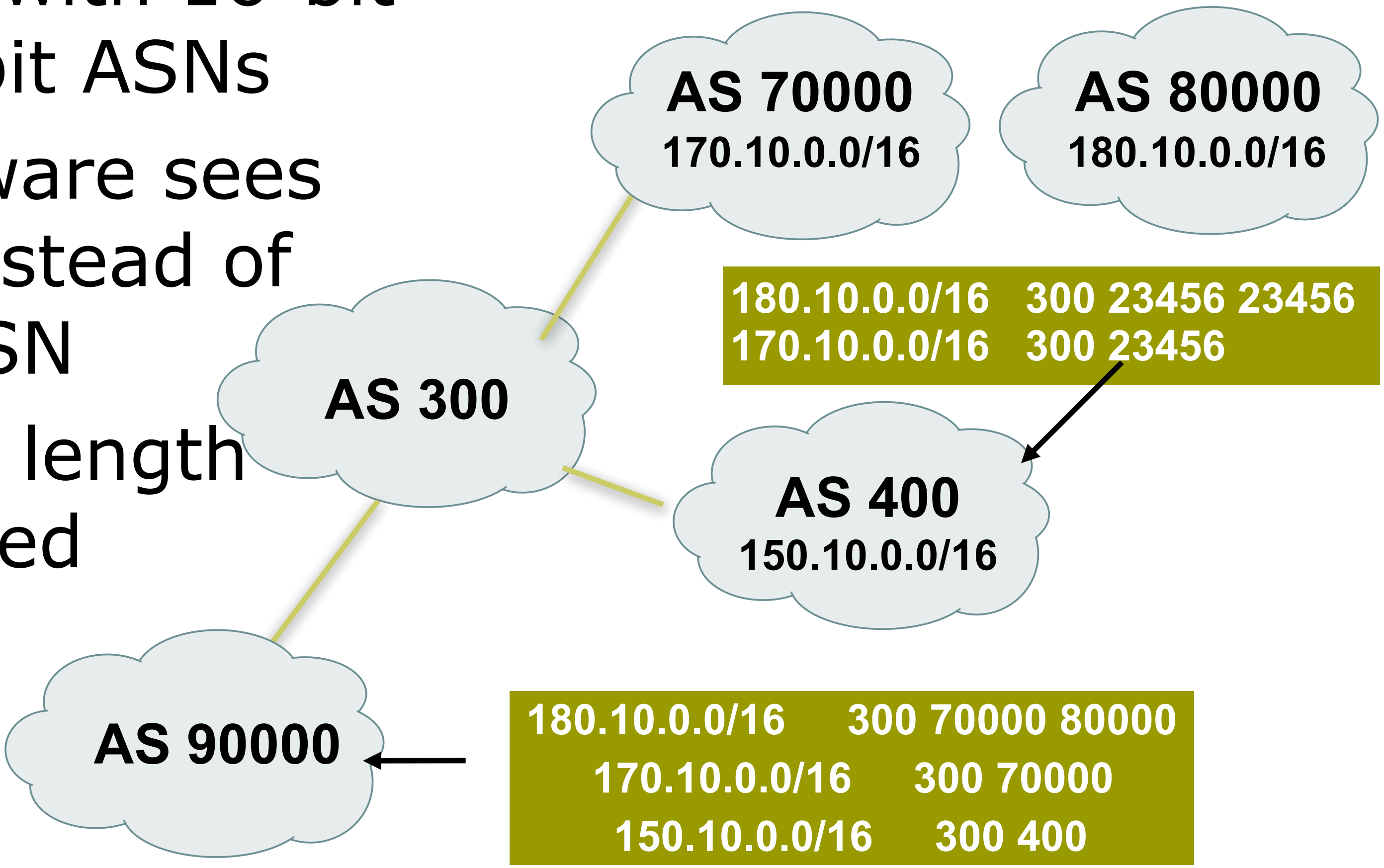


Network	Path
180.10.0.0/16	300 200 100
170.10.0.0/16	300 200

Network	Path
180.10.0.0/16	300 200 100
170.10.0.0/16	300 200
150.10.0.0/16	300 400

AS-Path (with 16 and 32-bit ASNs)

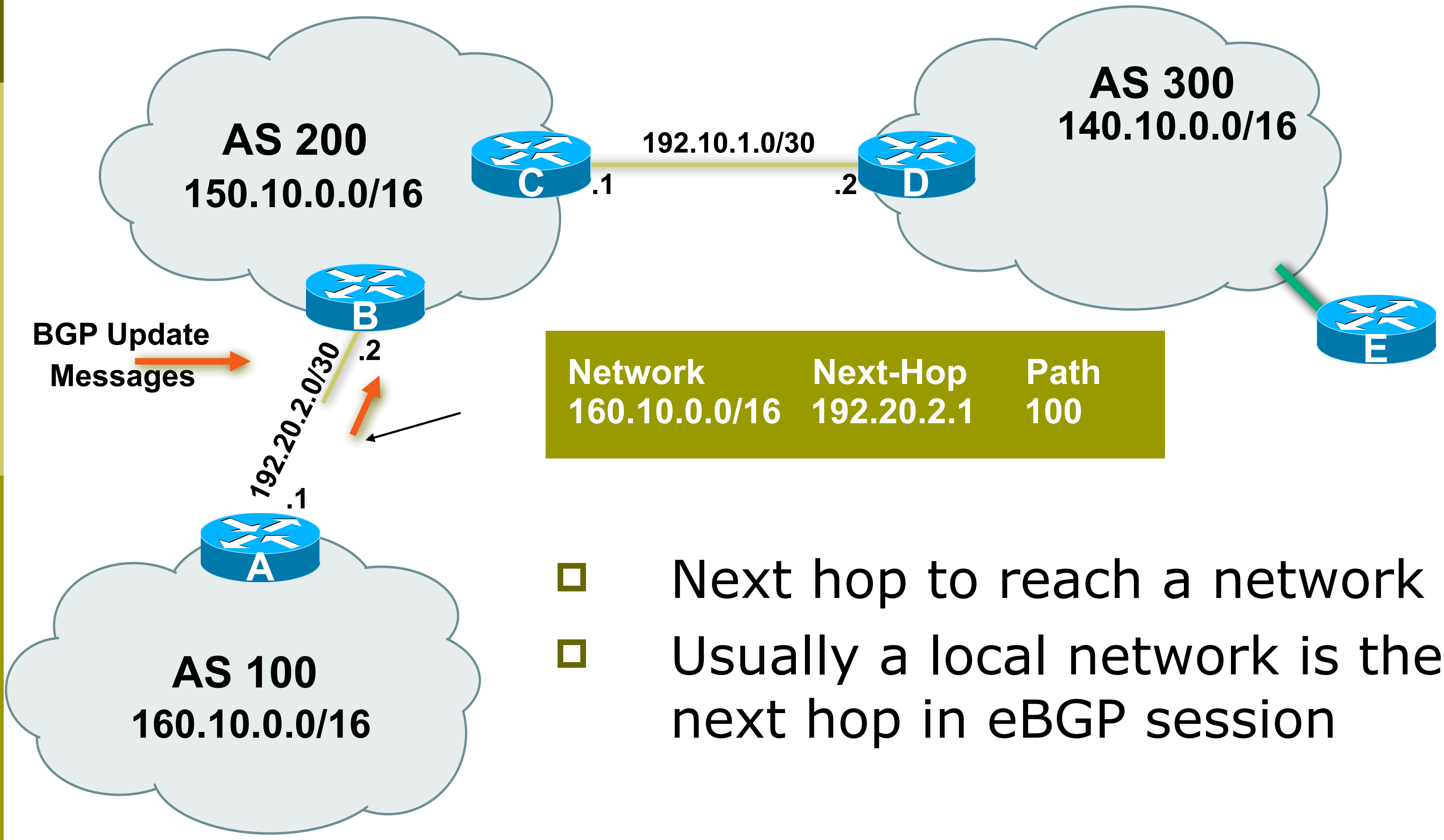
- Internet with 16-bit and 32-bit ASNs
- Old software sees 23456 instead of actual ASN
- AS-PATH length maintained



180.10.0.0/16	300 23456 23456
170.10.0.0/16	300 23456

180.10.0.0/16	300 70000 80000
170.10.0.0/16	300 70000
150.10.0.0/16	300 400

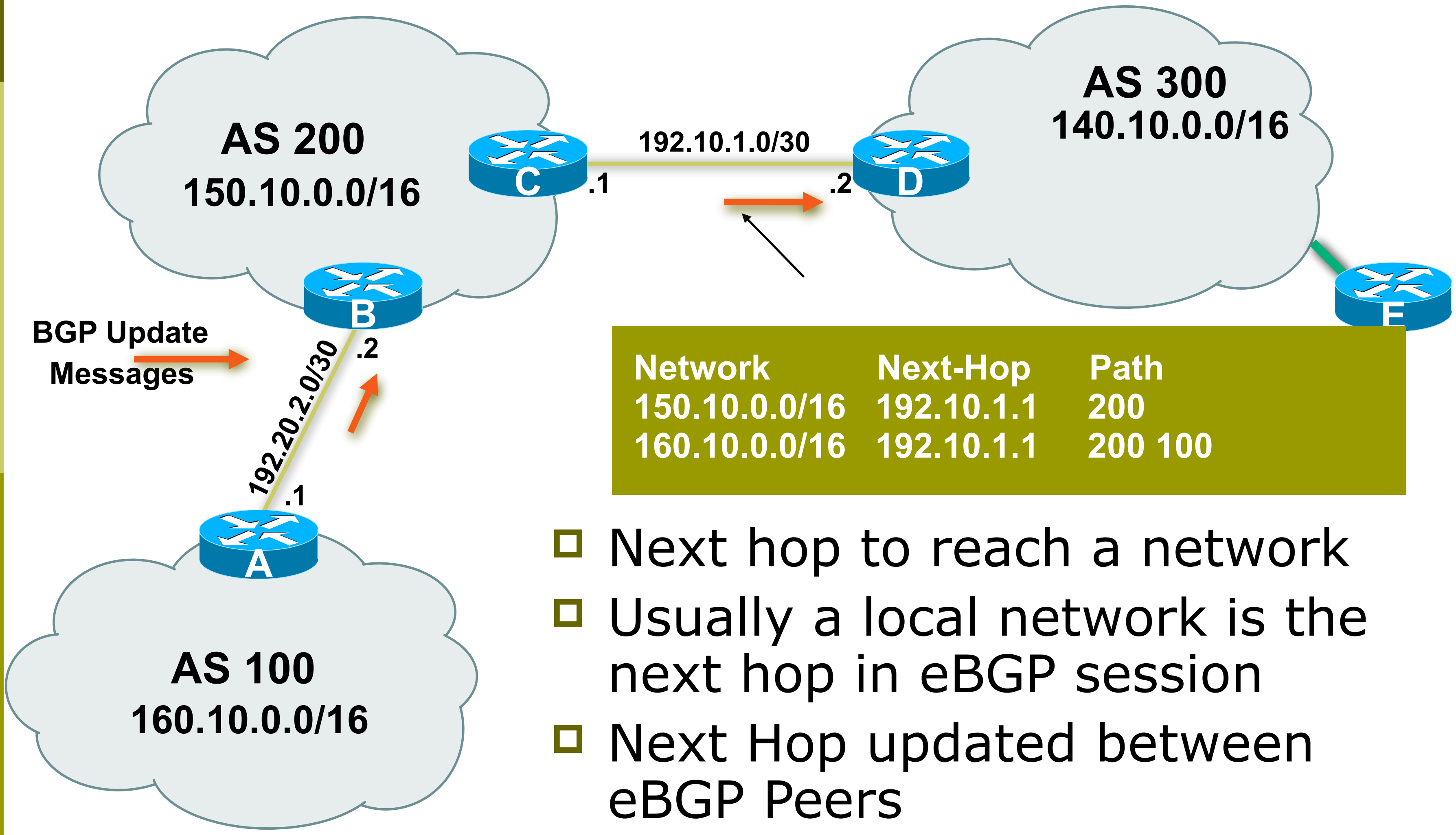
Next Hop Attribute



Network	Next-Hop	Path
160.10.0.0/16	192.20.2.1	100

- Next hop to reach a network
- Usually a local network is the next hop in eBGP session

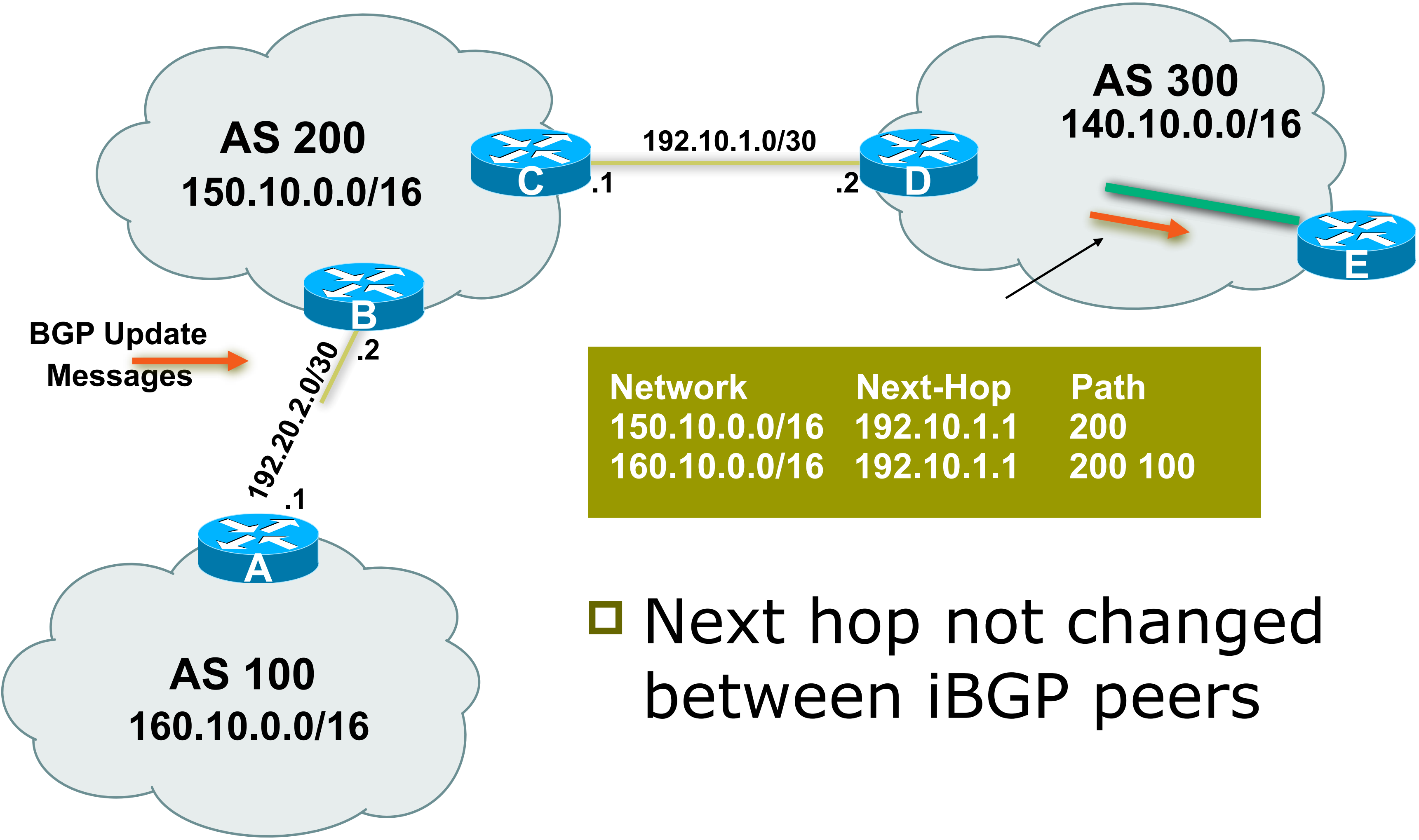
Next Hop Attribute



Network	Next-Hop	Path
150.10.0.0/16	192.10.1.1	200
160.10.0.0/16	192.10.1.1	200 100

- Next hop to reach a network
- Usually a local network is the next hop in eBGP session
- Next Hop updated between eBGP Peers

Next Hop Attribute



Network	Next-Hop	Path
150.10.0.0/16	192.10.1.1	200
160.10.0.0/16	192.10.1.1	200 100

- Next hop not changed between iBGP peers

Next Hop Attribute (more)

- IGP is used to carry route to next hops
- Recursive route look-up
  - BGP looks into IGP to find out next hop information
  - BGP is not permitted to use a BGP route as the next hop
- Isolates BGP from actual physical topology
- Allows IGP to make intelligent forwarding decision

Next Hop Best Practice

- Cisco IOS default is for external next-hop to be propagated unchanged to iBGP peers
  - This means that IGP has to carry external next-hops
  - Forgetting means external network is invisible
  - With many eBGP peers, it is extra load on IGP
- ISP best practice is to change external next-hop to be that of the local router

```
neighbor x.x.x.x next-hop-self
```

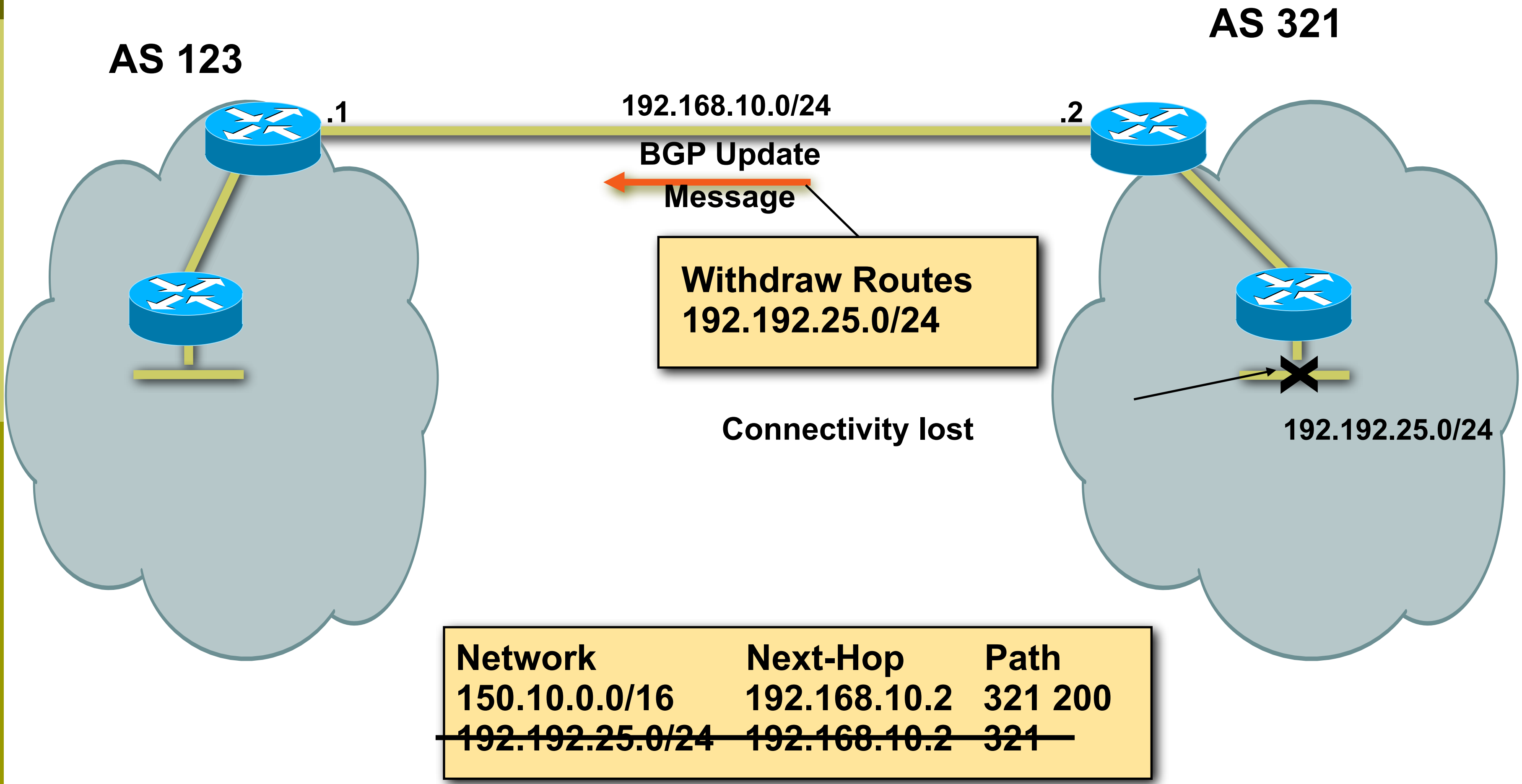
Community Attribute

- 32-bit number
- Conventionally written as two 16-bit numbers separated by colon
  - First half is usually an AS number
  - ISP determines the meaning (if any) of the second half
- Carried in BGP protocol messages
  - Used by administratively-defined filters
  - Not directly used by BGP protocol (except for a few “well known” communities)

BGP Updates: Withdrawn Routes

- Used to “withdraw” network reachability
- Each withdrawn route is composed of:
  - Network Prefix
  - Mask Length

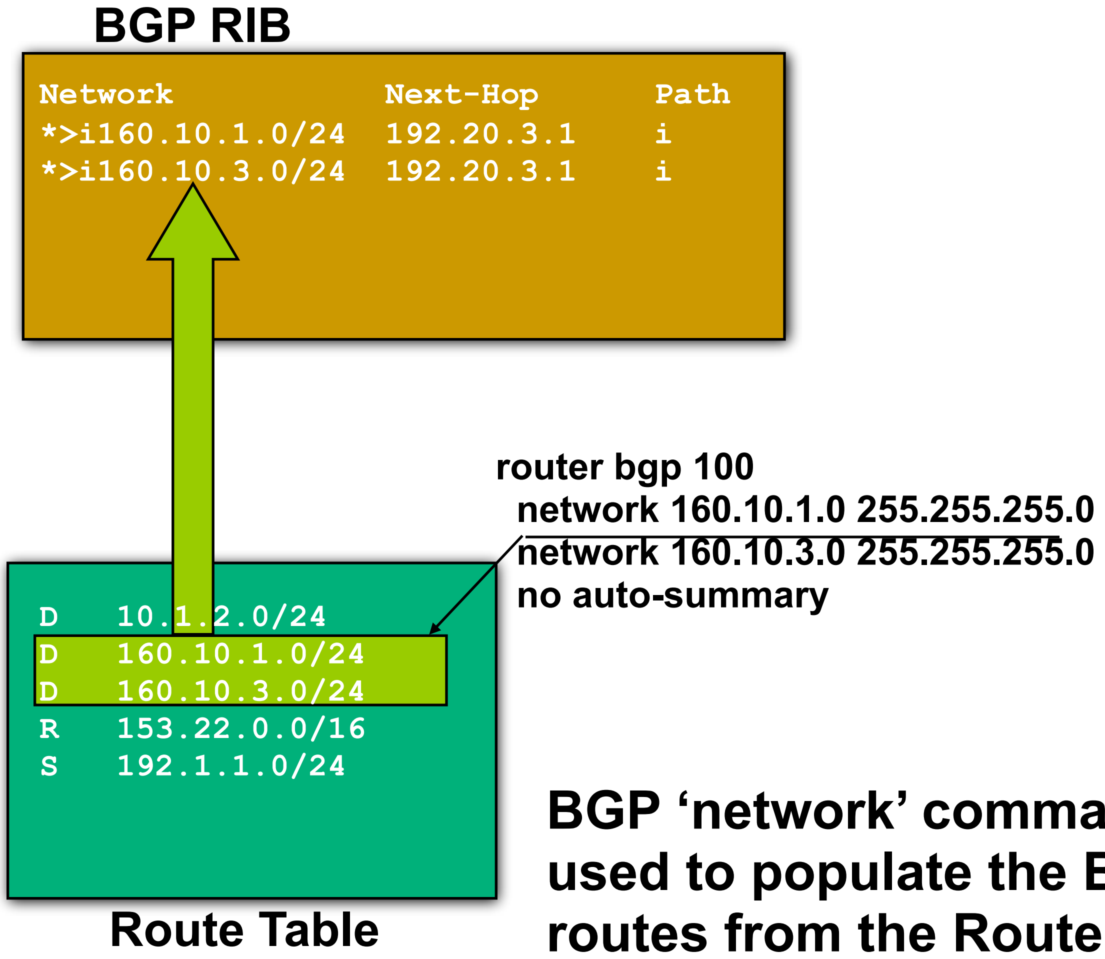
BGP Updates: Withdrawn Routes



Withdraw Routes
192.192.25.0/24

Network	Next-Hop	Path
150.10.0.0/16	192.168.10.2	321 200
~~192.192.25.0/24~~	~~192.168.10.2~~	~~321~~

BGP Routing Information Base



BGP RIB

```
Network              Next-Hop         Path
*>i160.10.1.0/24     192.20.3.1       i
*>i160.10.3.0/24     192.20.3.1       i
```

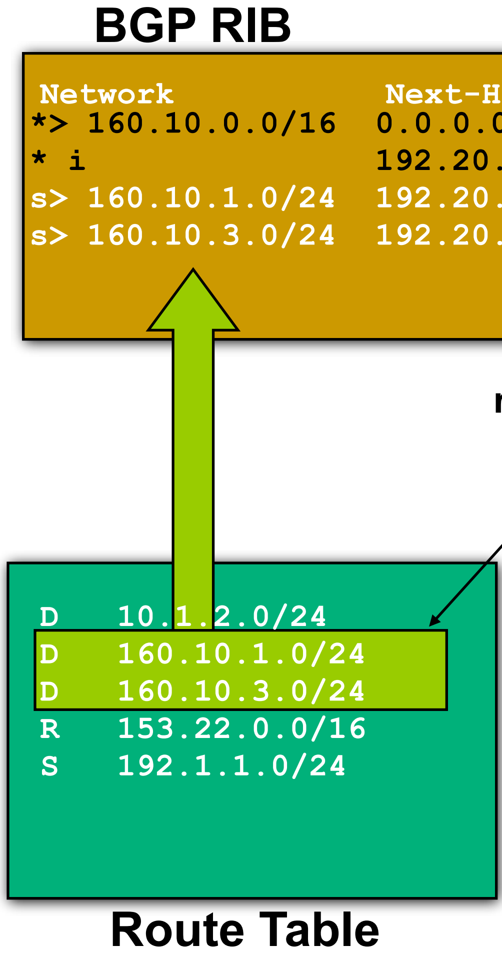
```
router bgp 100
  network 160.10.1.0 255.255.255.0
  network 160.10.3.0 255.255.255.0
  no auto-summary
```

```
D    10.1.2.0/24
D    160.10.1.0/24
D    160.10.3.0/24
R    153.22.0.0/16
S    192.1.1.0/24
```

Route Table

BGP ‘network’ commands are normally used to populate the BGP RIB with routes from the Route Table

BGP Routing Information Base



BGP RIB

```
 Network            Next-Hop      Path
*> 160.10.0.0/16   0.0.0.0       i
* i                192.20.3.1    i
s> 160.10.1.0/24   192.20.3.1    i
s> 160.10.3.0/24   192.20.3.1    i
```

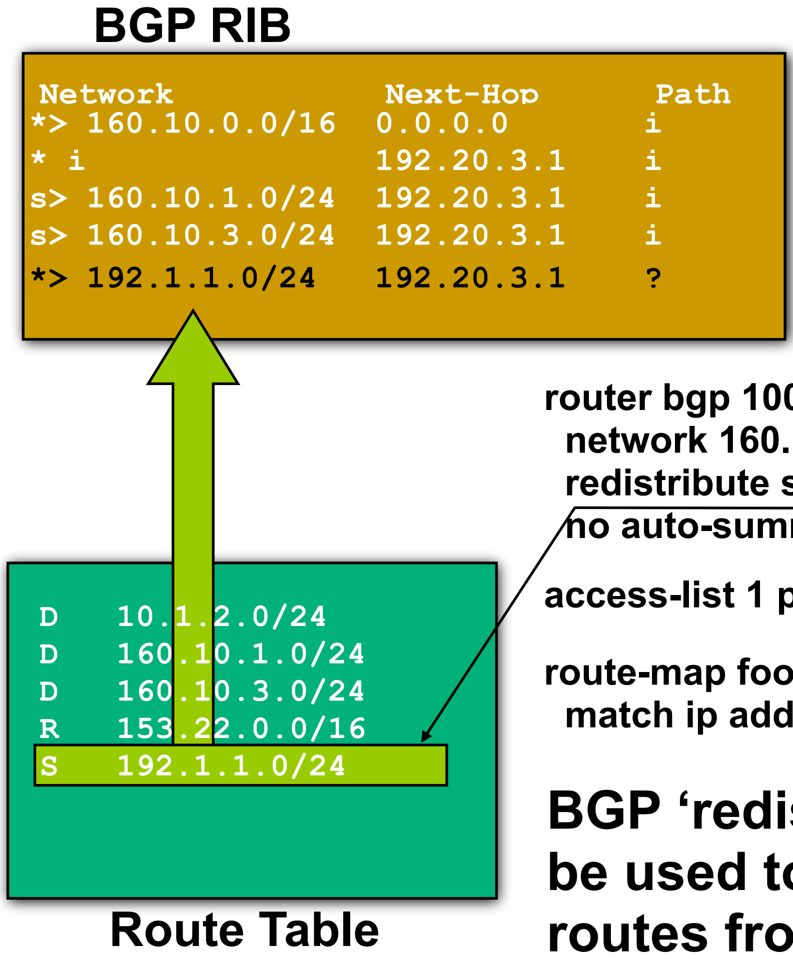
```
router bgp 100
  network 160.10.0.0 255.255.0.0
  aggregate-address 160.10.0.0 255.255.0.0 summary-only
  no auto-summary
```

```
D    10.1.2.0/24
D    160.10.1.0/24
D    160.10.3.0/24
R    153.22.0.0/16
S    192.1.1.0/24
```

Route Table

BGP ‘aggregate-address’ commands may be used to install summary routes in the BGP RIB

BGP Routing Information Base



BGP RIB

```
 Network           Next-Hop       Path
*> 160.10.0.0/16  0.0.0.0        i
* i               192.20.3.1     i
s> 160.10.1.0/24  192.20.3.1     i
s> 160.10.3.0/24  192.20.3.1     i
*> 192.1.1.0/24   192.20.3.1     ?
```

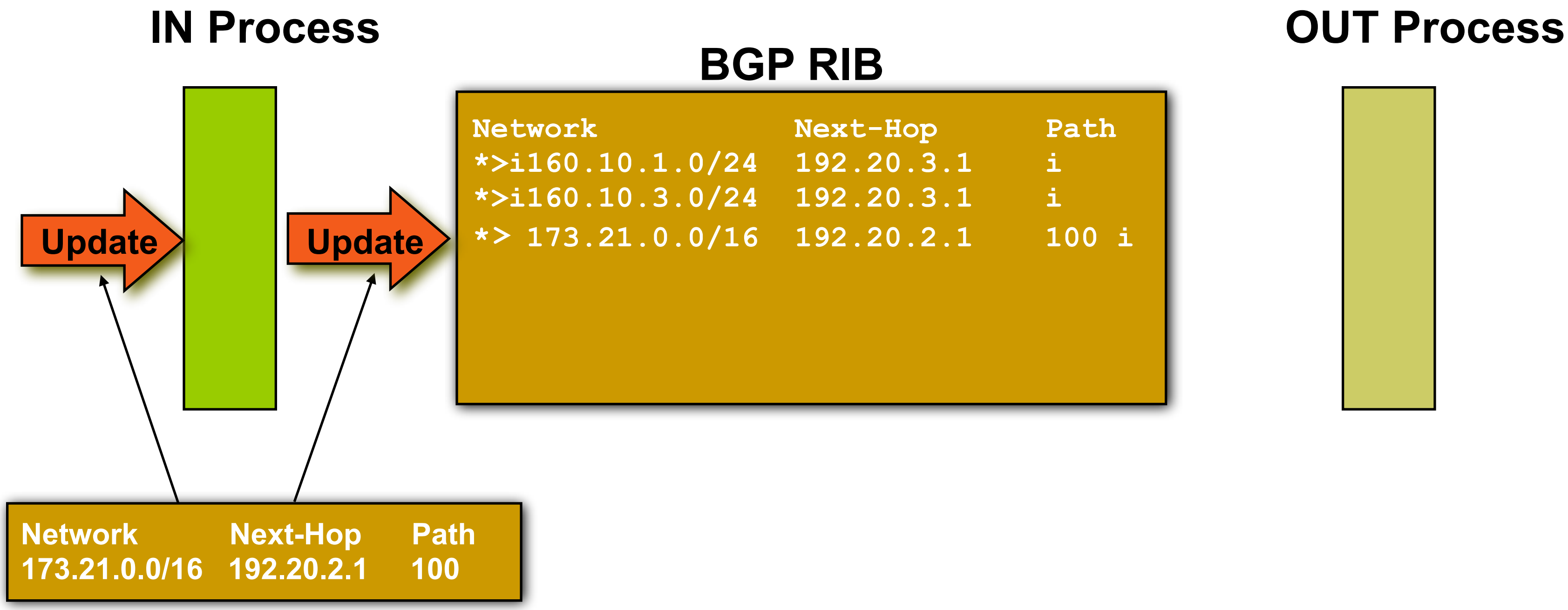
```
D   10.1.2.0/24
D   160.10.1.0/24
D   160.10.3.0/24
R   153.22.0.0/16
S   192.1.1.0/24
```

Route Table

```
router bgp 100
  network 160.10.0.0 255.255.0.0
  redistribute static route-map foo
  no auto-summary

access-list 1 permit 192.1.0.0 0.0.0.255

route-map foo permit 10
  match ip address 1
```

BGP ‘redistribute’ commands can also be used to populate the BGP RIB with routes from the Route Table

BGP Routing Information Base



IN Process

BGP RIB

OUT Process

Update

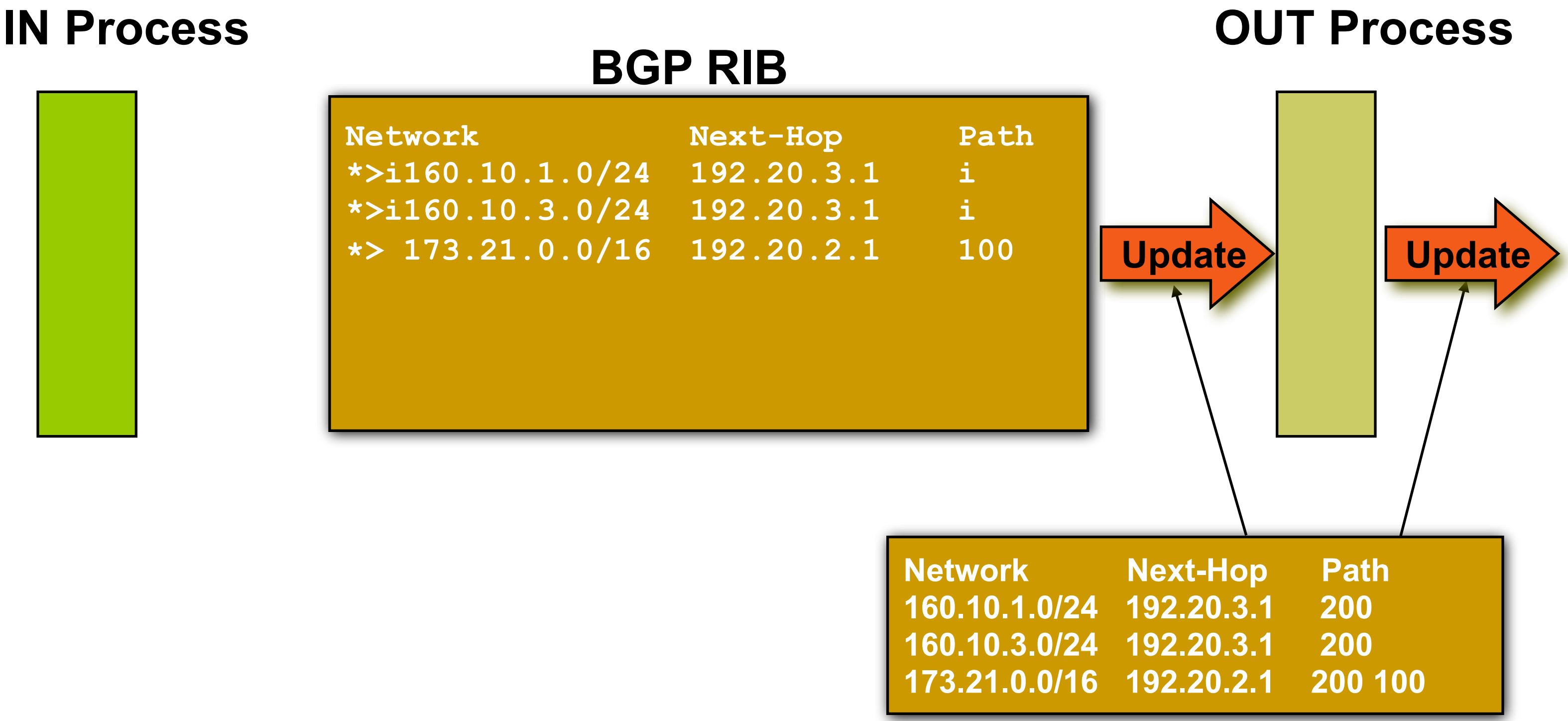
Update

```
Network            Next-Hop       Path
*>i160.10.1.0/24   192.20.3.1     i
*>i160.10.3.0/24   192.20.3.1     i
*> 173.21.0.0/16   192.20.2.1     100 i
```

Network	Next-Hop	Path
173.21.0.0/16	192.20.2.1	100

- BGP “in” process
  - receives path information from peers
  - results of BGP path selection placed in the BGP table
  - “best path” flagged (denoted by “>”)

BGP Routing Information Base

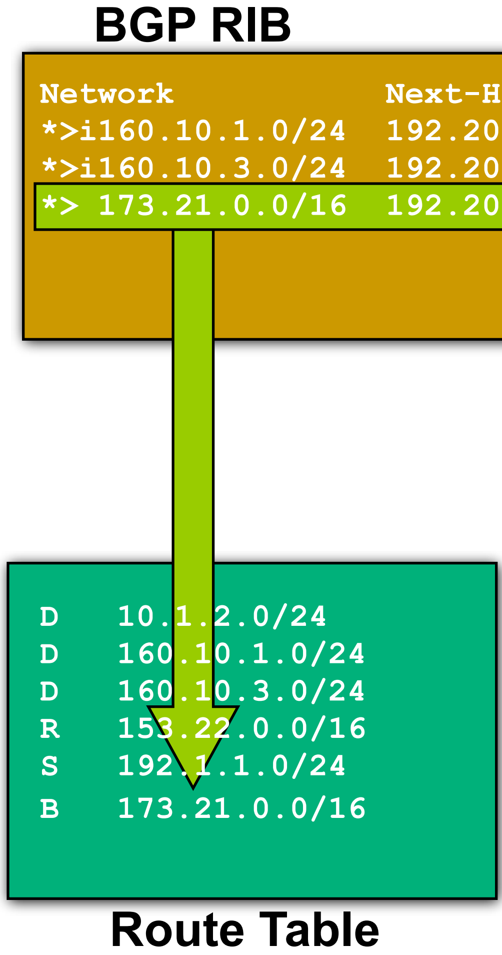


```
Network          Next-Hop       Path
*>i160.10.1.0/24  192.20.3.1     i
*>i160.10.3.0/24  192.20.3.1     i
*> 173.21.0.0/16  192.20.2.1     100
```

Network	Next-Hop	Path
160.10.1.0/24	192.20.3.1	200
160.10.3.0/24	192.20.3.1	200
173.21.0.0/16	192.20.2.1	200 100

- BGP “out” process
  - builds update using info from RIB
  - may modify update based on config
  - Sends update to peers

BGP Routing Information Base



BGP RIB

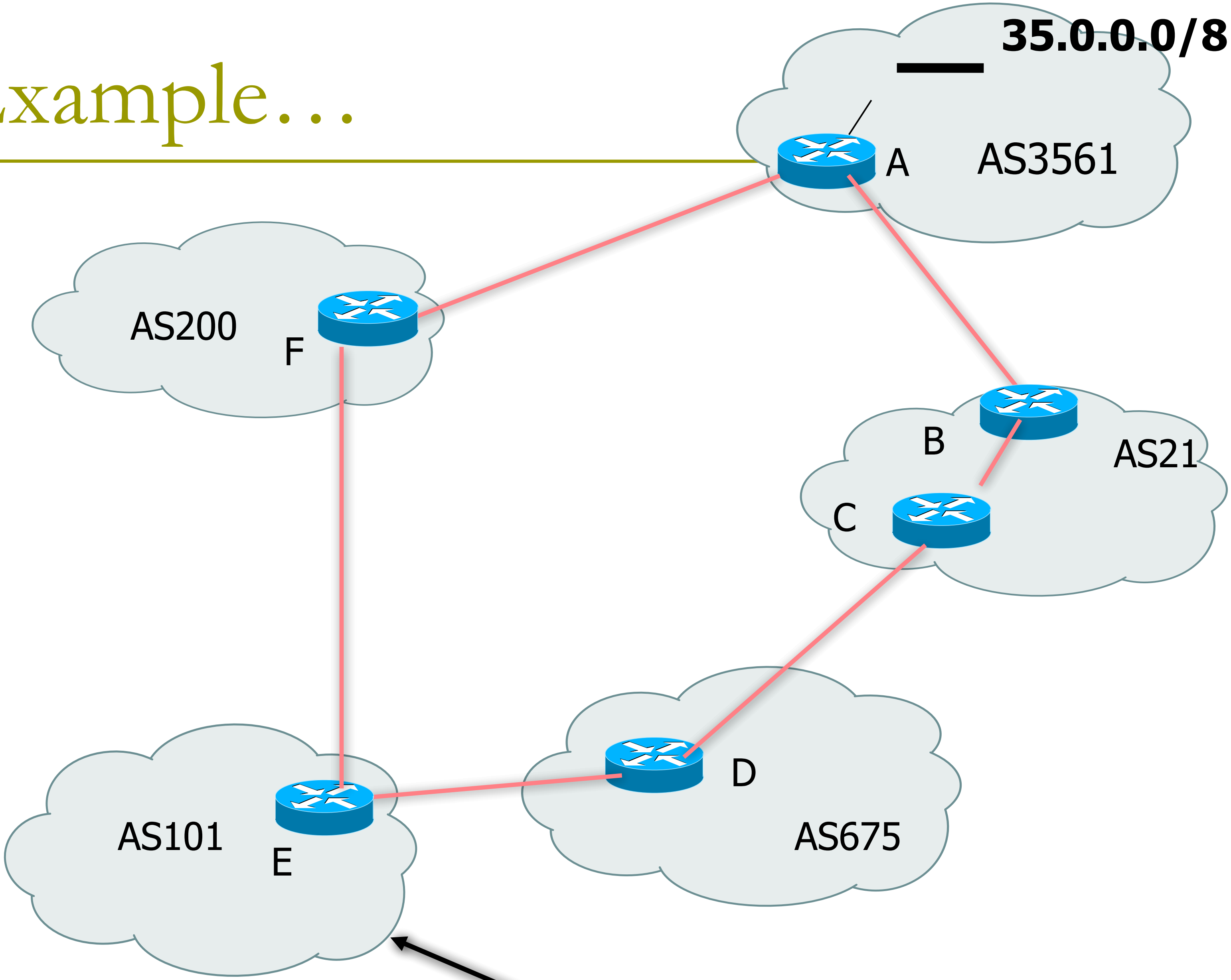
```
Network             Next-Hop        Path
*>i160.10.1.0/24    192.20.3.1      i
*>i160.10.3.0/24    192.20.3.1      i
*> 173.21.0.0/16    192.20.2.1      100
```

```
D    10.1.2.0/24
D    160.10.1.0/24
D    160.10.3.0/24
R    153.22.0.0/16
S    192.1.1.0/24
B    173.21.0.0/16
```

Route Table

- **Best paths installed in routing table if:**
- **prefix and prefix length are unique (not also in some other routing protocol)**
- **Or if BGP has a lower “administrative distance” than other protocol with the same prefix/length**

An Example…



Learns about 35.0.0.0/8 from F & D

BGP Case Study 2 and Exercise 2

Interconnecting your network

Case Study 2: Another ISP in the same country

- Uses same layout as Ex 1
- Start to involve the rest of your network in BGP
  - Why? iBGP is more scalable than IGP (OSPF) for client prefixes
- Propagate external connectivity

Case Study 2: Extending your network

- One upstream provider.
- Client routes are in your network, but setup either in your IGP (OSPF) and using static routes.
- Need to extend your network from simply peering at your edge to the rest of the network.
- Interconnect the rest of your network, to the external network.

Exercise 2: BGP configuration

- Refer to “BGP cheat sheet”.
- Add peers to previous configuration.
- “Virtually” connect local peers.
- No filters yet.

Exercise 2: What you should see

- You should see multiple routes to each destination
  - direct route to your peer
  - transit route through provider (AS 100)
  - any more?

Exercise 2: What you should see

- To see forwarding table, try:
  - IPv4: “show ip route”
  - IPv6: “show ipv6 route”
- To see BGP information, try:
  - IPv4: “show ip bgp”
  - IPv6: “show bgp ipv6”
- Look at the “next hop” and “AS path”
- Try some pings and traceroutes.

BGP Part 8

Routing Policy

Filtering

Terminology: “Policy”

- Where do you want your traffic to go?
  - It is difficult to get what you want, but you can try
- Control of how you accept and send routing updates to neighbors
  - prefer cheaper connections, load-sharing, etc.
- Accepting routes from some ISPs and not others
- Sending some routes to some ISPs and not others
- Preferring routes from some ISPs over others

Routing Policy

- Why?
  - To steer traffic through preferred paths
  - Inbound/Outbound prefix filtering
  - To enforce Customer-ISP agreements
- How?
  - AS based route filtering – filter list
  - Prefix based route filtering – prefix list
  - BGP attribute modification – route maps
  - Complex route filtering – route maps

Filter list rules: Regular Expressions

- Regular Expression is a pattern to match against an input string
- Used to match against AS-path attribute
- ex: ^3561_.*_100_.*_1$
- Flexible enough to generate complex filter list rules

Regular expressions (cisco specific)

^ matches start

$ matches end

_ matches start, or end, or space (boundary between words or numbers)

.* matches anything (0 or more characters)

.+ matches anything (1 or more characters)

[0-9] matches any number between 0 and 9

^$ matches the local AS (AS path is empty)

There are many more possibilities

Filter list – using as-path access list

- Listen to routes originated by AS 3561. Implicit deny everything else inbound.
- Don’t announce routes originated by AS 35, but announce everything else (outbound).

```
ip as-path access-list 1 permit _3561$
ip as-path access-list 2 deny _35$
ip as-path access-list 2 permit .*

router bgp 100
 neighbor 171.69.233.33 remote-as 33
 neighbor 171.69.233.33 filter-list 1 in
 neighbor 171.69.233.33 filter-list 2 out
```

Policy Control – Prefix Lists

- Per neighbor prefix filter
  - incremental configuration
- High performance access list
- Inbound or Outbound
- Based upon network numbers (using CIDR address/mask format)
- First relevant “allow” or “deny” rule wins
- Implicit Deny All as last entry in list

Prefix Lists – Examples

- Deny default route

```
ip prefix-list Example deny 0.0.0.0/0
```

- Permit the prefix 35.0.0.0/8

```
ip prefix-list Example permit 35.0.0.0/8
```

- Deny the prefix 172.16.0.0/12, and all more-specific routes

```
ip prefix-list Example deny 172.16.0.0/12 ge 12
```

  - "ge 12" means "prefix length /12 or longer". For example, 172.17.0.0/16 will also be denied.

- In 192.0.0.0/8, allow any /24 or shorter prefixes

```
ip prefix-list Example permit 192.0.0.0/8 le 24
```

  - This will not allow any /25, /26, /27, /28, /29, /30, /31 or /32

Prefix Lists – More Examples

- In 192/8 deny /25 and above

```
ip prefix-list Example deny 192.0.0.0/8 ge 25
```

  - This denies all prefix sizes /25, /26, /27, /28, /29, /30, /31 and /32 in the address block 192.0.0.0/8
  - It has the same effect as the previous example

- In 192/8 permit prefixes between /12 and /20

```
ip prefix-list Example permit 192.0.0.0/8 ge 12 le 20
```

  - This denies all prefix sizes /8, /9, /10, /11, /21, /22 and higher in the address block 193.0.0.0/8

- Permit all prefixes
  - `ip prefix-list Example permit 0.0.0.0/0 le 32`

Policy Control Using Prefix Lists

- Example Configuration

```
router bgp 200
 network 215.7.0.0
 neighbor 220.200.1.1 remote-as 210
 neighbor 220.200.1.1 prefix-list PEER-IN in
 neighbor 220.200.1.1 prefix-list PEER-OUT out
!
ip prefix-list PEER-IN deny 218.10.0.0/16 le 32
ip prefix-list PEER-IN permit 0.0.0.0/0 le 32
ip prefix-list PEER-OUT permit 215.7.0.0/16
ip prefix-list PEER-OUT deny 0.0.0.0/0 le 32
```

  - Accept everything except our network from our peer
  - Send only our network to our peer

Prefix-lists in IPv6

- Prefix-lists in IPv6 work the same way as they do in IPv4
  - Caveat: ipv6 prefix-lists cannot be used for ipv4 neighbours - and vice-versa
  - Syntax is very similar, for example:

```
ip prefix-list ipv4-ebgp permit 0.0.0.0/0 le 32
ip prefix-list v4out permit 172.16.0.0/16
!
ipv6 prefix-list ipv6-ebgp permit ::/0 le 128
ipv6 prefix-list v6out permit 2001:db8::/32
```

Policy Control – Route Maps

- A route-map is like a “program” for Cisco IOS
- Has “line” numbers, like programs
- Each line is a separate condition/action
- Concept is basically:

```
if match then do expression and exit
else
if match then do expression and exit
else etc
```

Route-map match & set clauses

- Match Clauses
  - AS-path
  - Community
  - IP address
- Set Clauses
  - AS-path prepend
  - Community
  - Local-Preference
  - MED
  - Origin
  - Weight
  - Others...

Route Map: Example One

```
router bgp 300
 neighbor 2.2.2.2 remote-as 100
 neighbor 2.2.2.2 route-map SETCOMMUNITY out
!
route-map SETCOMMUNITY permit 10
 match ip address 1
 match community 1
 set community 300:100
!
access-list 1 permit 35.0.0.0
ip community-list 1 permit 100:200

! When you are sending information OUT to neighbor
! 2.2.2.2, then: if the prefix/mask matches
! access-list 1, and if the community matches
! community-list 1, then:
! do “set community 300:100”
```

Route Map: Example Two

- Example Configuration as AS PATH prepend

```
router bgp 300
 network 215.7.0.0
 neighbor 2.2.2.2 remote-as 100
 neighbor 2.2.2.2 route-map SETPATH out
!
route-map SETPATH permit 10
 set as-path prepend 300 300
```

- Use your own AS number for prepending
  - Otherwise BGP loop detection will cause disconnects

BGP Exercise 3

Filtering peer routes using AS-path regular expression

Exercise 3: Filtering peer routes using AS-path

- Create “ip as-path access-list <number>” to match your own routes
  - ip as-path access-list 2 permit ^$
- Apply the filters to both IPv4 and IPv6 peers:
  - “neighbor <address> filter-list 1 in”
  - “neighbor <address> filter-list 2 out”
  - As-path filters are protocol independent, so the same filter can be applied to both IPv4 and IPv6 peers!
- Apply the outbound filter to the AS100 upstream
  - “neighbor <upstream-addr> filter-list 2 out”

Exercise 3: What you should see

- From peers: only their routes, no transit
  - They send all routes, but you filter
- To peers: your routes
  - They will ignore the transit routes if you mistakenly send them
- From upstream: all routes
- To upstream: your routes, no transit

Exercise 3: Did it work?

- IPv4 show commands:
  - “show ip route” – your forwarding table
  - “show ip bgp” – your BGP table
  - “show ip bgp neighbor xxx received-routes” – from your neighbour before filtering
  - “show ip bgp neighbor xxx routes” – from neighbour, after filtering
  - “show ip bgp neighbor advertised-routes” – to neighbour, after filtering

Exercise 3: Did it work?

- IPv6 show commands:
  - “show ipv6 route” – your forwarding table
  - “show bgp ipv6” – your BGP table
  - “show bgp ipv6 neighbor xxx received-routes” – from your neighbour before filtering
  - “show bgp ipv6 neighbor xxx routes” – from neighbour, after filtering
  - “show bgp ipv6 neighbor advertised-routes” – to neighbour, after filtering

BGP Exercise 4

Filtering peer routes using prefix-lists

Exercise 4: Filtering peer routes using prefix-list

- Create “ip prefix-list my-routes” to match your own routes
- Create “ip prefix-list peer-as-xxx” to match your peer’s routes
- Apply the filters to your peers
  - “neighbor xxx prefix-list my-routes out”
  - “neighbor xxx prefix-list peer-as-xxx in”
- Apply the outbound filter to your upstream provider
  - “neighbor xxx prefix-list my-routes out”

Exercise 4: Filtering peer routes using prefix-list

- Create “ipv6 prefix-list myv6-routes” to match your own routes
- Create “ipv6 prefix-list peer-as-xxx-v6” to match your peer’s routes
- Apply the filters to your IPv6 peers
  - “neighbor xxx prefix-list myv6-routes out”
  - “neighbor xxx prefix-list peer-as-xxx-v6 in”
- Apply the outbound filter to your upstream provider
  - “neighbor xxx prefix-list myv6-routes out”

Exercise 4: What you should see

- From peers: only their routes, no transit
- To peers: only your routes, no transit
- From upstream: all routes
- To upstream: only your routes, no transit

- We still trust the upstream provider too much. Should filter it too!
  - See “ip prefix-list sanity-filter” and “ipv6 prefix-list v6sanity-filter” in the cheat sheet

Exercise 4: Did it work?

- IPv4 show commands:
  - “show ip route” – your forwarding table
  - “show ip bgp” – your BGP table
  - “show ip bgp neighbor xxx received-routes” – from your neighbour before filtering
  - “show ip bgp neighbor xxx routes” – from neighbour, after filtering
  - “show ip bgp neighbor advertised-routes” – to neighbour, after filtering

Exercise 4: Did it work?

- IPv6 show commands:
  - “show ipv6 route” – your routing table
  - “show bgp ipv6” – your BGP table
  - “show bgp ipv6 neighbor xxx received-routes” – from your neighbour before filtering
  - “show bgp ipv6 neighbor xxx routes” – from neighbour, after filtering
  - “show bgp ipv6 neighbor advertised-routes” – to neighbour, after filtering

BGP Part 9

More detail than you want

BGP Attributes
Synchronization
Path Selection

BGP Path Attributes: Why ?

- Encoded as Type, Length & Value (TLV)
- Transitive/Non-Transitive attributes
- Some are mandatory
- Used in path selection
- To apply policy for steering traffic

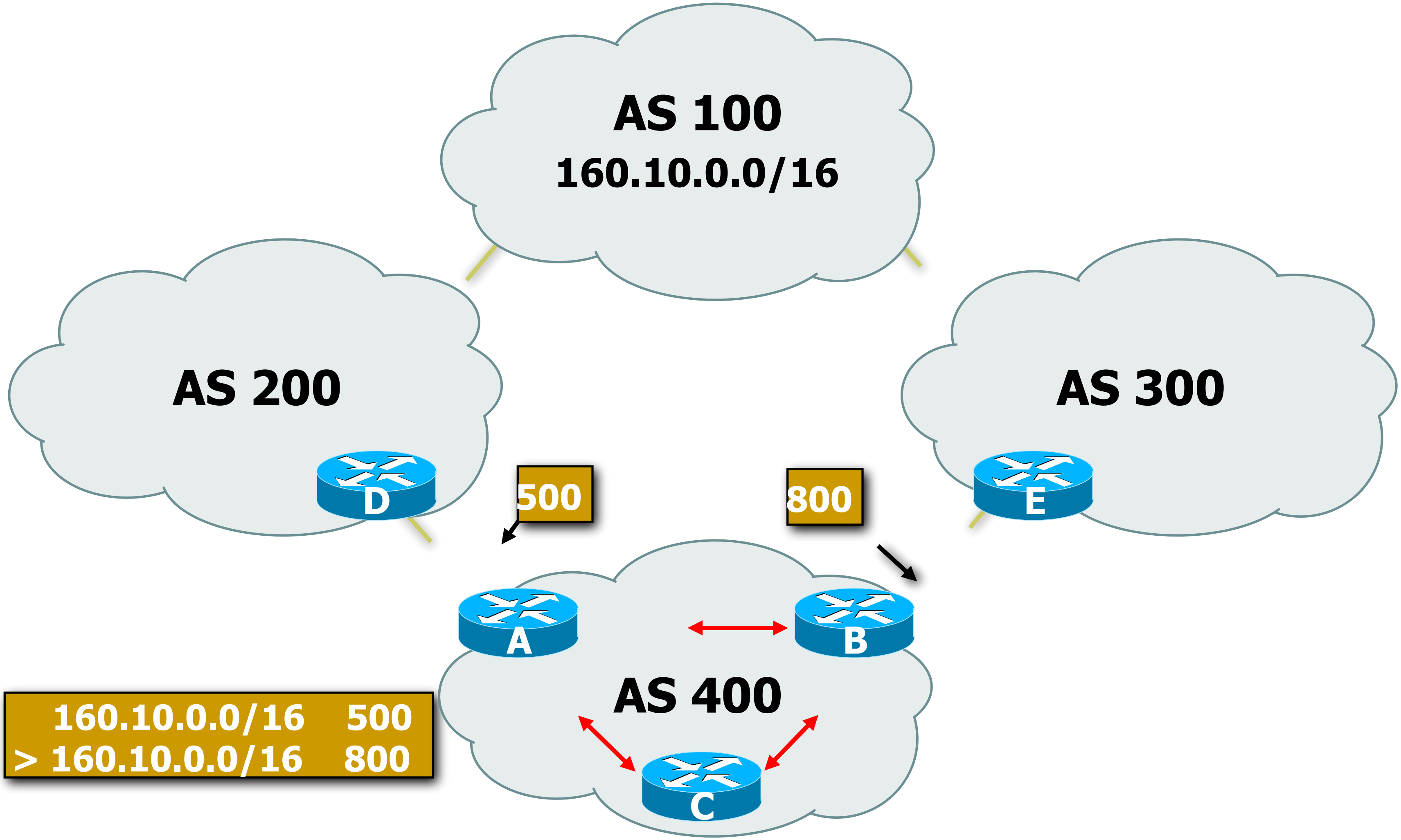
BGP Attributes

- Used to convey information associated with NLRI
  - AS path
  - Next hop
  - Local preference
  - Multi-Exit Discriminator (MED)
  - Community
  - Origin
  - Aggregator

Local Preference

- Not used by eBGP, mandatory for iBGP
- Default value of 100 on Cisco IOS
- Local to an AS
- Used to prefer one exit over another
- Path with highest local preference wins

Local Preference

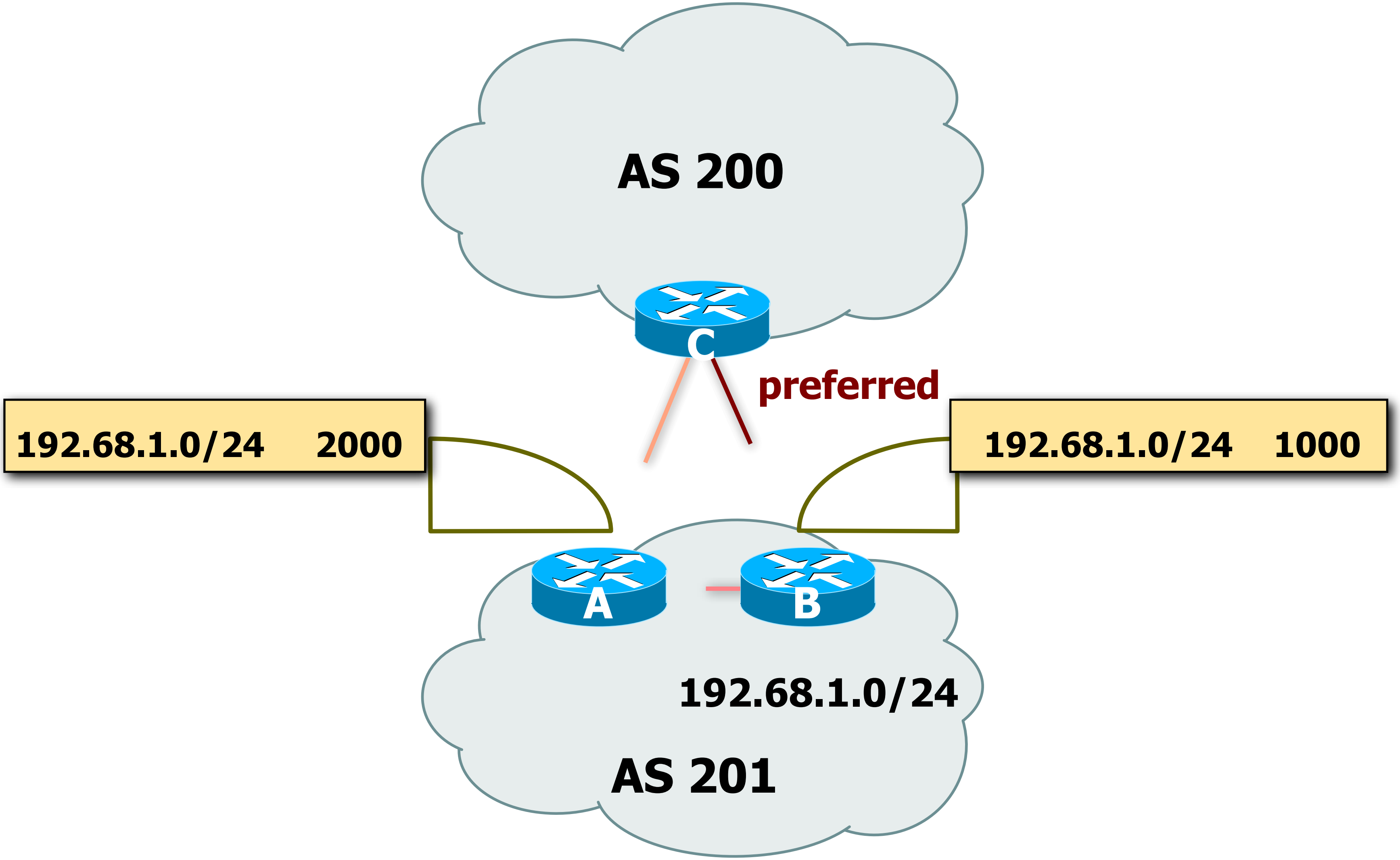


```
  160.10.0.0/16    500
> 160.10.0.0/16    800
```

Multi-Exit Discriminator

- Non-transitive
- Represented as a numerical value
  - Range 0x0 – 0xffffffff
- Used to convey relative preference of entry points to an AS
- Comparable if the paths are from the same AS
- Path with the lowest MED wins
- IGP metric can be conveyed as MED

Multi-Exit Discriminator (MED)



Origin

- Conveys the origin of the prefix
  - Historical attribute
- Three values:
  - IGP – from BGP network statement
    - E.g. – *network 35.0.0.0*
  - EGP – redistributed from EGP (not used today)
  - Incomplete – redistributed from another routing protocol
    - E.g. – *redistribute static*
- IGP < EGP < incomplete
  - Lowest origin code wins

Weight

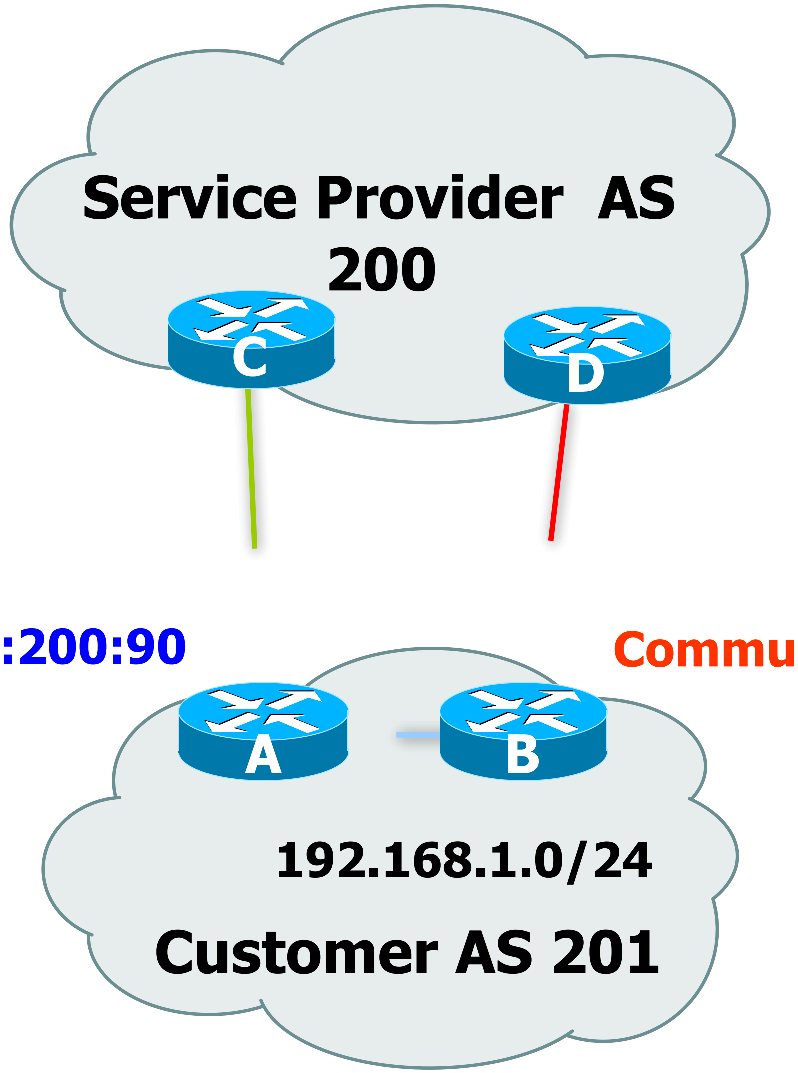
Not really an attribute (Cisco proprietary)

- Used when there is more than one route to same destination
- Local to the router on which it is assigned, and not propagated in routing updates
- Default is 32768 for paths that the router originates and zero for other paths
- Routes with a higher weight are preferred when there are multiple routes to the same destination

Communities

- Transitive, Non-mandatory
- Represented as a numeric value
  - 0x0 – 0xffffffff
  - Internet convention is ASN:<0-65535>
- Used to group destinations
- Each destination could be member of multiple communities
- Flexibility to scope a set of prefixes within or across AS for applying policy

Communities


Service Provider AS 200

C

D

Community:200:90

Community:200:120

A

B

192.168.1.0/24

Customer AS 201

Community	Local Preference
200:90	90
200:120	120

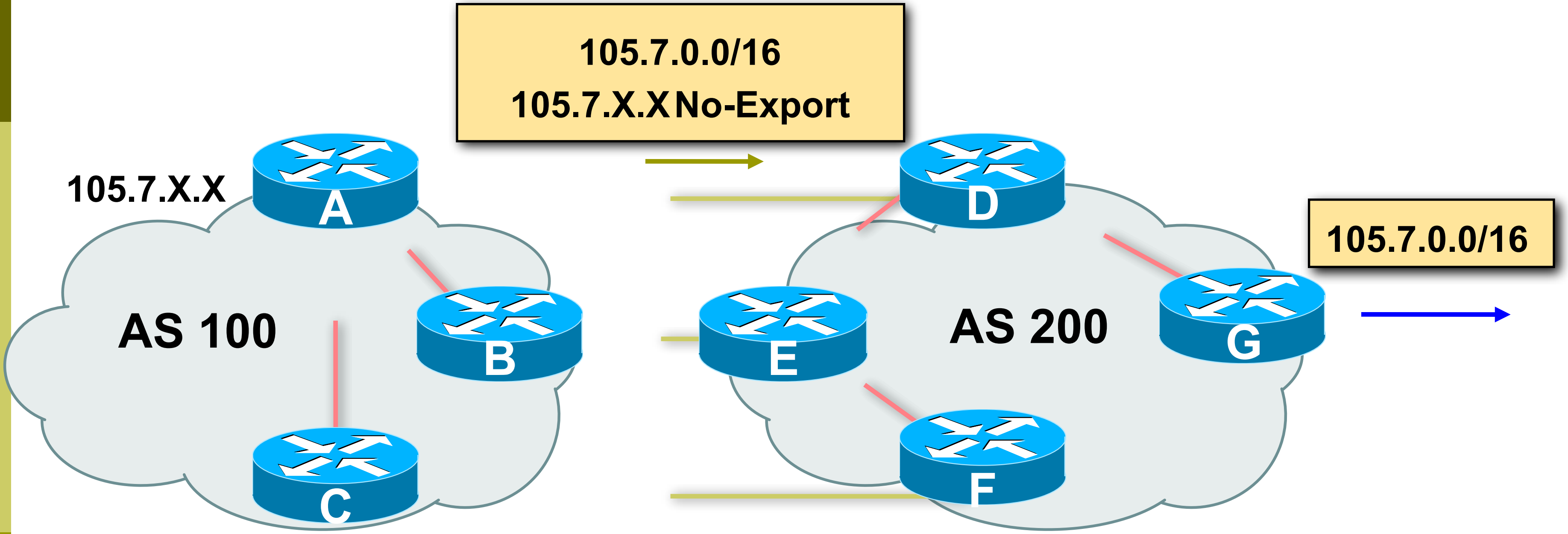
Well-Known Communities

- Several well known communities

www.iana.org/assignments/bgp-well-known-communities

- no-export 65535:65281
  - do not advertise to any eBGP peers
- no-advertise 65535:65282
  - do not advertise to any BGP peer
- no-export-subconfed 65535:65283
  - do not advertise outside local AS (only used with confederations)
- no-peer 65535:65284
  - do not advertise to bi-lateral peers (RFC3765)

No-Export Community

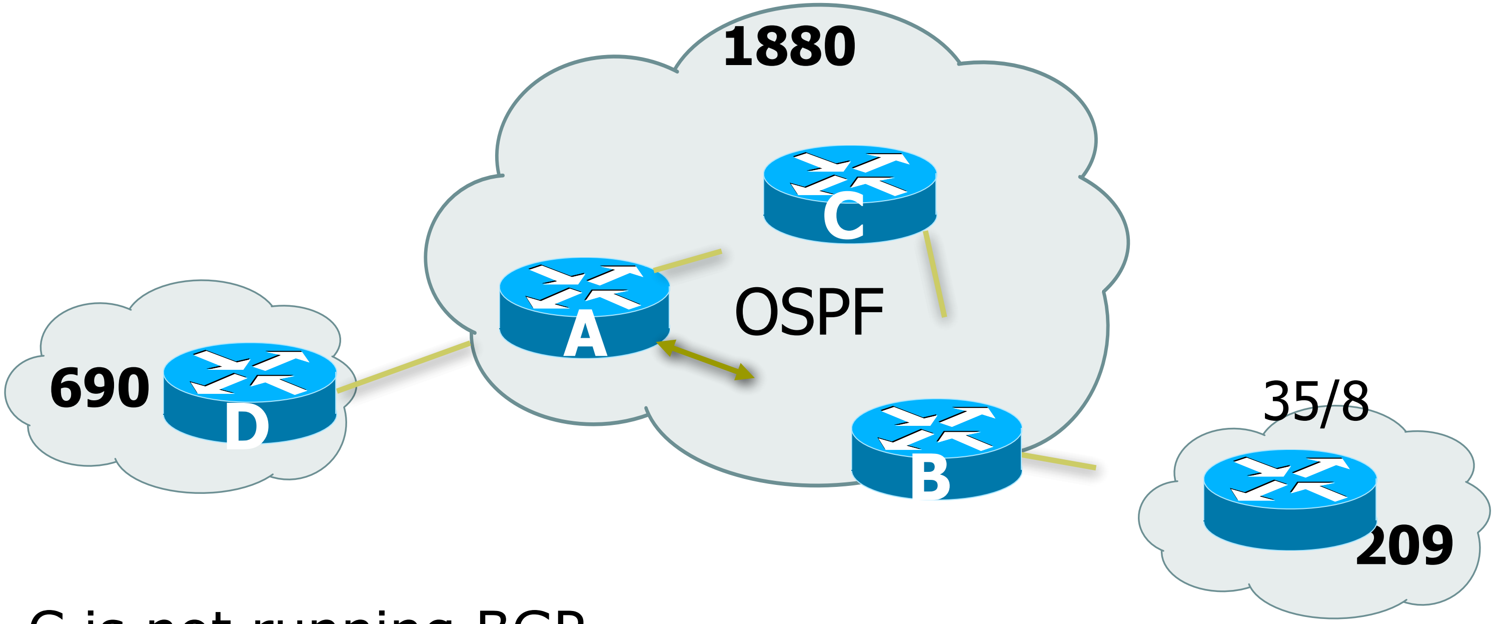


- AS100 announces aggregate and subprefixes
  - Intention is to improve loadsharing by leaking subprefixes
- Subprefixes marked with no-export community
- Router G in AS200 does not announce prefixes with no-export community set

Administrative Distance

- Routes can be learned via more than one protocol
  - Used to discriminate between them
- Route with lowest distance installed in forwarding table
- BGP defaults
  - Local routes originated on router: 200
  - iBGP routes: 200
  - eBGP routes: 20
- Does not influence the BGP path selection algorithm but influences whether BGP learned routes enter the forwarding table

Synchronization



- C is not running BGP
- A won’t advertised 35/8 to D until the IGP is in sync
- Turn synchronization off!

```
router bgp 1880
 no synchronization
```

Synchronization

- In Cisco IOS, BGP does not advertise a route before all routers in the AS have learned it via an IGP
  - Default in IOS prior to 12.4; very unhelpful to most ISPs
- Disable synchronization if:
  - AS doesn’t pass traffic from one AS to another, or
  - All transit routers in AS run BGP, or
  - iBGP is used across backbone
- You should always use iBGP
  - so, always use “no synchronization”

BGP route selection (bestpath)

- Route has to be synchronized
  - Only if synchronization is enabled
  - Prefix must be in forwarding table
- Next-hop has to be accessible
  - Next-hop must be in forwarding table
- Largest weight
- Largest local preference

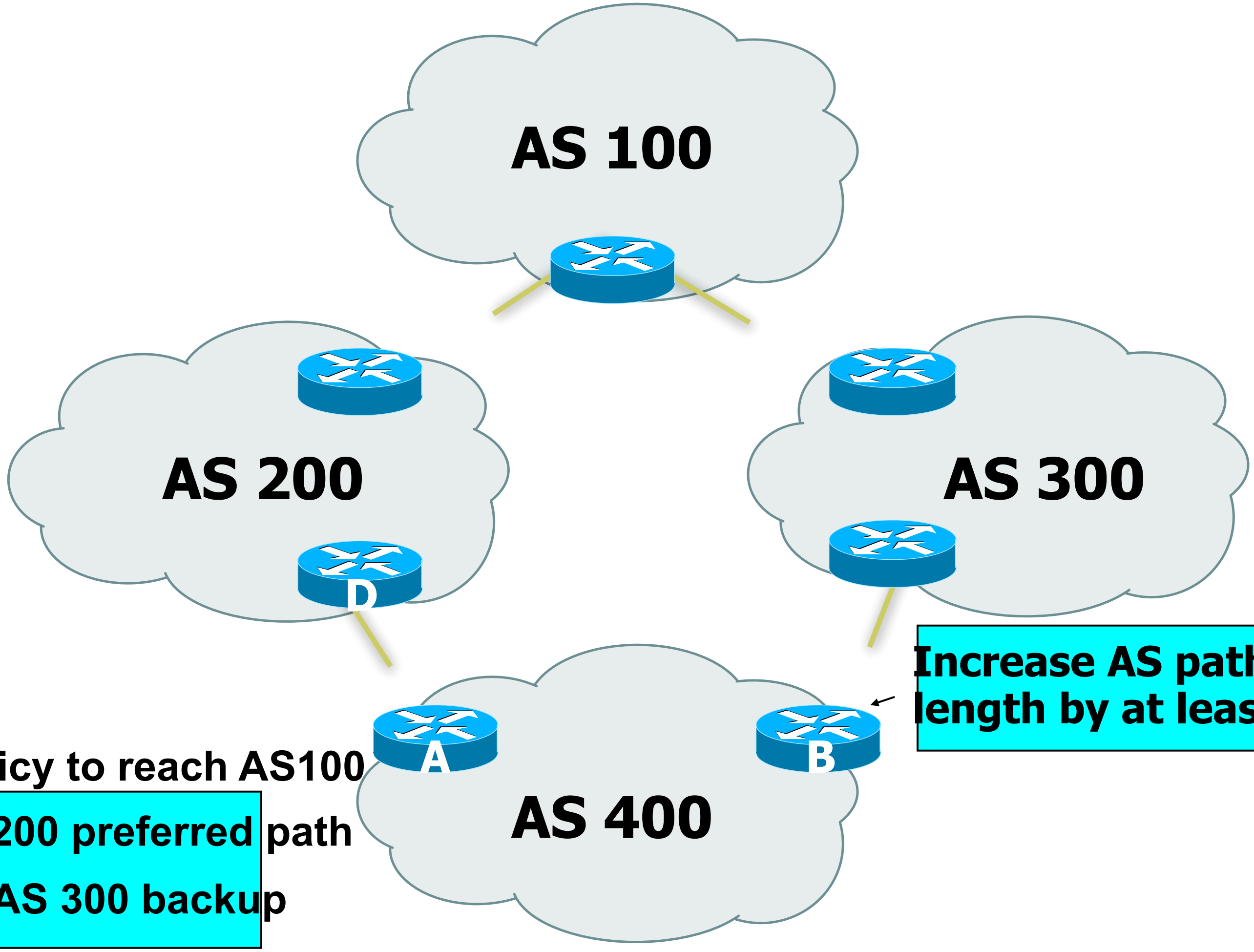
BGP route selection (bestpath)

- Locally sourced
  - Via redistribute or network statement
- Shortest AS path length
  - Number of ASes in the AS-PATH attribute
- Lowest origin
  - IGP < EGP < incomplete
- Lowest MED
  - Compared from paths from the same AS

BGP route selection (bestpath)

- External before internal
  - Choose external path before internal
- Closest next-hop
  - Lower IGP metric, nearest exit to router
- Lowest router ID
- Lowest IP address of neighbour

BGP Route Selection…



Increase AS path attribute length by at least 1

AS 400's Policy to reach AS100

AS 200 preferred path

AS 300 backup

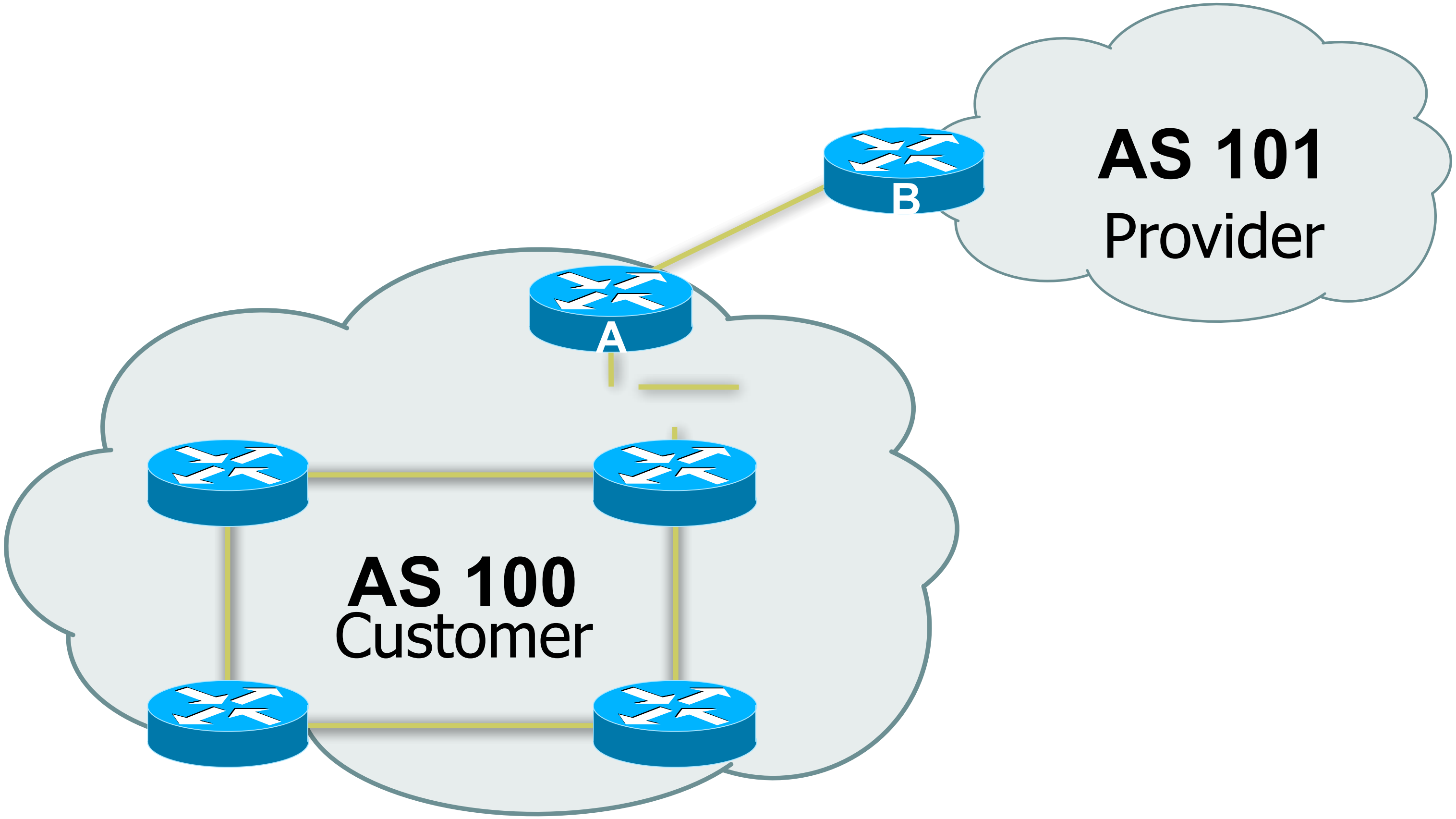
BGP Part 10

BGP and Network Design

Stub AS

- Enterprise network, or small ISP
- Typically no need for BGP
- Point default towards the ISP
- ISP advertises the stub network to Internet
- Policy confined within ISP policy

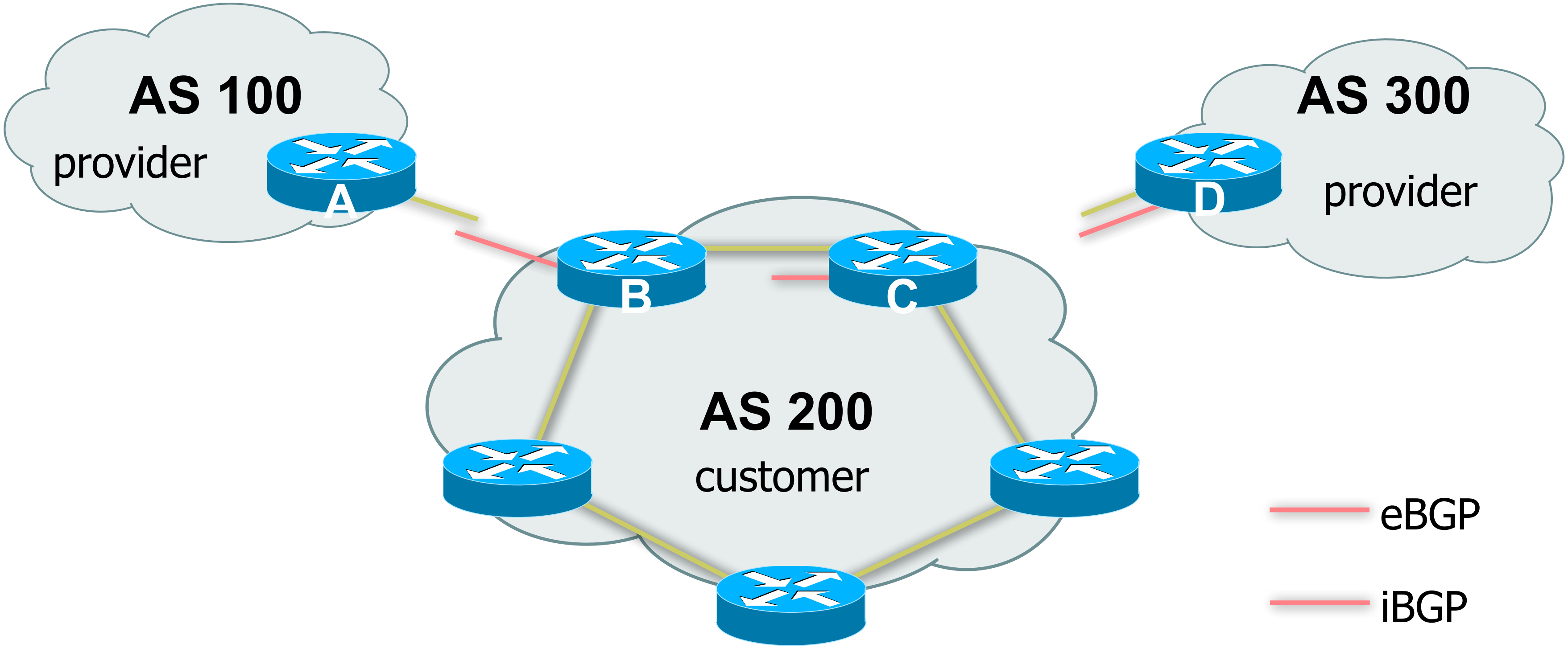
Stub AS



Multihomed AS

- Enterprise network or small ISP
- Only border routers speak BGP
  - And others on direct path between them
- iBGP only between border routers
- Rest of network either has:
  - exterior routes redistributed in a controlled fashion into IGP…
  - …or use defaults (much preferred!)

Multi-homed AS

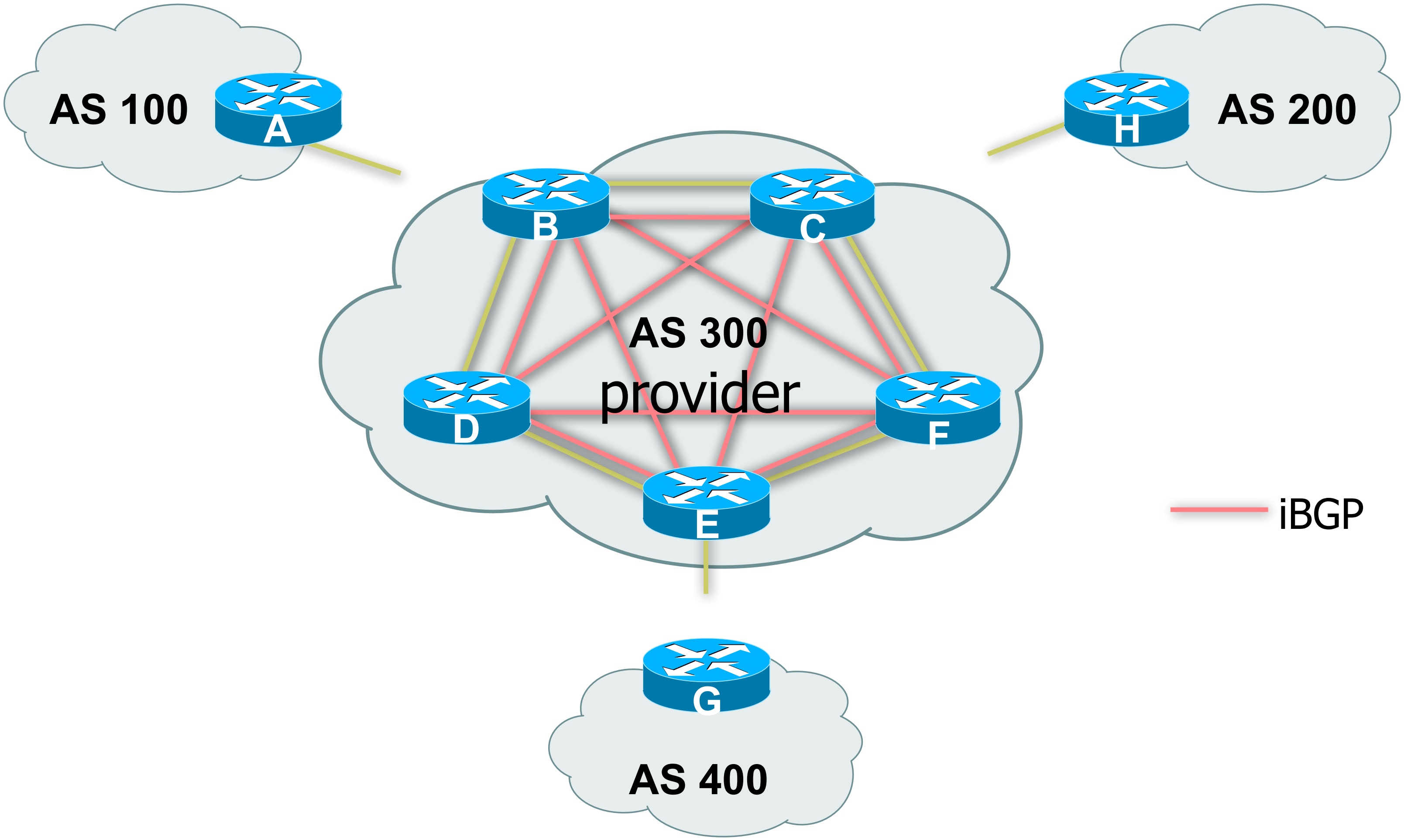


- More details on multihoming coming up…

Service Provider Network

- iBGP used to carry exterior routes
  - No redistribution into IGP
- IGP used to track topology inside your network
- Full iBGP mesh required
  - Every router in ISP backbone should talk iBGP to every other router
  - This has scaling problems, and solutions (e.g. route reflectors)

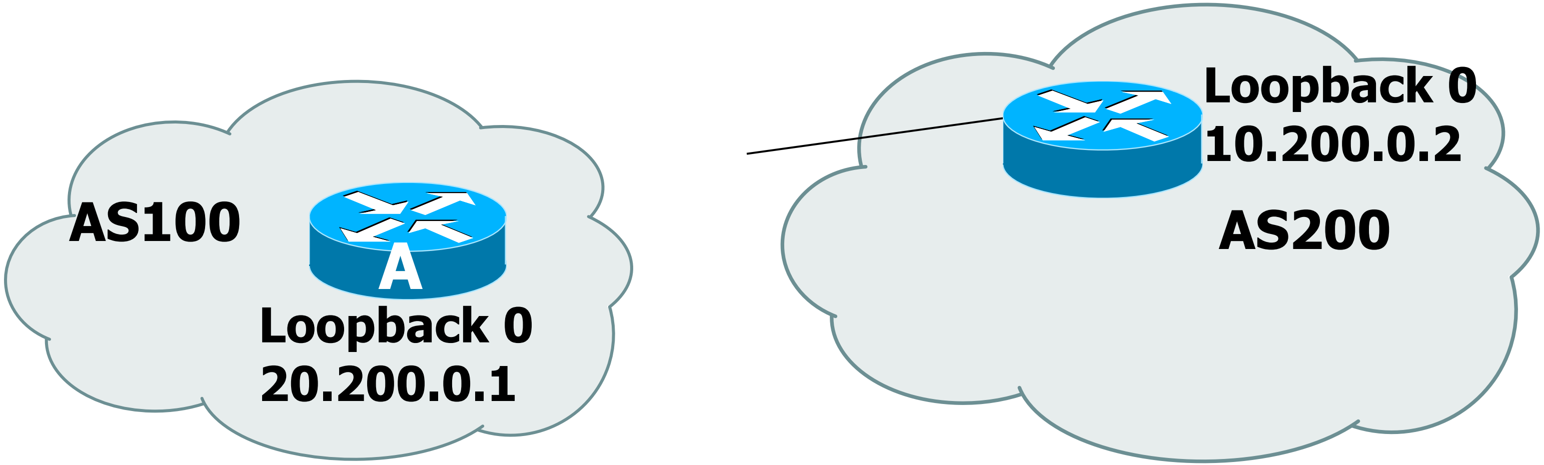
Common Service Provider Network



Load-sharing – single path

- Router A:

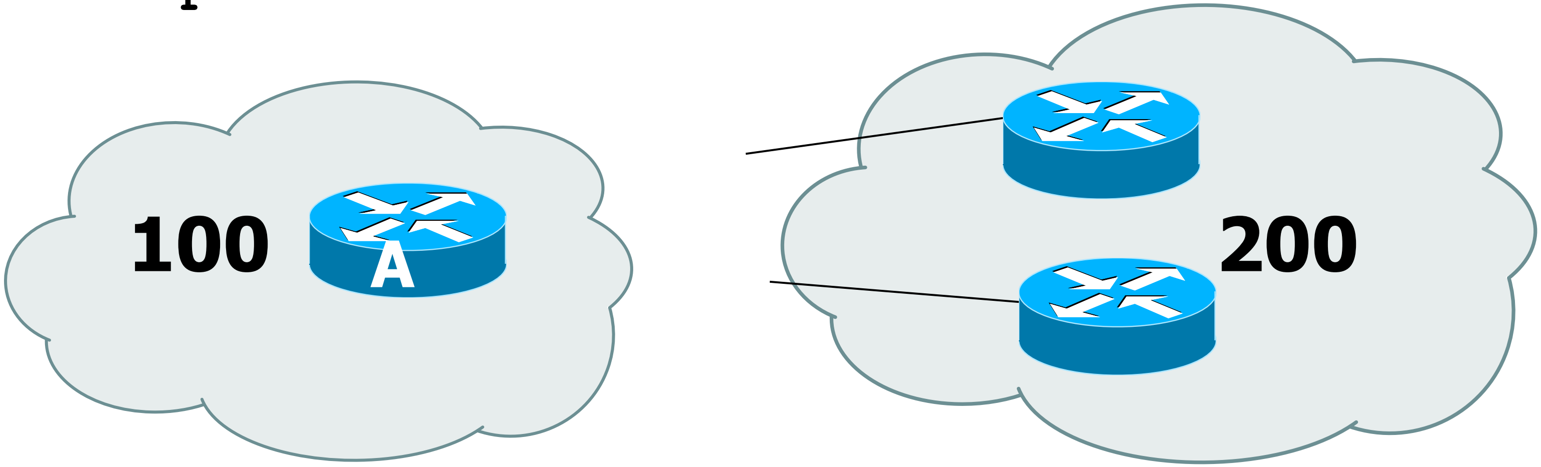
```
interface loopback 0
 ip address 20.200.0.1 255.255.255.255
!
router bgp 100
 neighbor 10.200.0.2 remote-as 200
 neighbor 10.200.0.2 update-source loopback0
 neighbor 10.200.0.2 ebgp-multihop 2
!
ip route 10.200.0.2 255.255.255.255 <DMZ-link1>
ip route 10.200.0.2 255.255.255.255 <DMZ-link2>
```



Load-sharing – multiple paths from the same AS

- Router A:

```
router bgp 100
 neighbor 10.200.0.1 remote-as 200
 neighbor 10.300.0.1 remote-as 200
 maximum-paths 2
```



Note: A still only advertises one “best” path to iBGP peers

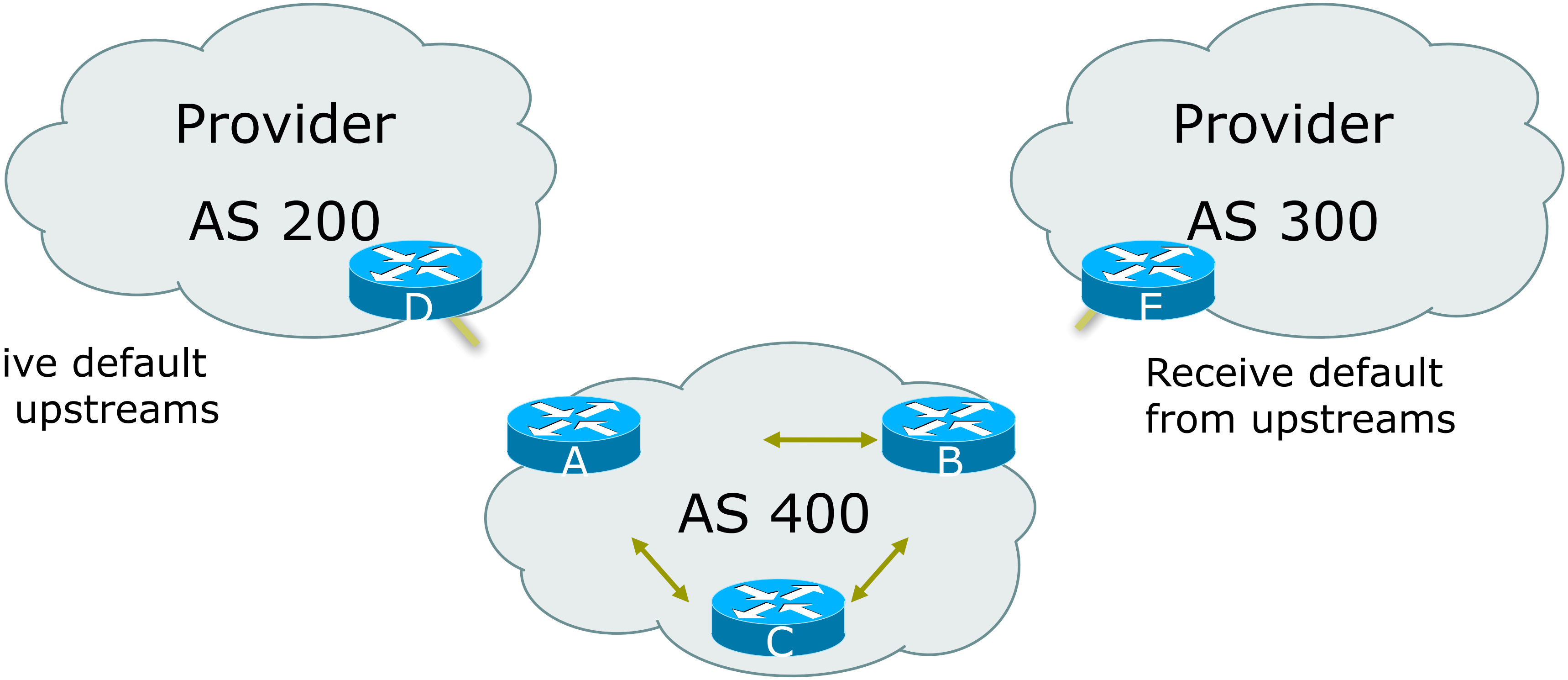
Redundancy – Multi-homing

- Reliable connection to Internet
- 3 common cases of multi-homing
  - default from all providers
  - customer + default from all providers
  - full routes from all providers
- Address Space
  - comes from upstream providers, or
  - allocated directly from registries

Default from all providers

- Low memory/CPU solution
- Provider sends BGP default
  - provider is selected based on IGP metric
- Inbound traffic decided by providers’ policy
  - Can influence using outbound policy, example: AS-path prepend

Default from all providers



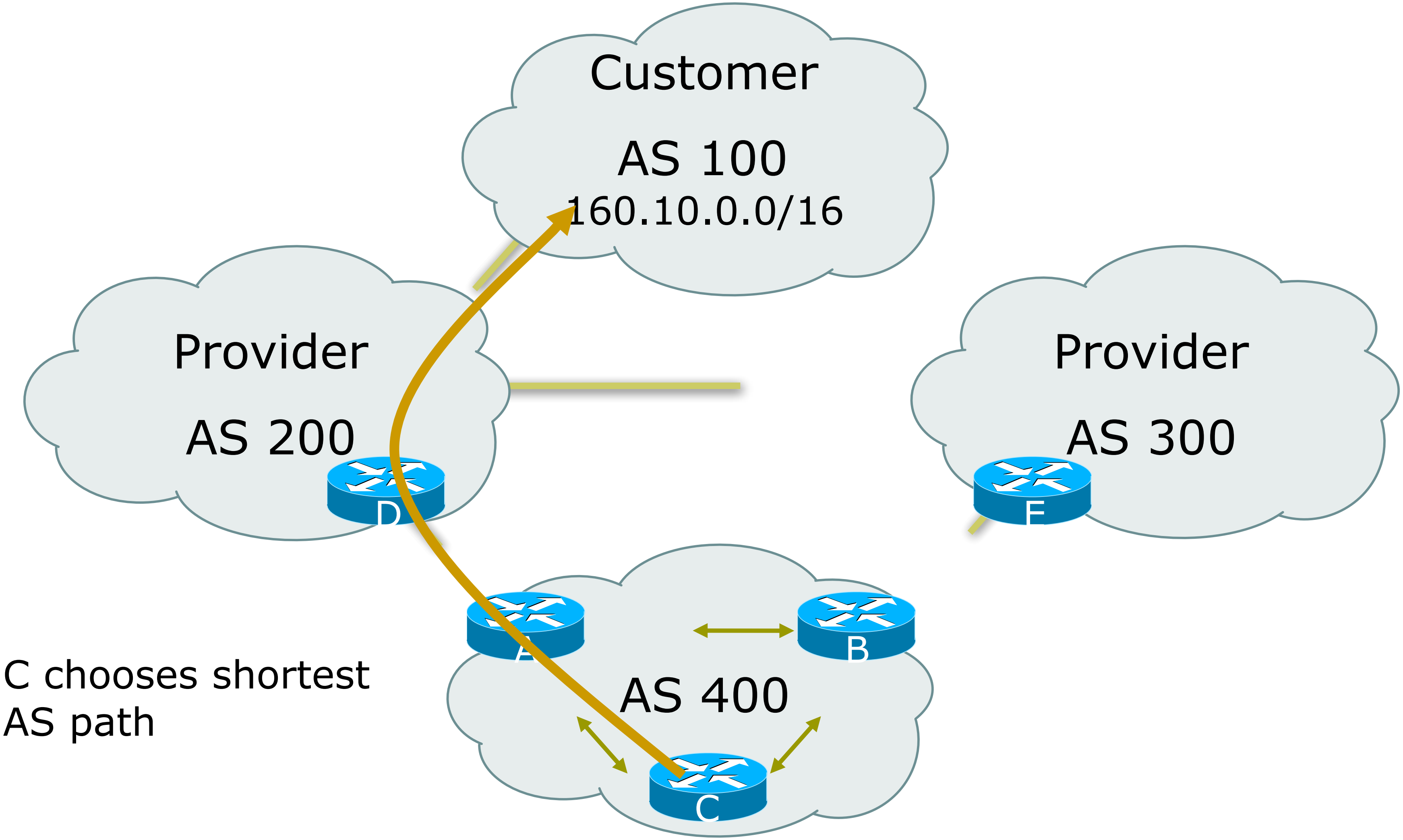
Receive default from upstreams

Receive default from upstreams

Customer prefixes plus default from all providers

- Medium memory and CPU solution
- Granular routing for customer routes, default for the rest
  - Route directly to customers as those have specific policies
- Inbound traffic decided by providers' policies
  - Can influence using outbound policy

Customer routes from all providers

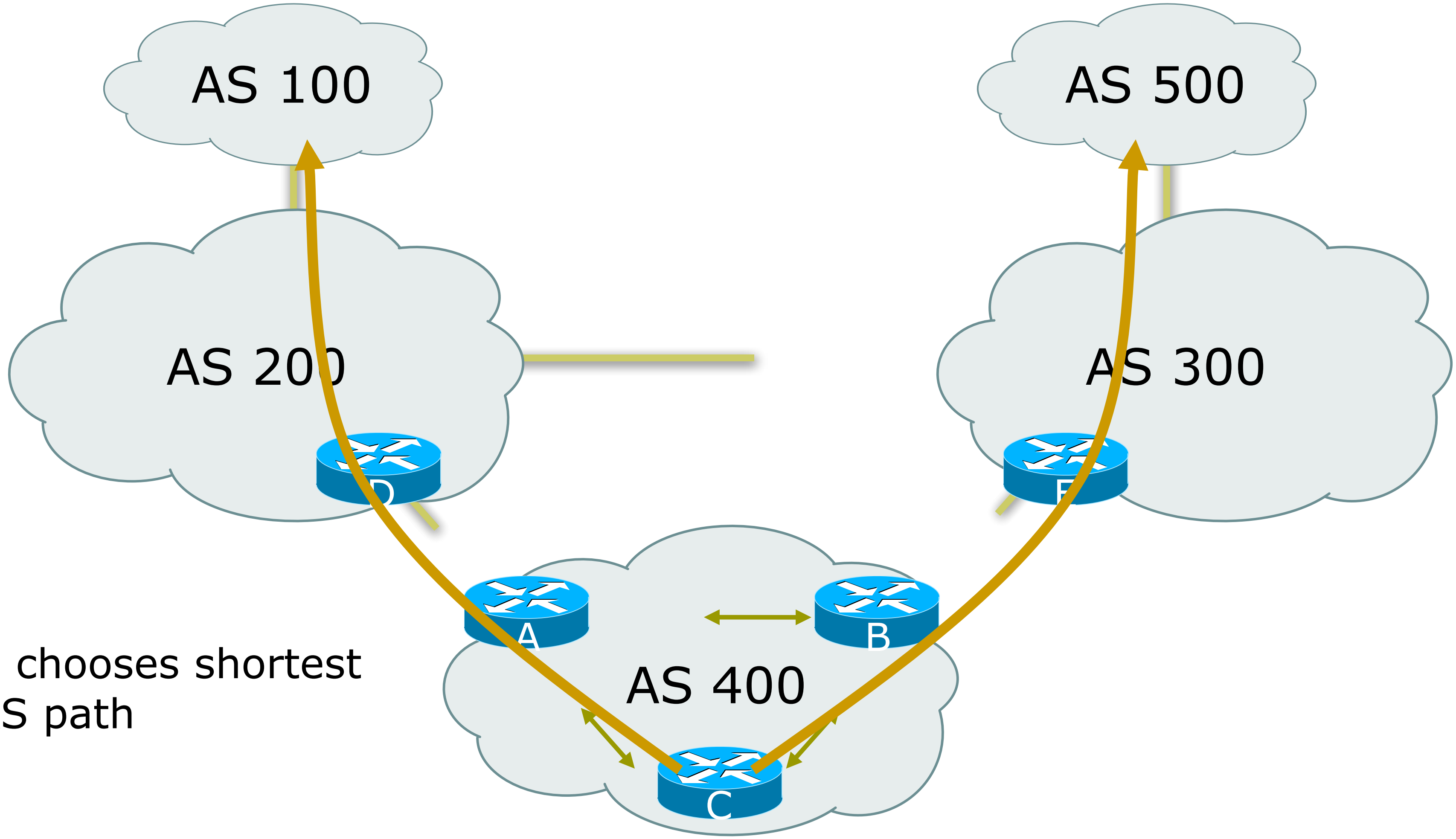


C chooses shortest AS path

Full routes from all providers

- More memory/CPU
- Fine grained routing control
- Usually transit ASes take full routes
- Usually pervasive BGP

Full routes from all providers



C chooses shortest AS path

Best Practices
IGP in Backbone

- IGP connects your backbone together, not your clients' routes
  - Clients' routes go into iBGP
  - Hosting and service LANs go into iBGP
  - Dial/Broadband/Wireless pools go into iBGP
- IGP must converge quickly
  - The fewer prefixes in the IGP the better
- IGP should carry netmask information – OSPF, IS-IS, EIGRP

Best Practices iBGP in Backbone

- iBGP runs between all routers in backbone
- Configuration essentials:
  - Runs between loopbacks
  - Next-hop-self
  - Send-community
  - Passwords
  - All non-infrastructure prefixes go here

Best Practices... Connecting to a customer

- Static routes
  - You control directly
  - No route flaps
- Shared routing protocol or leaking
  - Strongly discouraged
  - You must filter your customers info
  - Route flaps
- BGP for multi-homed customers
  - Private AS for those who multihome on to your backbone
  - Public AS for the rest

Best Practices... Connecting to other ISPs

- Advertise only what you serve
- Take back as little as you can
- Take the shortest exit
- Aggregate your routes!!
  - Consult RIPE-399 document for recommendations:
  - http://www.ripe.net/docs/ripe-399.html
- FILTER! FILTER! FILTER!

Best Practices…
The Internet Exchange

- Long distance connectivity is:
  - Expensive
  - Slow (speed of light limitations)
  - Congested
- Connect to several providers at a single point
  - Cheap
  - Fast
- More details later!

Summary

- We have learned about:
  - BGP Protocol Basics
  - Routing Policy and Filtering
  - BGP Best Path Computation
  - Typical BGP topologies
  - Routing Policy
  - BGP Network Design
  - Redundancy/Load sharing
  - Some best practices