



# BGP Attributes and Policy Control

ISP/IXP Workshops

# Agenda

- BGP Attributes
- BGP Path Selection
- Applying Policy



# BGP Attributes

The “tools” available for the job

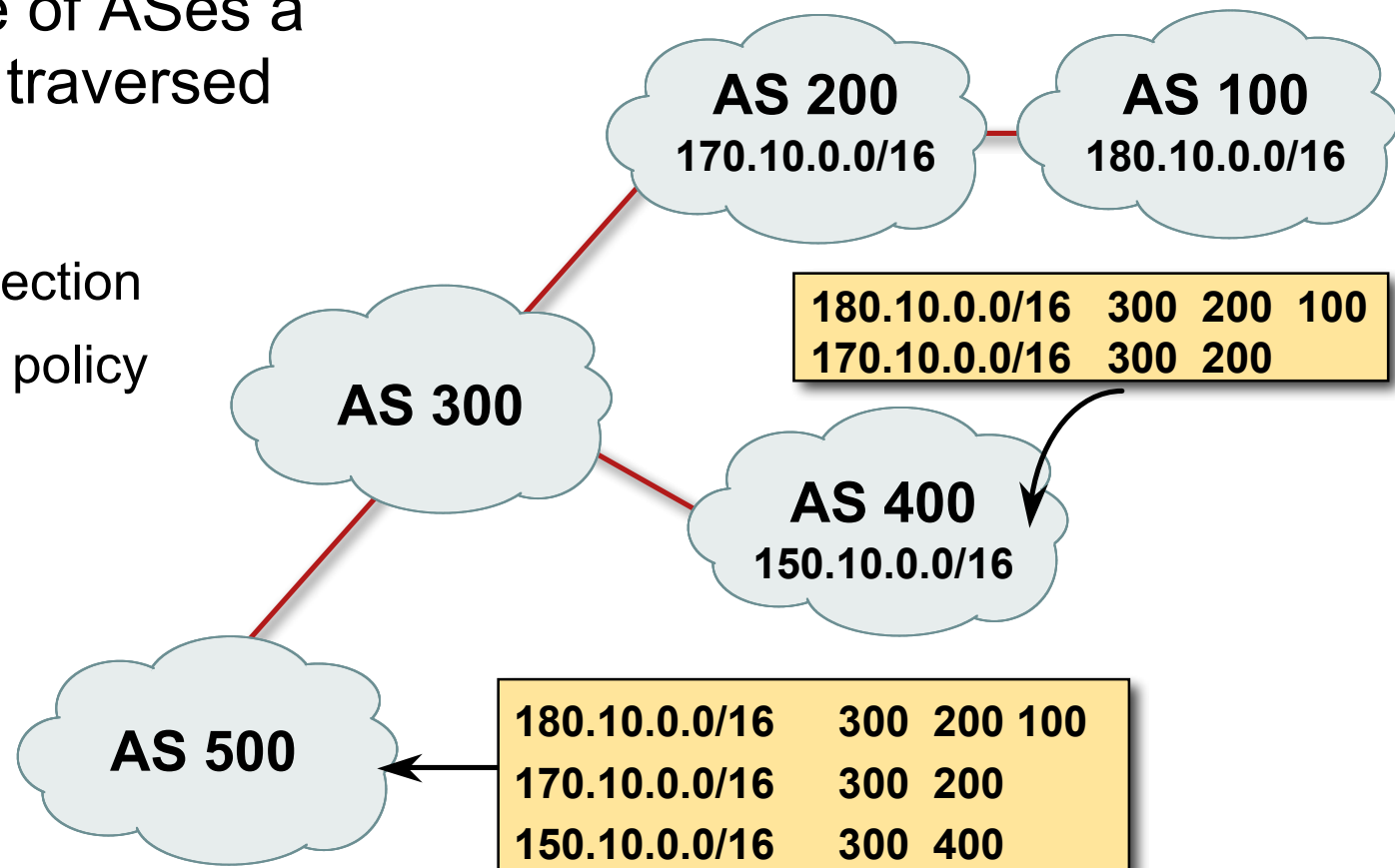
# What Is an Attribute?



- Describes the characteristics of prefix
- Transitive or non-transitive
- Some are mandatory

# AS-Path

- Sequence of ASes a route has traversed
- Used for:
  - Loop detection
  - Applying policy

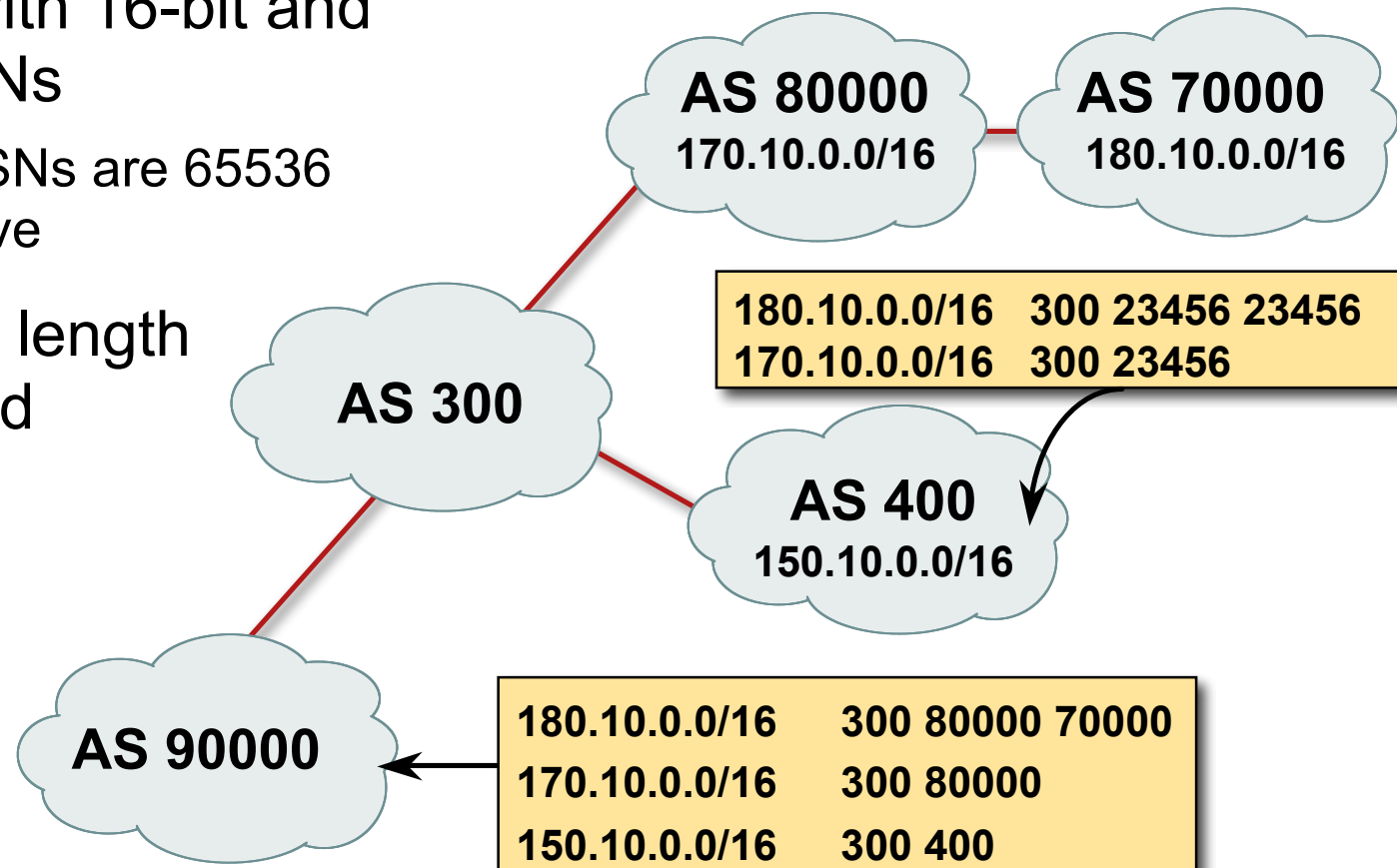


# AS-Path (with 16 and 32-bit ASNs)

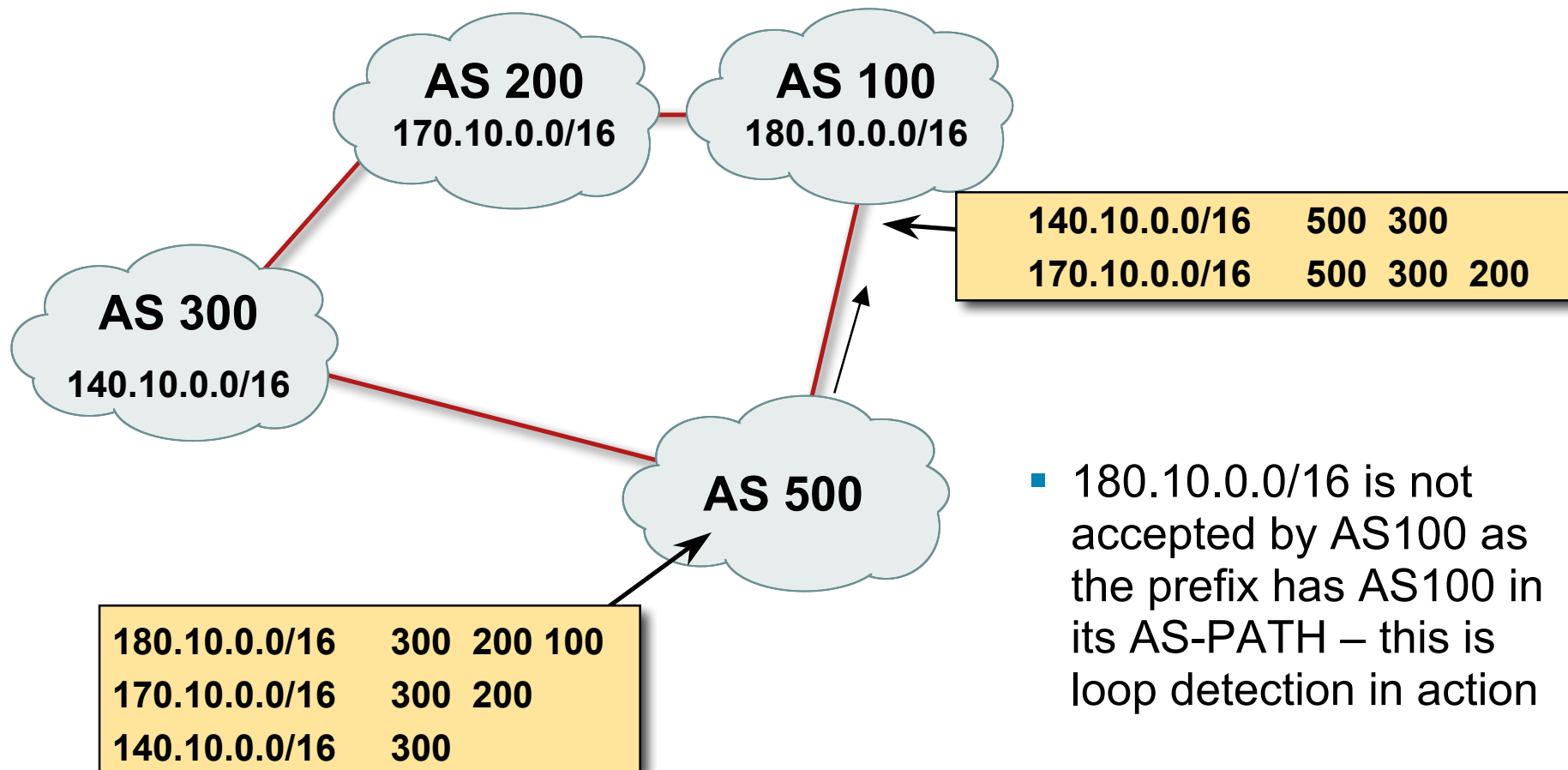
- Internet with 16-bit and 32-bit ASNs

32-bit ASNs are 65536 and above

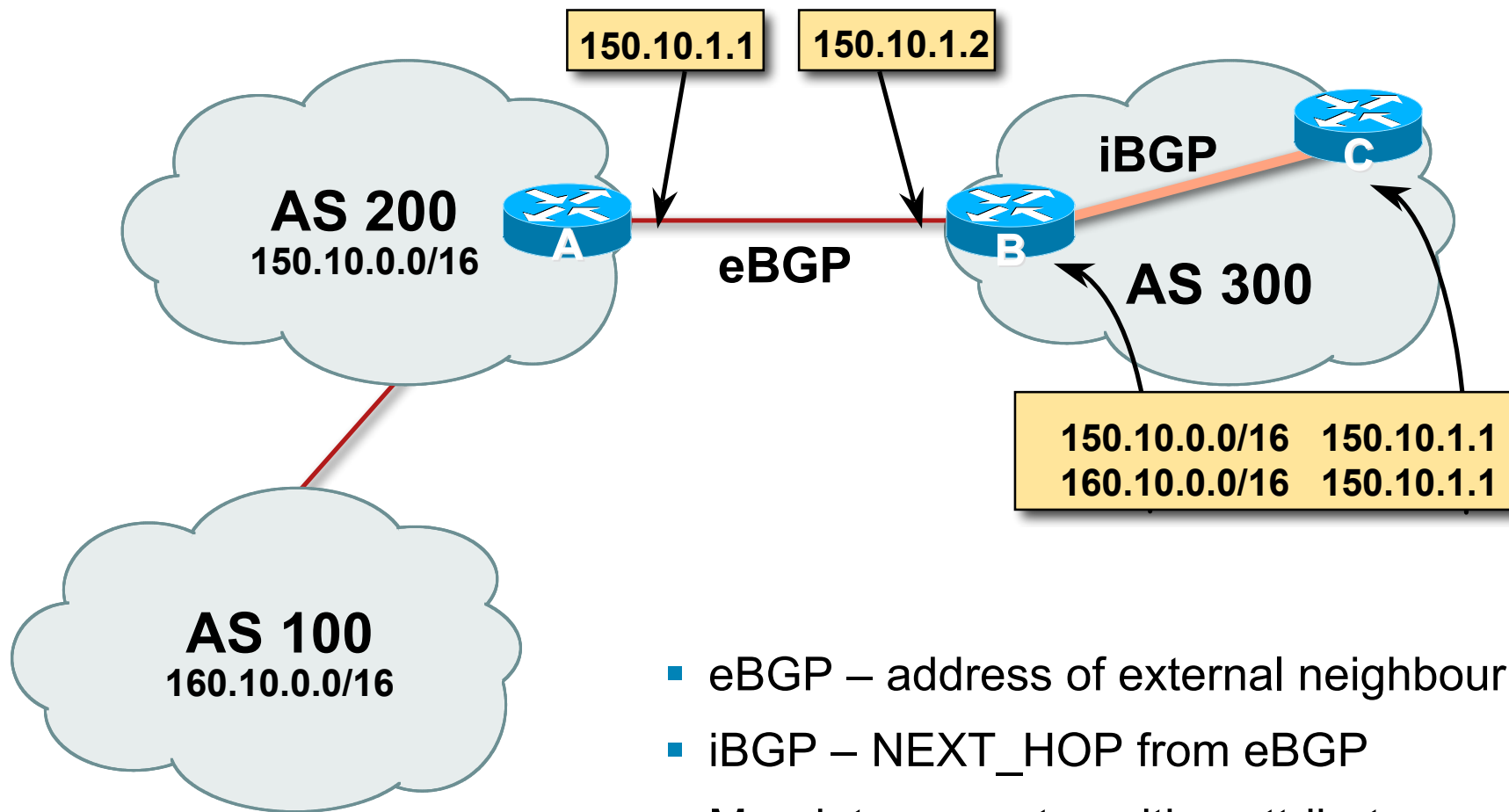
- AS-PATH length maintained



# AS-Path loop detection



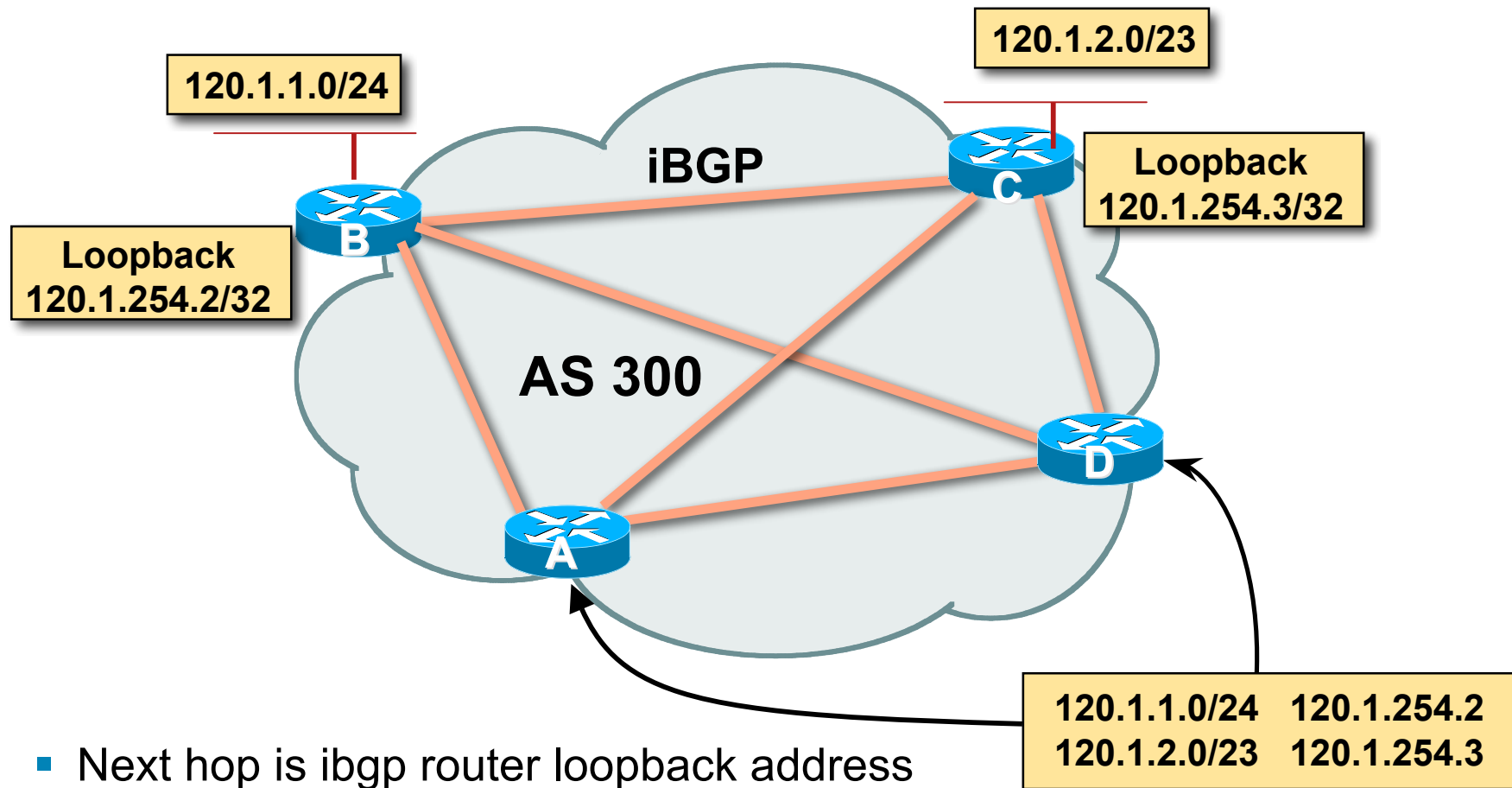
# Next Hop



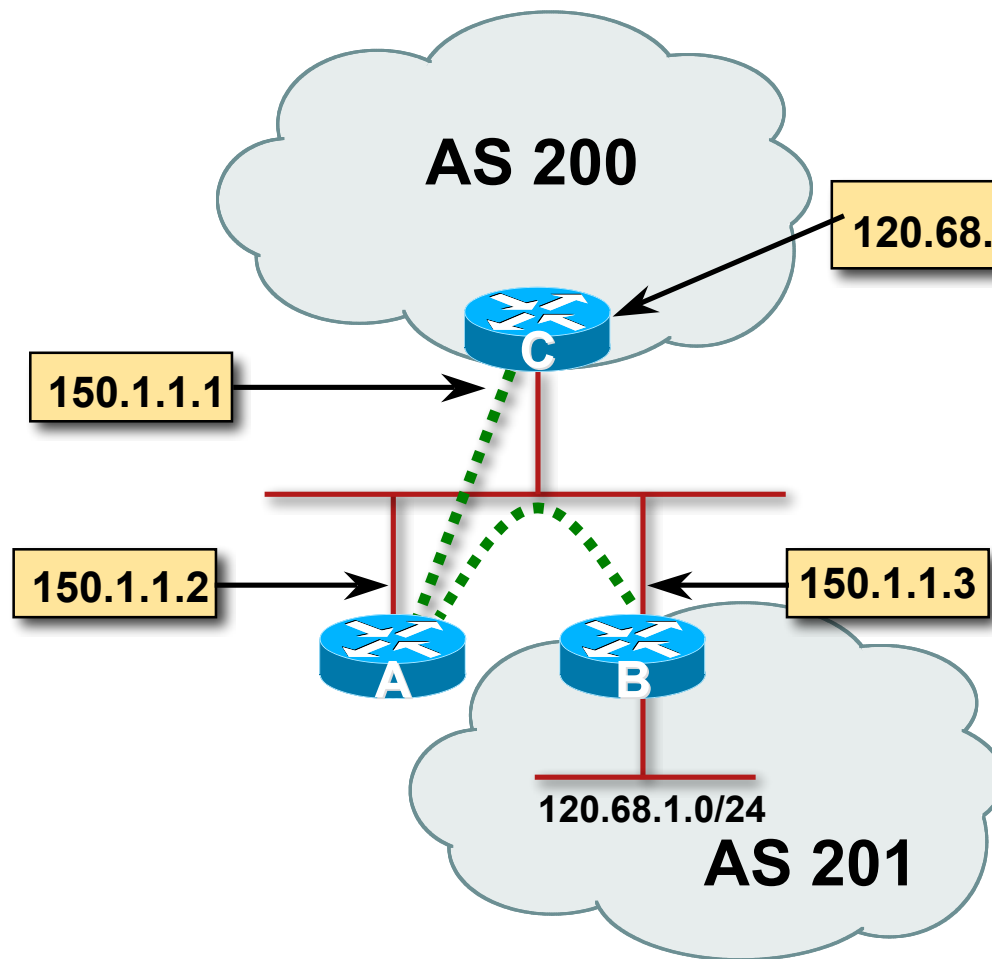
- eBGP – address of external neighbour
- iBGP – NEXT\_HOP from eBGP
- Mandatory non-transitive attribute



# iBGP Next Hop



# Third Party Next Hop



- eBGP between Router A and Router C
- eBGP between Router A and Router B
- 120.68.1/24 prefix has next hop address of 150.1.1.3 – this is passed on to Router C instead of 150.1.1.2
- More efficient
- No extra config needed

# Next Hop Best Practice

- 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 unnecessary 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
```

## Next Hop (Summary)

- IGP should carry route to next hops
- Recursive route look-up
- Unlinks BGP from actual physical topology
- Use “next-hop-self” for external next hops
- Allows IGP to make intelligent forwarding decision

# Origin

- Conveys the origin of the prefix
- **Historical** attribute
  - Used in transition from EGP to BGP
- Transitive and Mandatory Attribute
- Influences best path selection
- Three values: IGP, EGP, incomplete
  - IGP – generated by BGP network statement
  - EGP – generated by EGP
  - incomplete – redistributed from another routing protocol

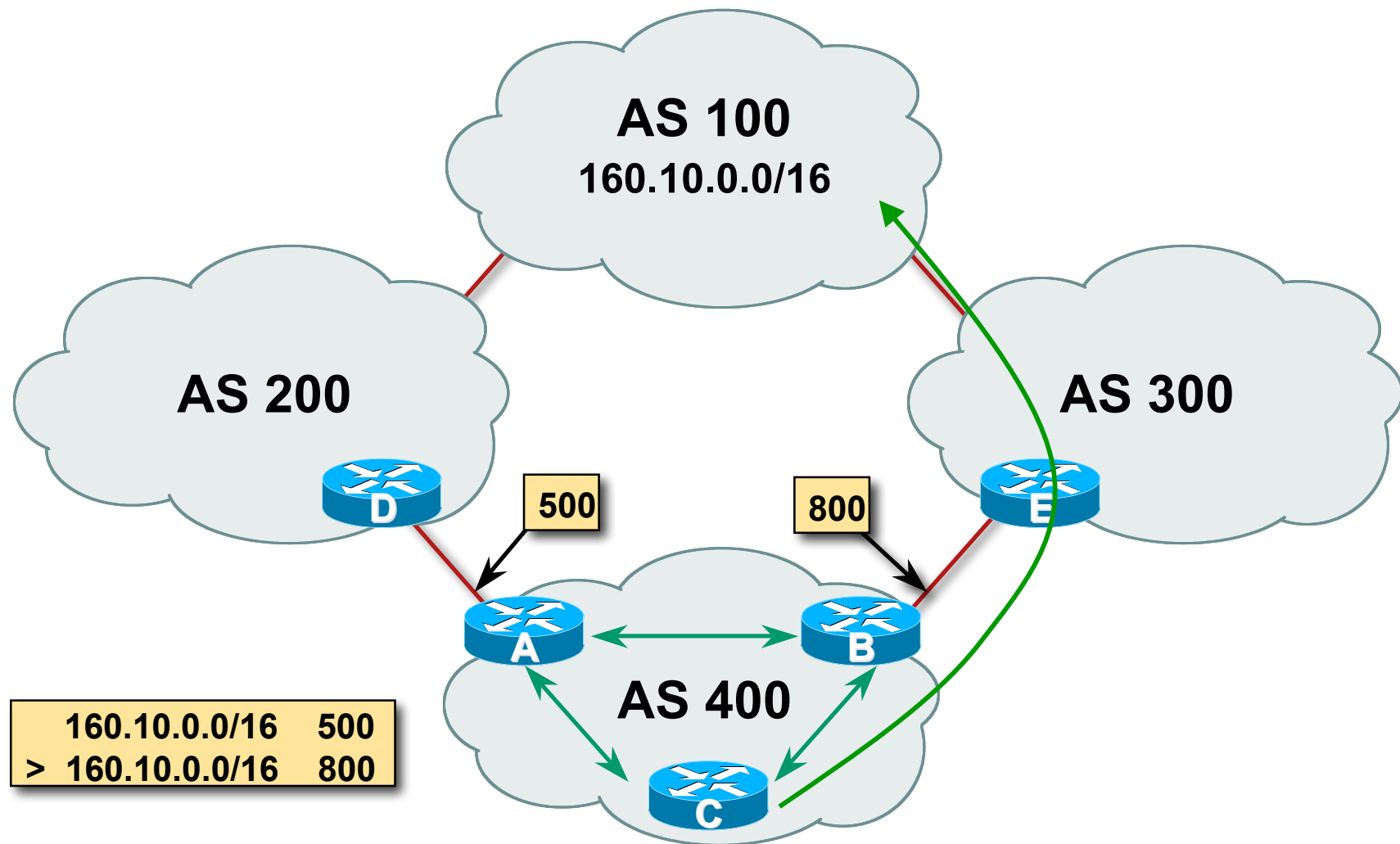
# Aggregator

- Conveys the IP address of the router or BGP speaker generating the aggregate route
- Optional & transitive attribute
- Useful for debugging purposes
- Does not influence best path selection
- Creating aggregate using “aggregate-address” sets the aggregator attribute:

```
router bgp 100
```

```
aggregate-address 100.1.0.0 255.255.0.0
```

# Local Preference



# Local Preference

- Non-transitive and optional attribute
- Local to an AS only
  - Default local preference is 100 (IOS)
- Used to influence BGP path selection
  - determines best path for *outbound* traffic
- Path with highest local preference wins

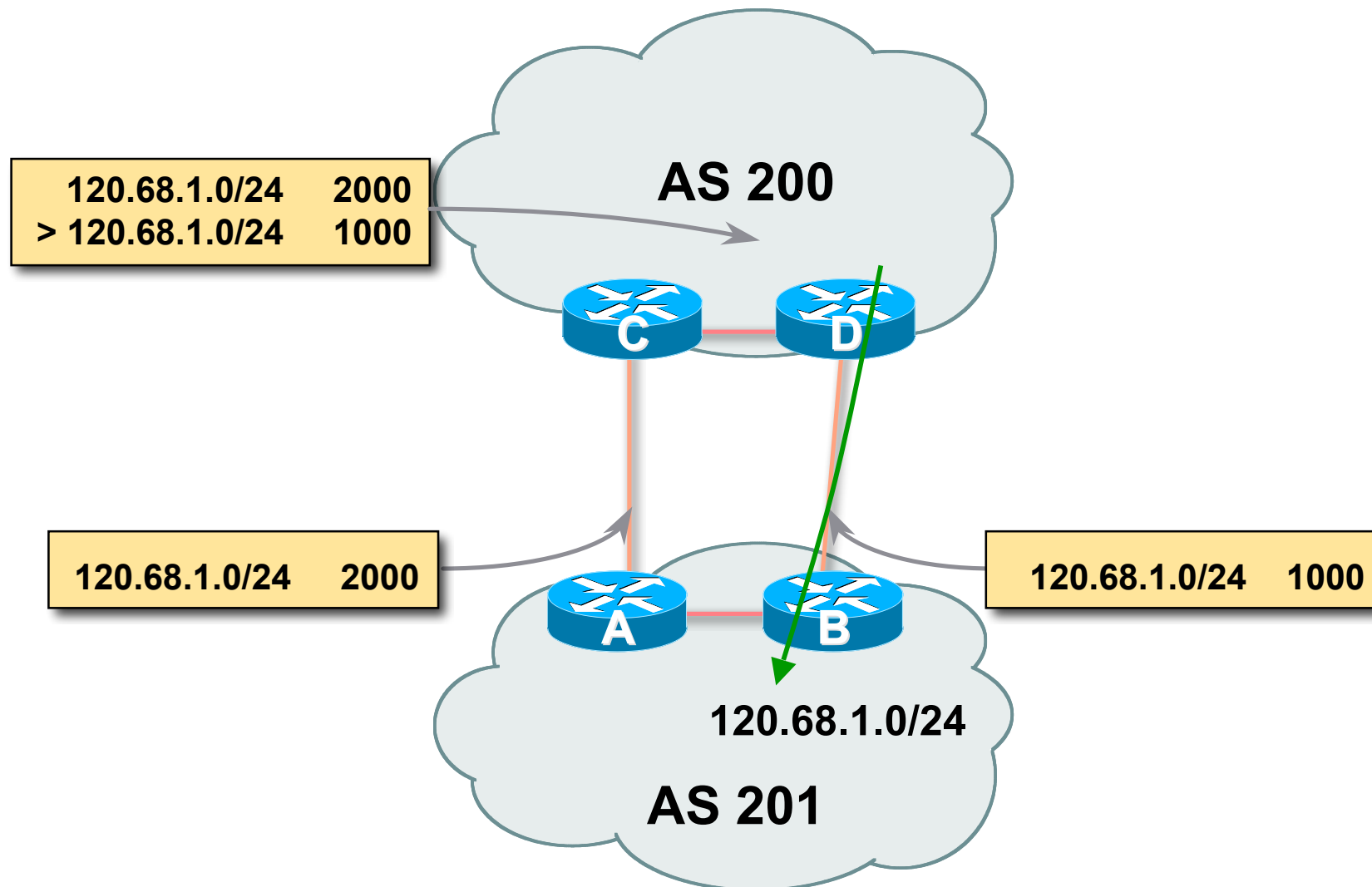


# Local Preference

- Configuration of Router B:

```
router bgp 400
  neighbor 120.5.1.1 remote-as 300
  neighbor 120.5.1.1 route-map local-pref in
!
route-map local-pref permit 10
  match ip address prefix-list MATCH
  set local-preference 800
!
ip prefix-list MATCH permit 160.10.0.0/16
```

# Multi-Exit Discriminator (MED)



# Multi-Exit Discriminator

- Inter-AS – non-transitive & optional attribute
- Used to convey the relative preference of entry points  
determines best path for inbound traffic
- Comparable if paths are from same AS  
`bgp always-compare-med` allows comparisons of MEDs  
from different ASes
- Path with lowest MED wins
- Absence of MED attribute implies MED value of **zero**  
(RFC4271)

# MED & IGP Metric

- IGP metric can be conveyed as MED

`set metric-type internal` in route-map

enables BGP to advertise a MED which corresponds to the IGP metric values

changes are monitored (and re-advertised if needed) every 600s

`bgp dynamic-med-interval <secs>`

# Multi-Exit Discriminator

- Configuration of Router B:

```
router bgp 400
  neighbor 120.5.1.1 remote-as 200
  neighbor 120.5.1.1 route-map set-med out
!
route-map set-med permit 10
  match ip address prefix-list MATCH
  set metric 1000
!
ip prefix-list MATCH permit 120.68.1.0/24
```

# Weight

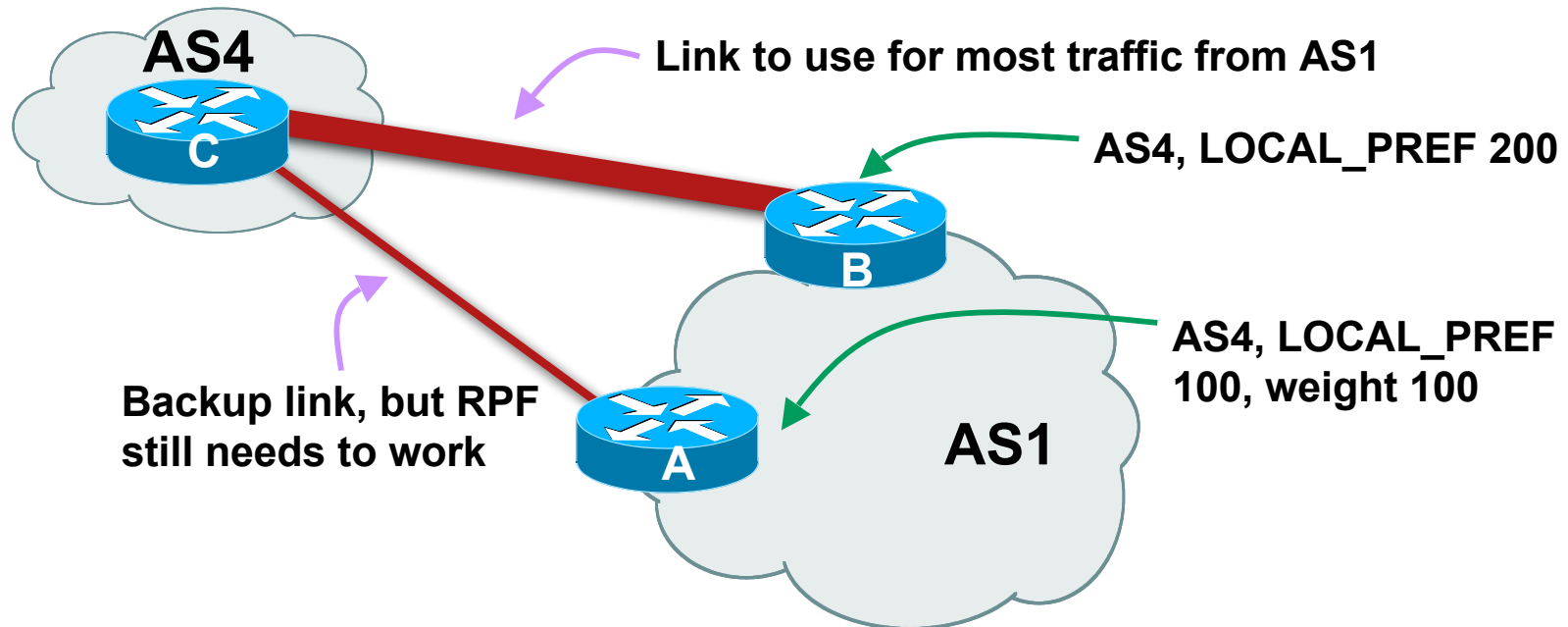
- Not really an attribute – local to router
- Highest weight wins
- Applied to all routes from a neighbour

```
neighbor 120.5.7.1 weight 100
```

- Weight assigned to routes based on filter

```
neighbor 120.5.7.3 filter-list 3 weight 50
```

# Weight – Used to help Deploy RPF



- Best path to AS4 from AS1 is always via B due to local-pref
- But packets arriving at A from AS4 over the direct C to A link will pass the RPF check as that path has a priority due to the weight being set

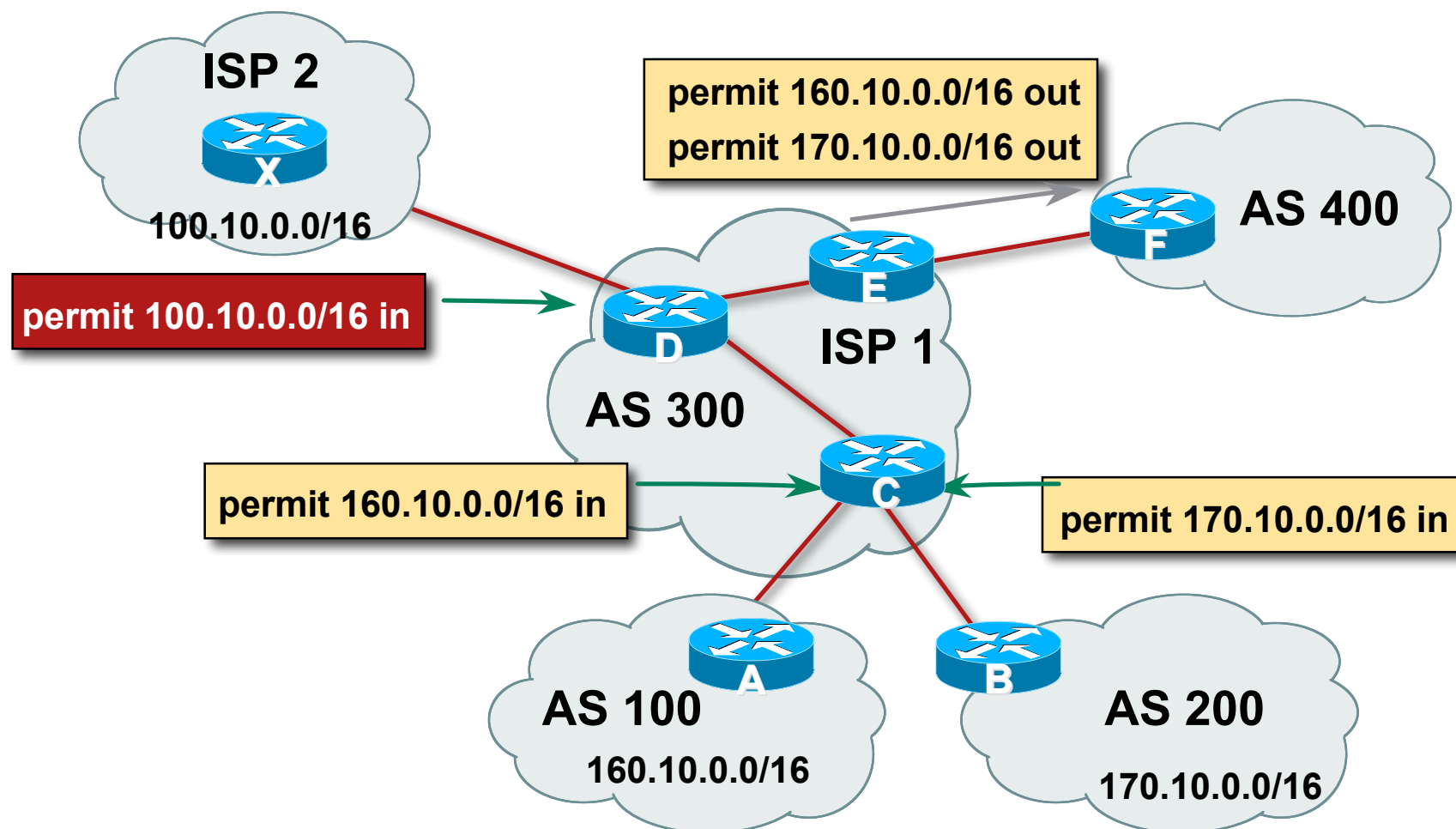
If weight was not set, best path back to AS4 would be via B, and the RPF check would fail

# Community

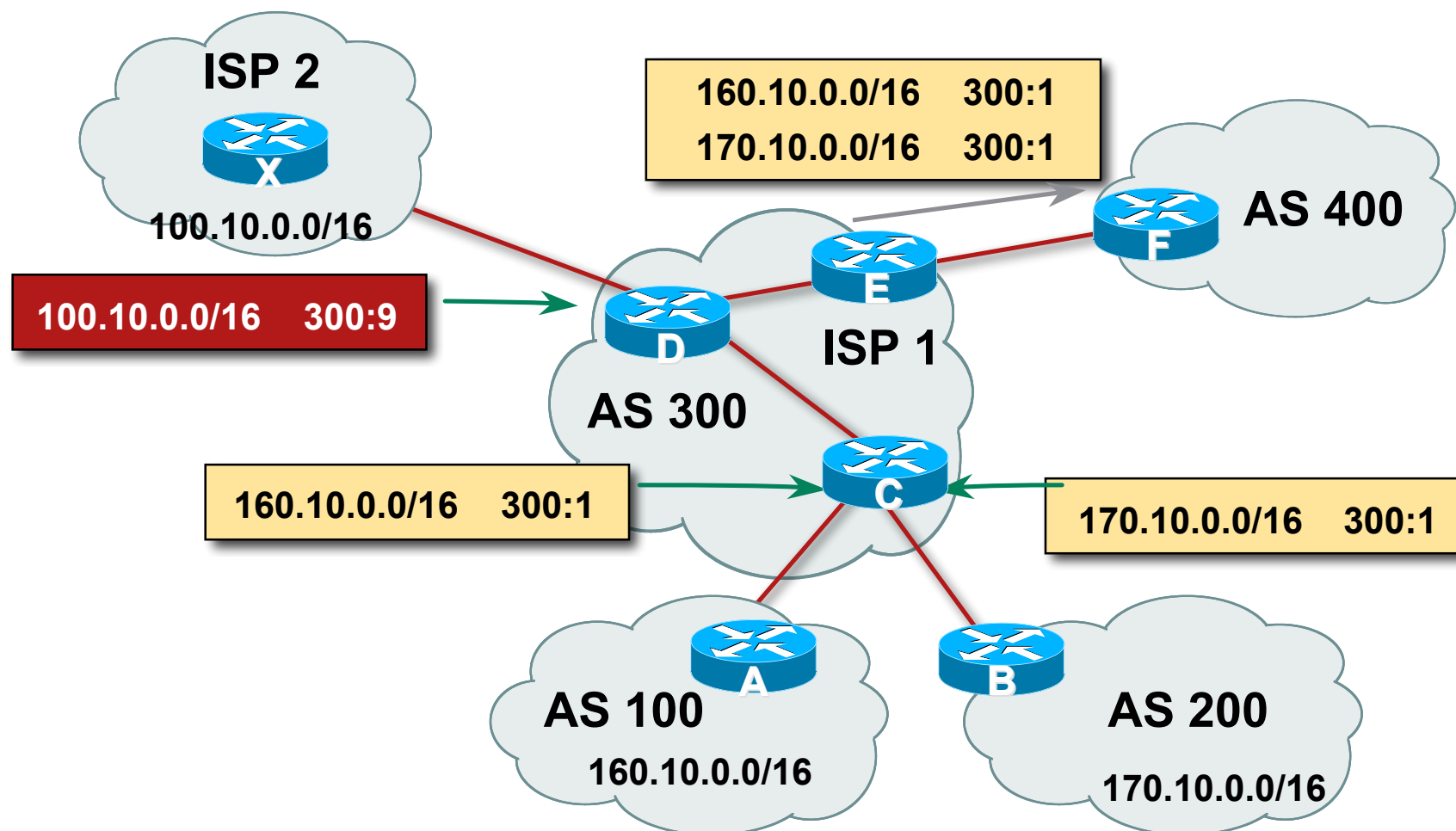
- Communities are described in RFC1997  
Transitive and Optional Attribute
- 32 bit integer  
Represented as two 16 bit integers (RFC1998)  
Common format is <local-ASN>:xx  
0:0 to 0:65535 and 65535:0 to 65535:65535 are reserved
- Used to group destinations  
Each destination could be member of multiple communities
- Very useful in applying policies within and between ASes



# Community Example (before)



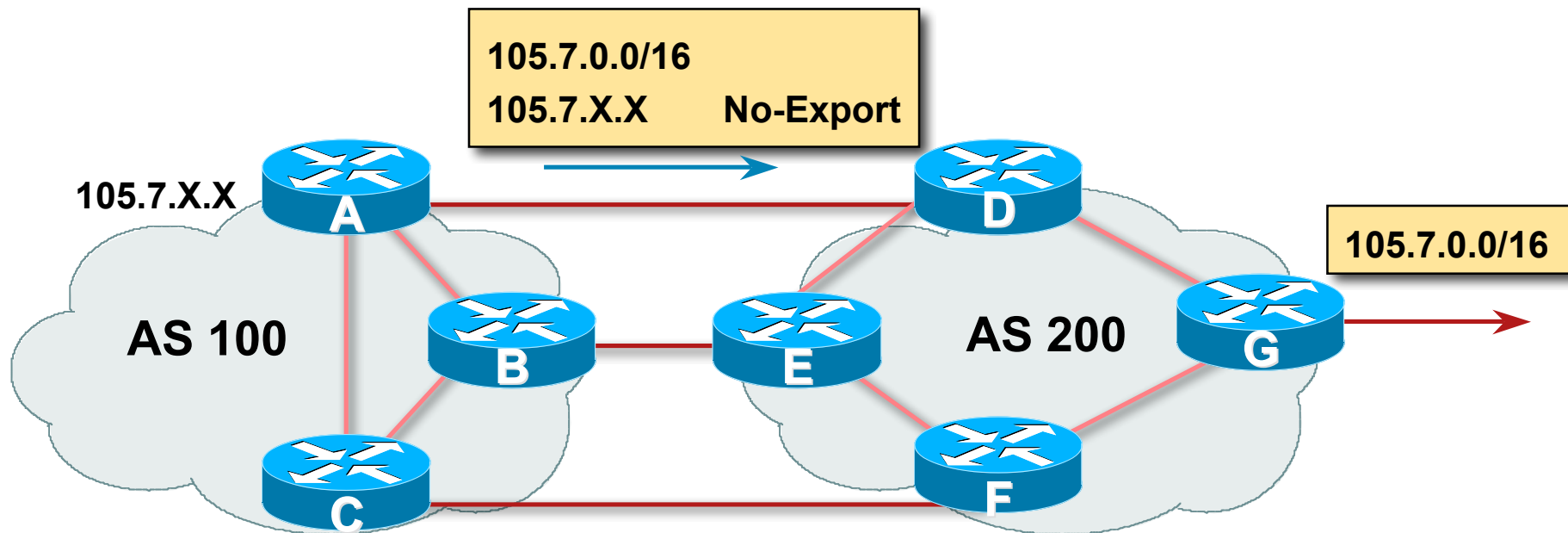
# Community Example (after)



# Well-Known Communities

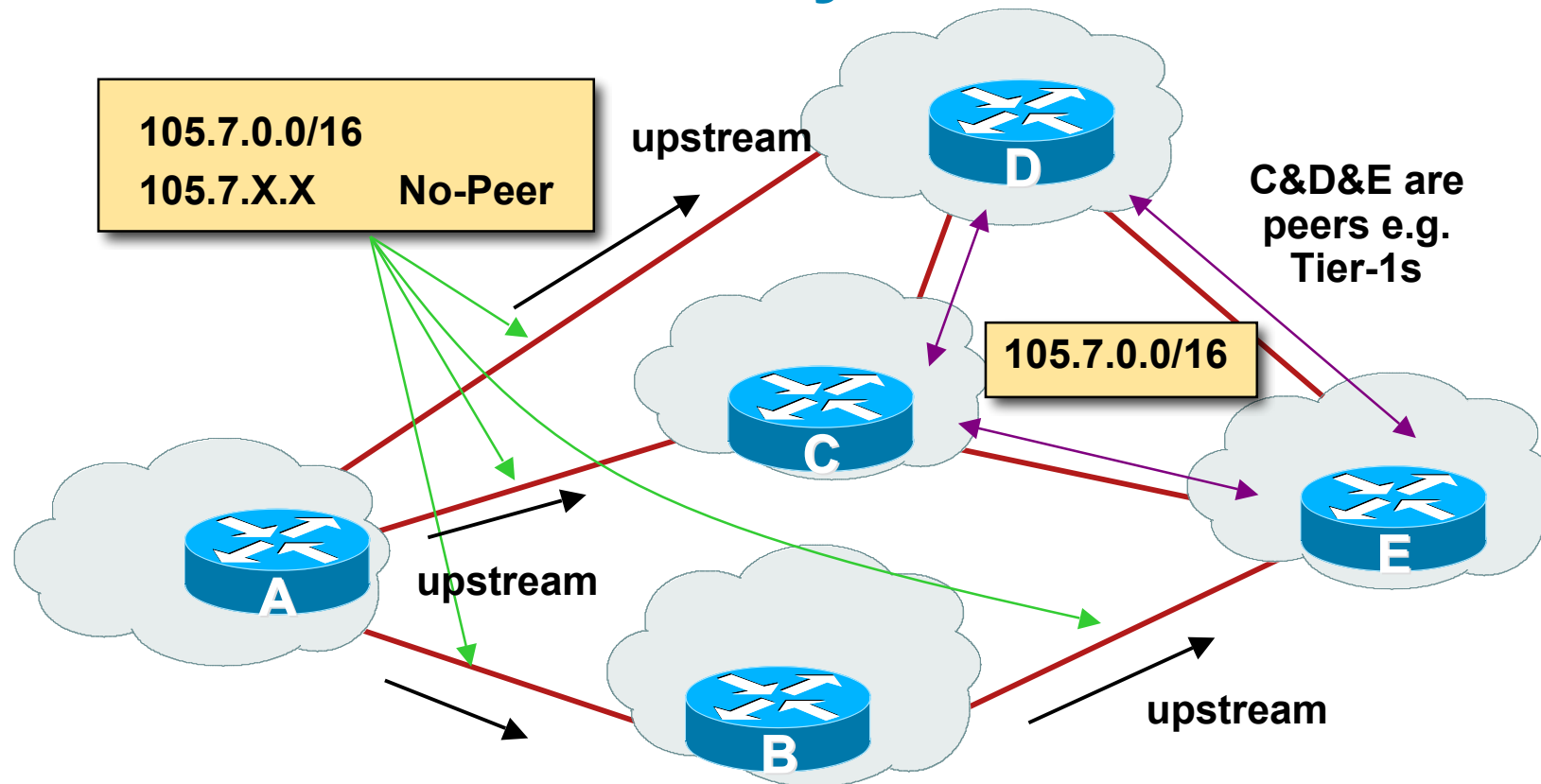
- Several well known communities  
[www.iana.org/assignments/bgp-well-known-communities](http://www.iana.org/assignments/bgp-well-known-communities)
- no-export **65535:65281**  
do not advertise to any eBGP peers
- no-advertise **65535:65282**  
do not advertise to any BGP peer
- no-export-subconfed **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

# No-Peer Community



- Sub-prefixes marked with **no-peer** community are not sent to bi-lateral peers

They are only sent to upstream providers

# Summary

## Attributes in Action

```
Router6>sh ip bgp
```

```
BGP table version is 30, local router ID is 10.0.15.246
```

```
Status codes: s suppressed, d damped, h history, * valid, > best,  
               i - internal, r RIB-failure, S Stale
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i10.0.0.0/26	10.0.15.241	0	100	0	i
*>i10.0.0.64/26	10.0.15.242	0	100	0	i
*>i10.0.0.128/26	10.0.15.243	0	100	0	i
*>i10.0.0.192/26	10.0.15.244	0	100	0	i
*>i10.0.1.0/26	10.0.15.245	0	100	0	i
*> 10.0.1.64/26	0.0.0.0	0		32768	i
...					



# BGP Path Selection Algorithm

Why is this the best path?

# BGP Path Selection Algorithm for IOS

## Part One

- Do not consider path if no route to next hop
- Do not consider iBGP path if not synchronised (Cisco IOS)
- Highest weight (local to router)
- Highest local preference (global within AS)
- Prefer locally originated route
- Shortest AS path



# BGP Path Selection Algorithm for IOS

## Part Two

- Lowest origin code  
IGP < EGP < incomplete
- Lowest Multi-Exit Discriminator (MED)
  - If **bgp deterministic-med**, order the paths before comparing
  - If **bgp always-compare-med**, then compare for all paths
  - otherwise MED only considered if paths are from the same AS (default)

# BGP Path Selection Algorithm for IOS

## Part Three

- Prefer eBGP path over iBGP path
- Path with lowest IGP metric to next-hop
- For eBGP paths:
  - If multipath is enabled, install N parallel paths in forwarding table
  - If router-id is the same, go to next step
  - If router-id is not the same, select the oldest path

# BGP Path Selection Algorithm for IOS

## Part Four

- Lowest router-id (originator-id for reflected routes)
- Shortest cluster-list
  - Client must be aware of Route Reflector attributes!
- Lowest neighbour address



# Applying Policy with BGP

How to use the “tools”

# Applying Policy with BGP

- Policy-based on AS path, community or the prefix
- Rejecting/accepting selected routes
- Set attributes to influence path selection
- Tools:
  - Prefix-list (filters prefixes)
  - Filter-list (filters ASes)
  - Route-maps and communities

# Policy Control – Prefix List

- Per neighbour prefix filter
  - incremental configuration
- Inbound or Outbound
- Based upon network numbers (using familiar IPv4 address/mask format)
- Using access-lists for filtering prefixes was deprecated long ago
  - Strongly discouraged!**

# Prefix-list Command Syntax

- Syntax:

```
[no] ip prefix-list list-name [seq seq-value]  
permit|deny network/len [ge ge-value] [le le-value]
```

*network/len*: The prefix and its length

*ge ge-value*: "greater than or equal to"

*le le-value*: "less than or equal to"

- Both "ge" and "le" are optional

Used to specify the range of the prefix length to be matched for prefixes that are more specific than *network/len*

- Sequence number is also optional

`no ip prefix-list sequence-number` to disable display of sequence numbers

# Prefix Lists – Examples

- Deny default route

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

- Permit the prefix 35.0.0.0/8

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

- Deny the prefix 172.16.0.0/12

```
ip prefix-list EG deny 172.16.0.0/12
```

- In 192/8 allow up to /24

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

This allows all prefix sizes in the 192.0.0.0/8 address block, apart from /25, /26, /27, /28, /29, /30, /31 and /32.



# Prefix Lists – Examples

- In 192/8 deny /25 and above

```
ip prefix-list EG 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 193/8 permit prefixes between /12 and /20

```
ip prefix-list EG permit 193.0.0.0/8 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 EG permit 0.0.0.0/0 le 32
```

0.0.0.0 matches all possible addresses, “0 le 32” matches all possible prefix lengths

# Policy Control – Prefix List

- Example Configuration

```
router bgp 100
  network 105.7.0.0 mask 255.255.0.0
  neighbor 102.10.1.1 remote-as 110
  neighbor 102.10.1.1 prefix-list AS110-IN in
  neighbor 102.10.1.1 prefix-list AS110-OUT out
!
ip prefix-list AS110-IN deny 218.10.0.0/16
ip prefix-list AS110-IN permit 0.0.0.0/0 le 32
ip prefix-list AS110-OUT permit 105.7.0.0/16
ip prefix-list AS110-OUT deny 0.0.0.0/0 le 32
```

# Policy Control – Filter List

- Filter routes based on AS path

Inbound or Outbound

- Example Configuration:

```
router bgp 100
  network 105.7.0.0 mask 255.255.0.0
  neighbor 102.10.1.1 filter-list 5 out
  neighbor 102.10.1.1 filter-list 6 in
!
ip as-path access-list 5 permit ^200$
ip as-path access-list 6 permit ^150$
```

# Policy Control – Regular Expressions

- Like Unix regular expressions

.	Match one character
*	Match any number of preceding expression
+	Match at least one of preceding expression
^	Beginning of line
\$	End of line
\	Escape a regular expression character
_	Beginning, end, white-space, brace
	Or
()	brackets to contain expression
[]	brackets to contain number ranges

# Policy Control – Regular Expressions

- Simple Examples

<code>.*</code>	match anything
<code>.+</code>	match at least one character
<code>^\$</code>	match routes local to this AS
<code>_1800\$</code>	originated by AS1800
<code>^1800_</code>	received from AS1800
<code>_1800_</code>	via AS1800
<code>_790_1800_</code>	via AS1800 and AS790
<code>_(1800_)+</code>	multiple AS1800 in sequence (used to match AS-PATH prepends)
<code>_\\(65530\\)_</code>	via AS65530 (confederations)

# Policy Control – Regular Expressions

- Not so simple Examples

<code>^[0-9]+\$</code>	Match AS_PATH length of one
<code>^[0-9]+_[0-9]+\$</code>	Match AS_PATH length of two
<code>^[0-9]*_[0-9]+\$</code>	Match AS_PATH length of one or two
<code>^[0-9]*_[0-9]*\$</code>	Match AS_PATH length of one or two (will also match zero)
<code>^[0-9]+_[0-9]+_[0-9]+\$</code>	Match AS_PATH length of three
<code>_(701 1800)_</code>	Match anything which has gone through AS701 or AS1800
<code>_1849(_.+_)12163\$</code>	Match anything of origin AS12163 and passed through AS1849

# Policy Control – Route Maps

- A route-map is like a “programme” for IOS
- Has “line” numbers, like programmes
- 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 “continue” lets ISPs apply multiple conditions and actions in one route-map

## Route Maps – Caveats

- Lines can have multiple set statements
- Lines can have multiple match statements
- Line with only a match statement
  - Only prefixes matching go through, the rest are dropped
- Line with only a set statement
  - All prefixes are matched and set
  - Any following lines are ignored
- Line with a match/set statement and no following lines
  - Only prefixes matching are set, the rest are dropped



# Route Maps – Caveats

- Example

Omitting the third line below means that prefixes not matching **list-one** or **list-two** are dropped

```
route-map sample permit 10
  match ip address prefix-list list-one
  set local-preference 120
```

!

```
route-map sample permit 20
  match ip address prefix-list list-two
  set local-preference 80
```

!

```
route-map sample permit 30
```

! Don't forget this

# Route Maps – Matching prefixes

- Example Configuration

```
router bgp 100
  neighbor 1.1.1.1 route-map infilter in
  !
  route-map infilter permit 10
    match ip address prefix-list HIGH-PREF
    set local-preference 120
  !
  route-map infilter permit 20
    match ip address prefix-list LOW-PREF
    set local-preference 80
  !
  ip prefix-list HIGH-PREF permit 10.0.0.0/8
  ip prefix-list LOW-PREF permit 20.0.0.0/8
```

# Route Maps – AS-PATH filtering

- Example Configuration

```
router bgp 100
  neighbor 102.10.1.2 remote-as 200
  neighbor 102.10.1.2 route-map filter-on-as-path in
!
route-map filter-on-as-path permit 10
  match as-path 1
  set local-preference 80
!
route-map filter-on-as-path permit 20
  match as-path 2
  set local-preference 200
!
ip as-path access-list 1 permit _150$
ip as-path access-list 2 permit _210_
```

# Route Maps – AS-PATH prepends

- Example configuration of AS-PATH prepend

```
router bgp 300
  network 105.7.0.0 mask 255.255.0.0
  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 when prepending  
Otherwise BGP loop detection may cause disconnects

# Route Maps – Matching Communities

- Example Configuration

```
router bgp 100
  neighbor 102.10.1.2 remote-as 200
  neighbor 102.10.1.2 route-map filter-on-community in
!
route-map filter-on-community permit 10
  match community 1
  set local-preference 50
!
route-map filter-on-community permit 20
  match community 2 exact-match
  set local-preference 200
!
ip community-list 1 permit 150:3 200:5
ip community-list 2 permit 88:6
```

# Route Maps – Setting Communities

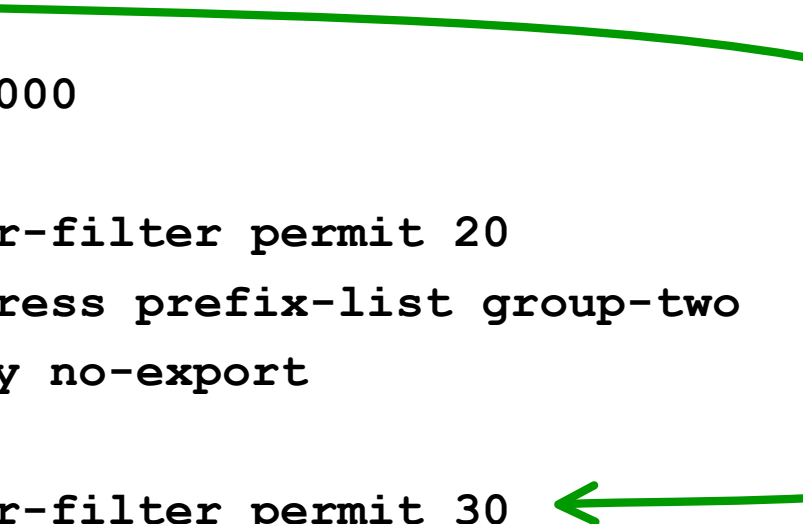
- Example Configuration

```
router bgp 100
  network 105.7.0.0 mask 255.255.0.0
  neighbor 102.10.1.1 remote-as 200
  neighbor 102.10.1.1 send-community
  neighbor 102.10.1.1 route-map set-community out
!
route-map set-community permit 10
  match ip address prefix-list NO-ANNOUNCE
  set community no-export
!
route-map set-community permit 20
  match ip address prefix-list AGGREGATE
!
ip prefix-list NO-ANNOUNCE permit 105.7.0.0/16 ge 17
ip prefix-list AGGREGATE permit 105.7.0.0/16
```

# Route Map Continue

- Handling multiple conditions and actions in one route-map (for BGP neighbour relationships only)

```
route-map peer-filter permit 10
  match ip address prefix-list group-one
  continue 30
  set metric 2000
!
route-map peer-filter permit 20
  match ip address prefix-list group-two
  set community no-export
!
route-map peer-filter permit 30
  match ip address prefix-list group-three
  set as-path prepend 100 100
!
```



# Managing Policy Changes

- New policies only apply to the updates going through the router **AFTER** the policy has been introduced or changed
- To facilitate policy changes on the entire BGP table the router handles the BGP peerings need to be “refreshed”

This is done by clearing the BGP session either in or out, for example:

```
clear ip bgp <neighbour-addr> in|out
```

- Do NOT forget **in** or **out** — doing so results in a hard reset of the BGP session



# Managing Policy Changes

- Ability to clear the BGP sessions of groups of neighbours configured according to several criteria

- **clear ip bgp <addr> [in|out]**

**<addr>** may be any of the following

**x.x.x.x**

IP address of a peer

**\***

all peers

**ASN**

all peers in an AS

**external**

all external peers

**peer-group <name>**

all peers in a peer-group



# BGP Attributes and Policy Control

ISP/IXP Workshops



# Supplementary Materials

# Policy Control – Route Maps

- Route Map MATCH Articles

as-path

clns address

clns next-hop

clns route-source

community

interface

ip address

ip next-hop

ip route-source

length

metric

nlri

route-type

tag

# Policy Control – Route Maps

- Route map SET Articles

as-path

automatic-tag

clns

comm-list

community

dampening

default interface

interface

ip default next-hop

ip next-hop

# Policy Control – Route Maps

- Route map SET Articles

ip precedence

ip qos-group

ip tos

level

local preference

metric

metric-type

next-hop

nlri multicast

nlri unicast

origin

tag

traffic-index

weight

# Aggregation Policies

- Suppress Map

Used to suppress selected more-specific prefixes (e.g. defined through a route-map) in the absence of the **summary-only** keyword.

- Unsuppress Map

Used to unsuppress selected more-specific prefixes per BGP peering when the **summary-only** keyword is in use.

# Aggregation Policies – Suppress Map

- Example

```
router bgp 100
  network 102.10.10.0
  network 102.10.11.0
  network 102.10.12.0
  network 102.10.33.0
  network 102.10.34.0
  aggregate-address 102.10.0.0 255.255.0.0 suppress-map block-net
  neighbor 102.5.7.2 remote-as 200
!
route-map block-net permit 10
  match ip address prefix-list SUPPRESS
!
ip prefix-list SUPPRESS permit 102.10.8.0/21 le 32
ip prefix-list SUPPRESS deny 0.0.0.0/0 le 32
!
```



# Aggregation Policies – Suppress Map

- **show ip bgp** on the local router

```
router1#sh ip bgp
```

```
BGP table version is 11, local router ID is 102.5.7.1
```

```
Status codes: s suppressed, d damped, h history, * valid,  
> best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 102.10.0.0/16	0.0.0.0			32768	i
s> 102.10.10.0	0.0.0.0	0		32768	i
s> 102.10.11.0	0.0.0.0	0		32768	i
s> 102.10.12.0	0.0.0.0	0		32768	i
*> 102.10.33.0	0.0.0.0	0		32768	i
*> 102.10.34.0	0.0.0.0	0		32768	i

# Aggregation Policies – Suppress Map

- `show ip bgp` on the remote router

```
router2#sh ip bgp
```

```
BGP table version is 90, local router ID is 102.5.7.2
```

```
Status codes: s suppressed, d damped, h history, * valid,  
> best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 102.10.0.0/16	102.5.7.1			0 100	i
*> 102.10.33.0	102.5.7.1	0		0 100	i
*> 102.10.34.0	102.5.7.1	0		0 100	i

# Aggregation Policies – Unsuppress Map

- Example

```
router bgp 100
  network 102.10.10.0
  network 102.10.11.0
  network 102.10.12.0
  network 102.10.33.0
  network 102.10.34.0
  aggregate-address 102.10.0.0 255.255.0.0 summary-only
  neighbor 102.5.7.2 remote-as 200
  neighbor 102.5.7.2 unsuppress-map leak-net
!
route-map leak-net permit 10
  match ip address prefix-list LEAK
!
ip prefix-list LEAK permit 102.10.8.0/21 le 32
ip prefix-list LEAK deny 0.0.0.0/0 le 32
```

# Aggregation Policies – Unsuppress Map

- **show ip bgp** on the local router

```
router1#sh ip bgp
```

```
BGP table version is 11, local router ID is 102.5.7.1
```

```
Status codes: s suppressed, d damped, h history, * valid,  
> best, i -internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 102.10.0.0/16	0.0.0.0			32768	i
s> 102.10.10.0	0.0.0.0	0		32768	i
s> 102.10.11.0	0.0.0.0	0		32768	i
s> 102.10.12.0	0.0.0.0	0		32768	i
s> 102.10.33.0	0.0.0.0	0		32768	i
s> 102.10.34.0	0.0.0.0	0		32768	i

# Aggregation Policies – Unsuppress Map

- **show ip bgp** on the remote router

```
router2#sh ip bgp
```

```
BGP table version is 90, local router ID is 102.5.7.2
```

```
Status codes: s suppressed, d damped, h history, * valid,  
> best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 102.10.0.0/16	102.5.7.1			0 100	i
*> 102.10.10.0	102.5.7.1	0		0 100	i
*> 102.10.11.0	102.5.7.1	0		0 100	i
*> 102.10.12.0	102.5.7.1	0		0 100	i

# Aggregation Policies – Aggregate Address

- Summary-only used
  - all subprefixes suppressed
  - unsuppress-map to selectively leak subprefixes
  - bgp per neighbour configuration
- Absence of summary-only
  - no subprefixes suppressed
  - suppress-map to selectively suppress subprefixes
  - bgp global configuration