Introduction to BGP

ISP/IXP Workshops

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Acknowledgements

- This material originated from the Cisco ISP/IXP Workshop Programme developed by Philip Smith & Barry Greene

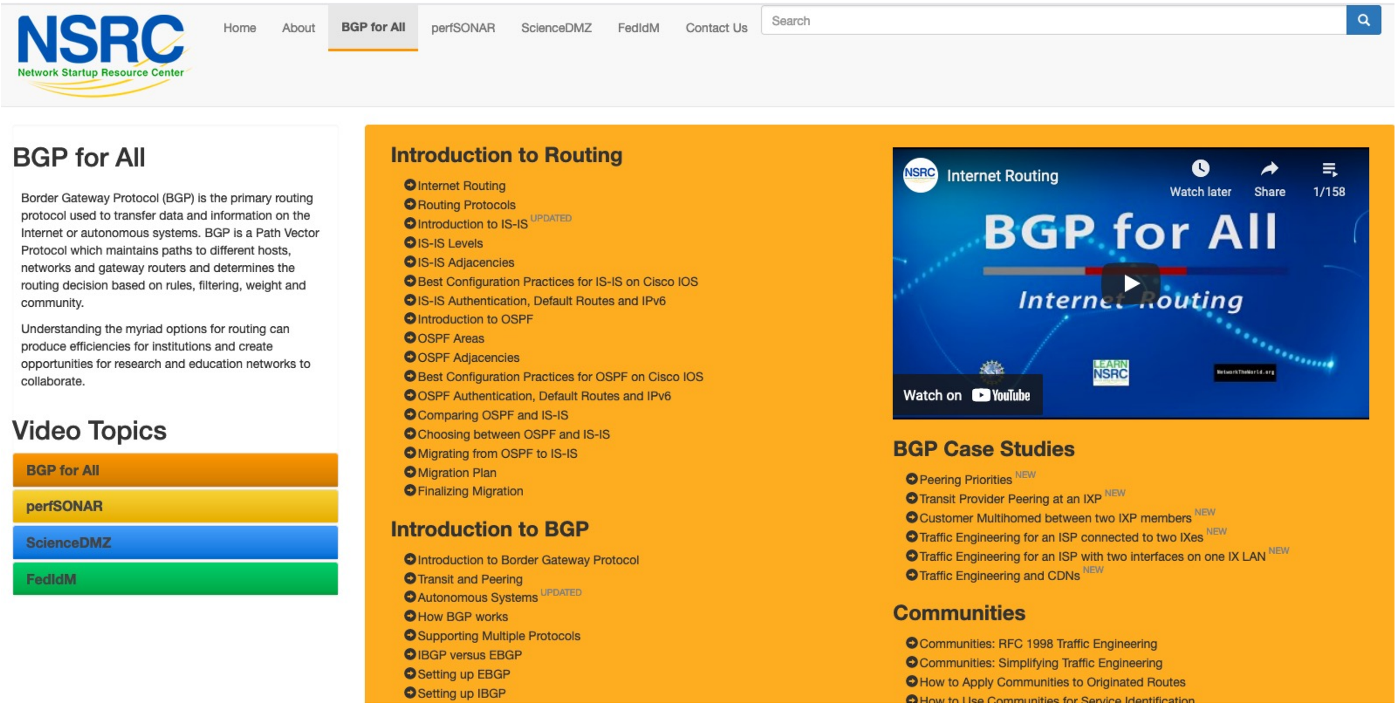
- Use of these materials is encouraged as long as the source is fully acknowledged and this notice remains in place

- Bug fixes and improvements are welcomed
  - Please email *workshop (at) bgp4all.com*

Philip Smith

BGP Videos

- NSRC has made a video recording of this presentation, as part of a library of BGP videos for the whole community to use:
  - https://learn.nsrc.org/bgp#intro_to_bgp



Border Gateway Protocol

- A Routing Protocol used to exchange routing information between different networks
  - Exterior gateway protocol
- Described in RFC4271
  - RFC4276 gives an implementation report on BGP
  - RFC4277 describes operational experiences using BGP
- The Autonomous System is the cornerstone of BGP
  - It is used to uniquely identify networks with a common routing policy

BGP

- Path Vector Protocol
- Incremental Updates
- Many options for policy enforcement
- Classless Inter Domain Routing (CIDR)
- Widely used for Internet backbone
- Autonomous systems

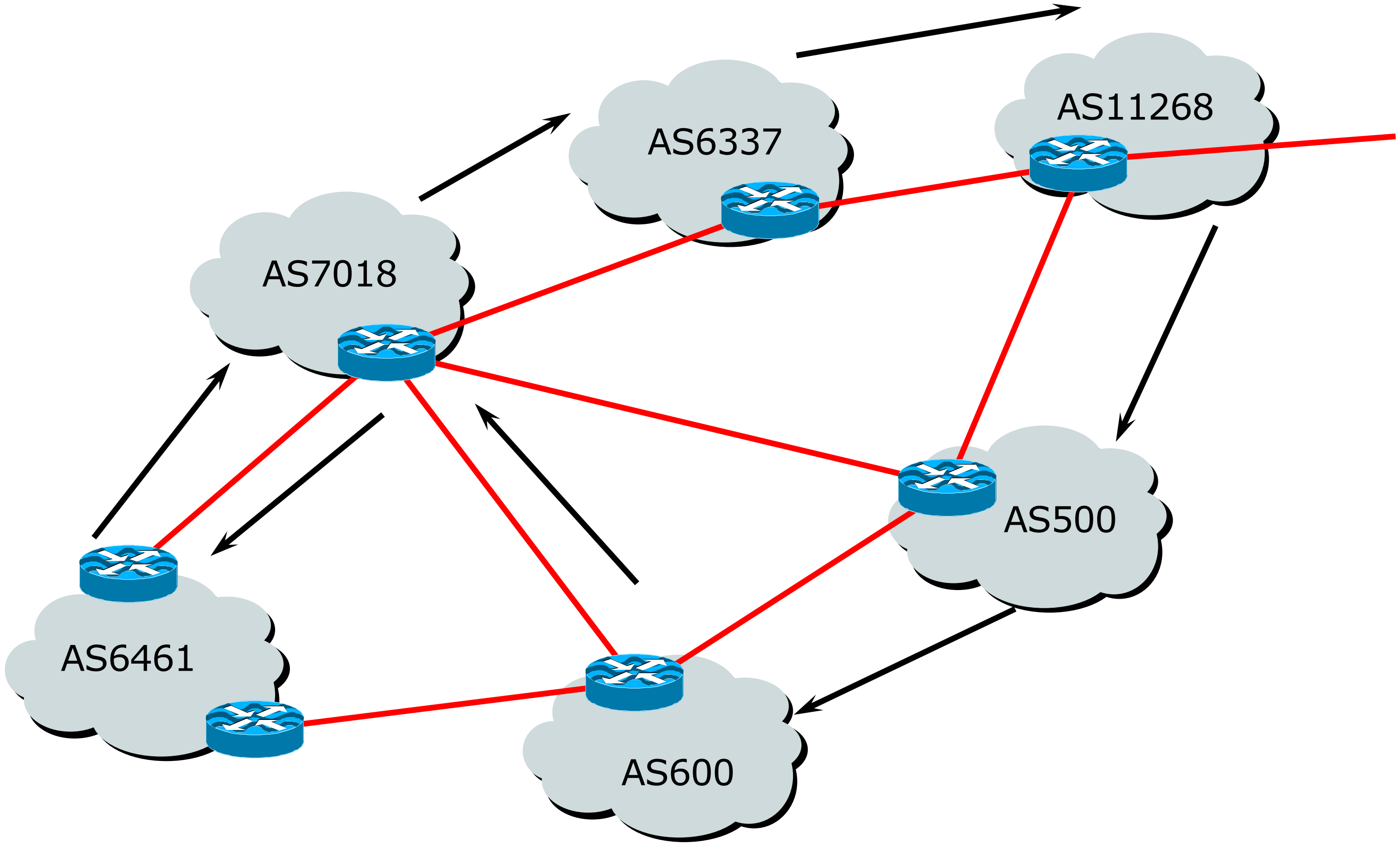
Path Vector Protocol

- BGP is classified as a *path vector* routing protocol (see RFC 1322)
  - A path vector protocol defines a route as a pairing between a destination and the attributes of the path to that destination.

```
12.6.126.0/24   207.126.96.43    1021   0     6461 7018 6337 11268  i
```

AS Path

Path Vector Protocol



Definitions

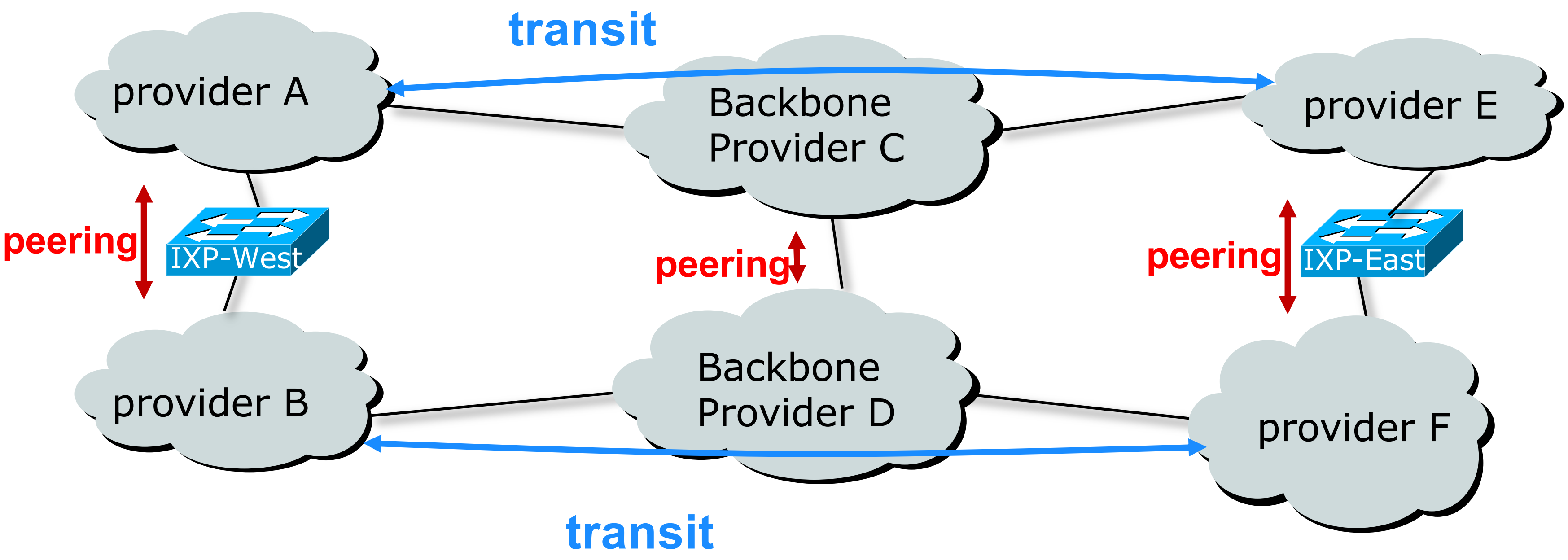
- Transit – carrying traffic across a network
  - (Commercially: for a fee)
- Peering – exchanging routing information and traffic
  - (Commercially: between similar sized networks, and for no fee)
- Default – where to send traffic when there is no explicit match in the routing table

Default Free Zone

The default free zone is made up of Internet routers which have routing information about the whole Internet, and therefore do not need to use a default route

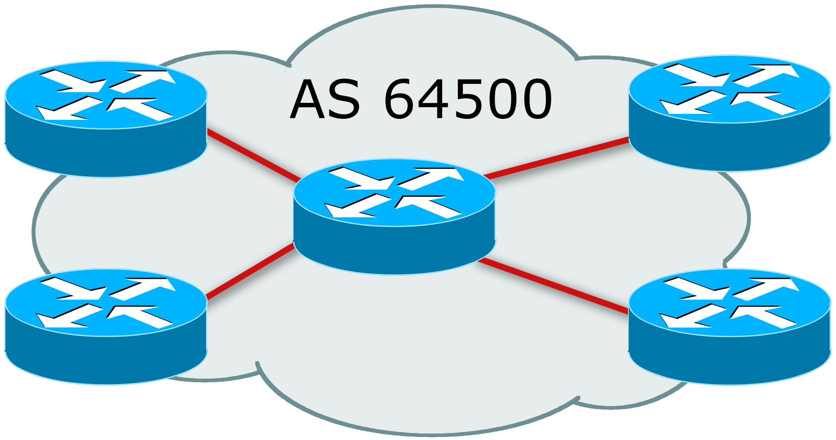
NB: is not related to where a network operator is in the hierarchy

Peering and Transit example



A and B peer for free, but need transit arrangements with C and D to get packets to/from E and F

Autonomous System (AS)



- Collection of networks with same routing policy
- Single routing protocol
- Usually under single ownership, trust and administrative control
- Identified by a unique 32-bit integer (ASN)

Autonomous System Number

Range:	
0-4294967295	(32-bit range – RFC6793)
	(0-65535 was original 16-bit range)
Usage:	
0 and 65535	(IANA Reserved)
1-64495	(public Internet)
64496-64511	(documentation – RFC5398)
64512-65534	(private use only)
23456	(represent 32-bit range in 16-bit world)
65536-65551	(documentation – RFC5398)
65552-131071	(IANA Reserved)
131072-458751	(public Internet)
458752-4199999999	(IANA Reserved/Unallocated)
4200000000-4294967294	(private use only – RFC6996)
4294967295	(IANA Reserved – RFC7300)

- 32-bit range representation specified in RFC5396
  - Defines “asplain” (traditional format) as standard notation

Autonomous System Number (ASN)

- ASNs are distributed by the Regional Internet Registries
  - They are also available from upstream ISPs who are members of one of the RIRs
- The entire 16-bit ASN pool has been assigned to the RIRs
  - Around 39400 16-bit ASNs are visible on the Internet
    - (this number is dropping slightly as 32-bit ASN announcements increase)
- Each RIR has also received a block of 32-bit ASNs
  - Out of 44500 assignments, around 36500 are visible on the Internet (May 2024)
- See www.iana.org/assignments/as-numbers

Configuring BGP in Cisco IOS

- This command enables BGP in Cisco IOS:

```
router bgp 64500
```

- For ASNs > 65535, the AS number can be entered in either plain or dot notation:

```
router bgp 131076
```

  - Or

```
router bgp 2.4
```

- IOS displays ASNs in plain notation by default
  - Dot notation is optional (and NOT recommended):

```
router bgp 2.4
 bgp asnotation dot
```

Configuring BGP in JunOS

- This command sets the local autonomous system number

```
set routing-options autonomous-system 131076
```

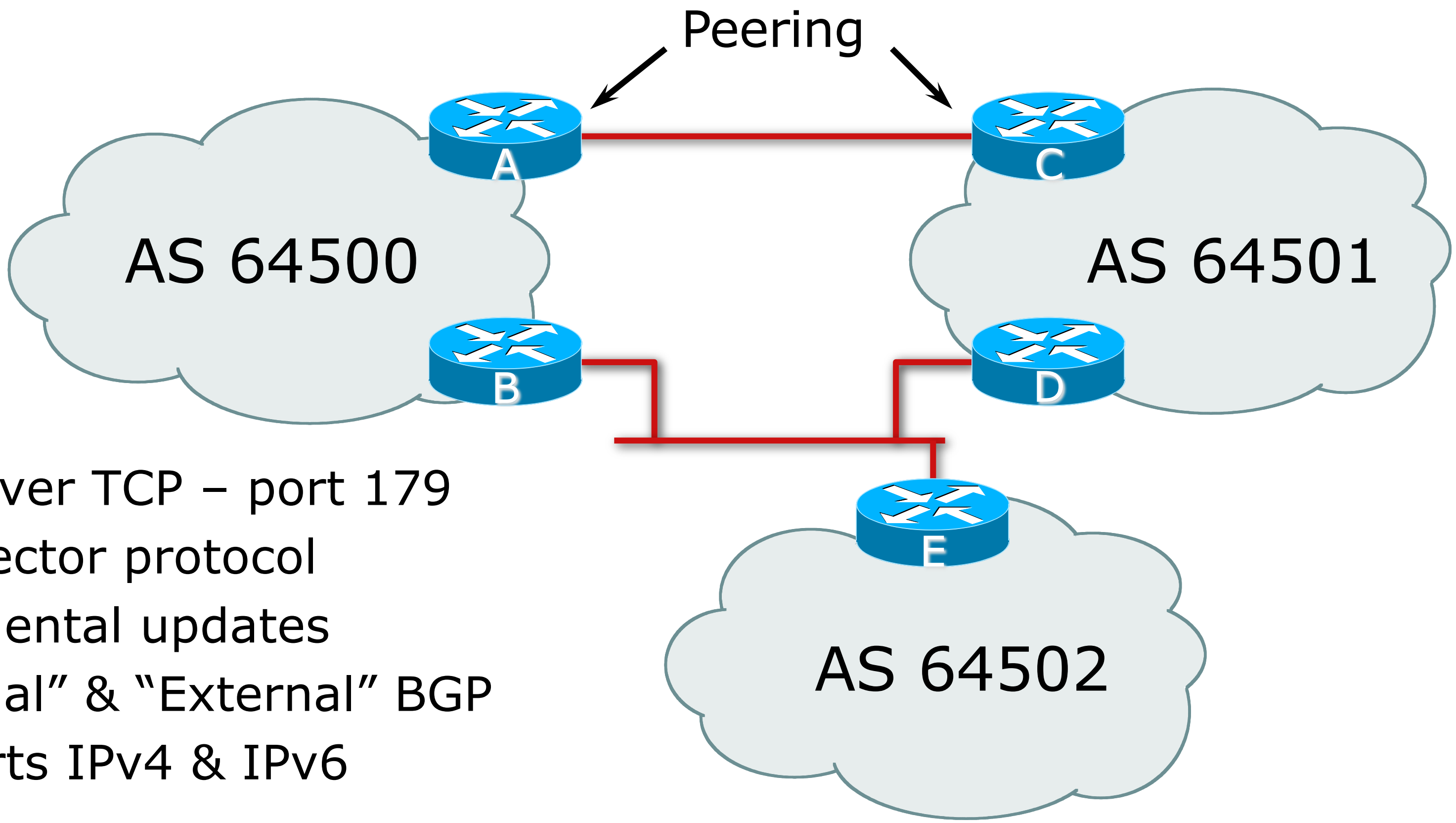
- All BGP configuration is then carried out under:

```
edit protocols bgp
```

- JunOS displays ASNs in plain notation by default
  - Dot notation is optional (and NOT recommended):

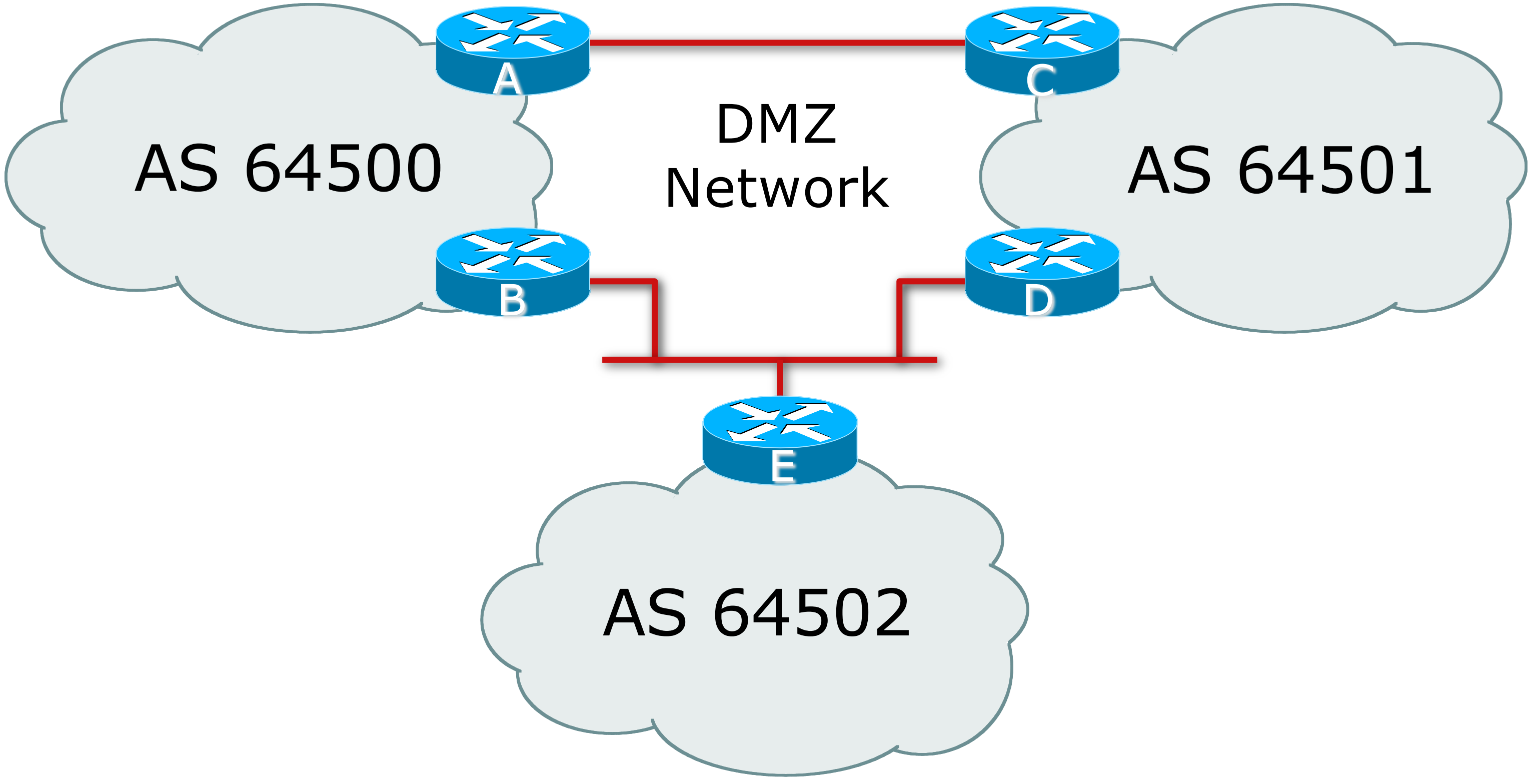
```
set routing-options autonomous-system asdot-notation 2.4
```

BGP Basics



- Runs over TCP – port 179
- Path vector protocol
- Incremental updates
- “Internal” & “External” BGP
- Supports IPv4 & IPv6

Demarcation Zone (DMZ)



- DMZ is the link or network shared between ASes

BGP General Operation

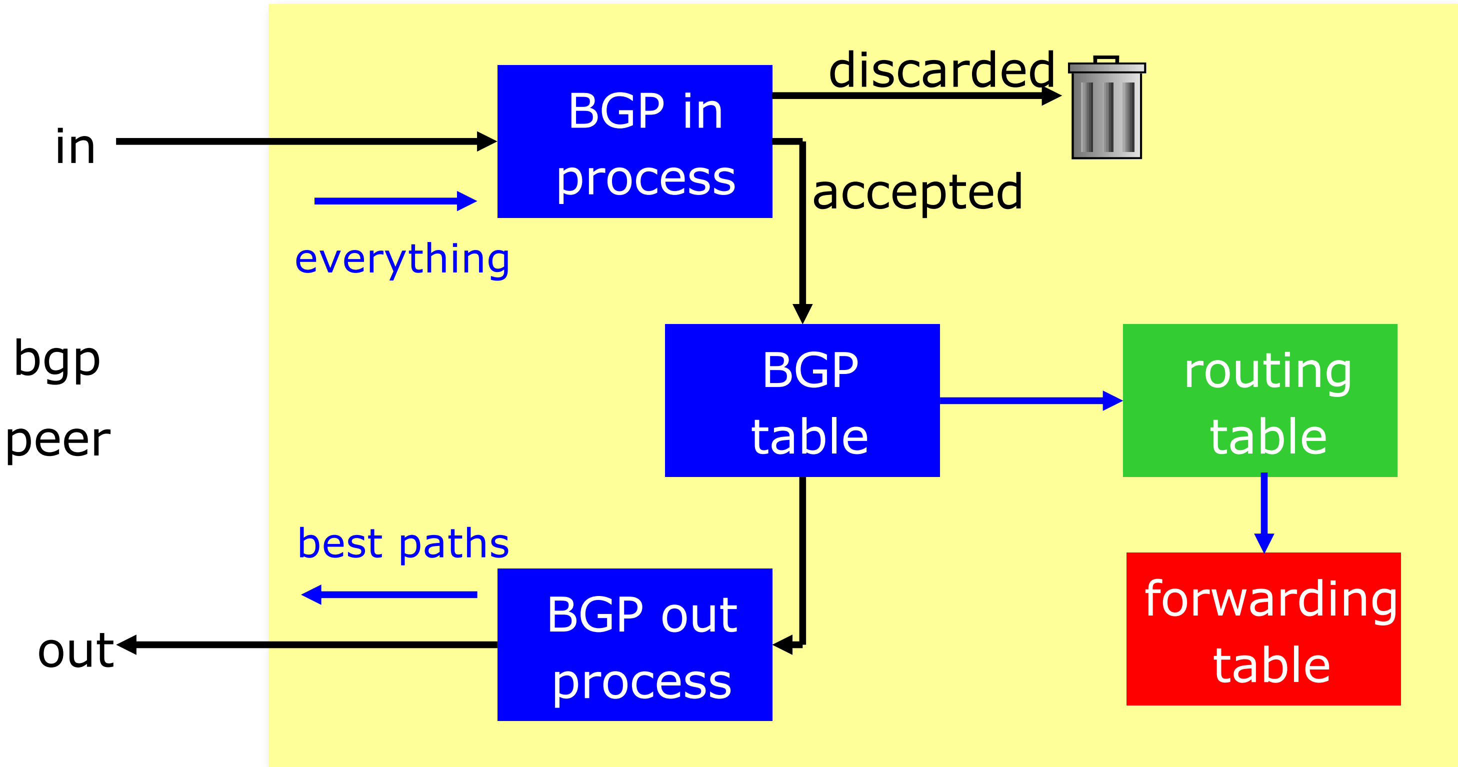
- Learns multiple paths via internal and external BGP speakers
- Picks the best path and installs it in the routing table (RIB)
- Best path is sent to external BGP neighbours
- Policies are applied by influencing the best path selection

Constructing the Forwarding Table

- BGP "in" process
  - Receives path information from peers
  - Results of BGP path selection placed in the BGP table
  - "best path" flagged
- BGP "out" process
  - Announces "best path" information to peers
- Best path stored in Routing Table (RIB) if:
  - Prefix and prefix length are unique (after best path selection)

    and
  - Lowest "protocol distance"
- Best paths in the RIB are installed in forwarding table (FIB)

Constructing the Forwarding Table



Supporting Multiple Protocols

- RFC4760
  - Defines Multi-protocol Extensions for BGP4
  - Enables BGP to carry routing information of protocols other than IPv4
    - e.g. MPLS, IPv6, Multicast etc
  - Exchange of multiprotocol NLRI must be negotiated at session startup
- RFC2545
  - Use of BGP Multiprotocol Extensions for IPv6 Inter-Domain Routing
  - Address family for IPv6

Supporting Multiple Protocols

- Independent operation
  - One RIB per protocol
    - IPv6 routes in BGP’s IPv6 RIB
    - IPv4 routes in BGP’s IPv4 RIB
  - Each protocol can have its own policies
- NEXTHOP
  - The IP address of the next router must belong to the same address family as that of the local router

Supporting Multiple Protocols

- Cisco IOS assumes that all BGP neighbours will exchange IPv4 unicast prefixes
  - Most other implementations do not
  - We need to remove this assumption in Cisco IOS

```
router bgp 64500
 no bgp default ipv4-unicast
```

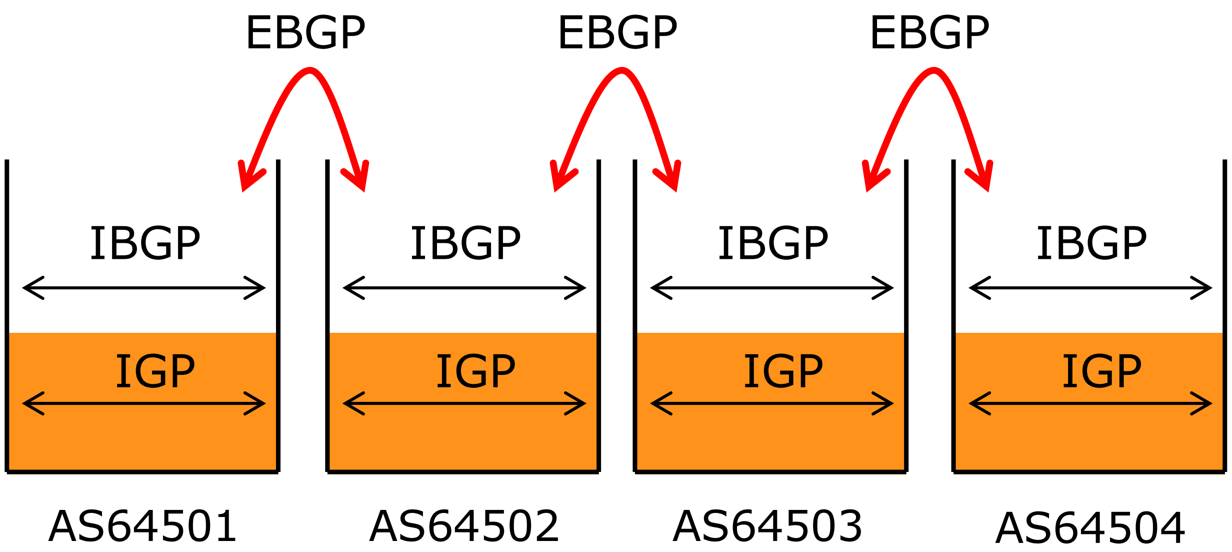
- For operational simplicity, the desire is for:
  - IPv4 neighbours to exchange IPv4 unicast prefixes
  - IPv6 neighbours to exchange IPv6 unicast prefixes
- Failure to do this results in:
  - IPv6 neighbours appearing to be set up to exchange IPv4 unicast prefixes
  - Cluttered configuration
  - Confusing troubleshooting and diagnosis

EBGP & IBGP

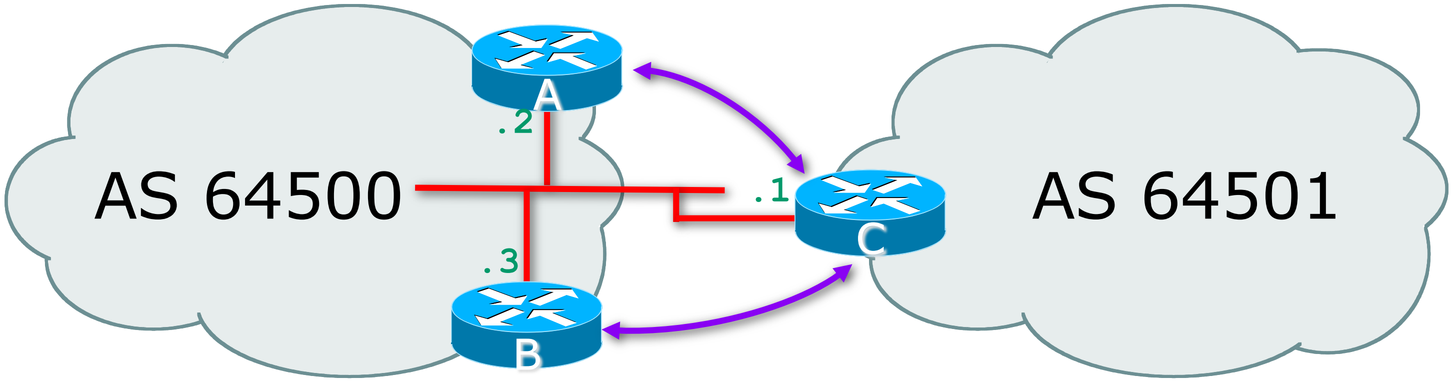
- BGP is used
  - Internally (IBGP)
  - Externally (EBGP)
- IBGP used to carry
  - Some/all Internet prefixes across network operator backbone
  - ISP's customer prefixes
- EBGP used to
  - Exchange prefixes with other ASes
  - Implement routing policy

BGP/IGP model used in service provider networks

- Model representation



External BGP Peering (EBGP)



- Between BGP speakers in different AS
- Should be directly connected
- **Never** run an IGP between EBGP peers

Configuring External BGP

- Router A in AS64500

```
interface FastEthernet 5/0
 ip address 102.102.10.2 255.255.255.240
!
router bgp 64500
 address-family ipv4
  network 100.100.8.0 mask 255.255.252.0
  neighbor 102.102.10.1 remote-as 64501
  neighbor 102.102.10.1 prefix-list RouterC-in in
  neighbor 102.102.10.1 prefix-list RouterC-out out
  neighbor 102.102.10.1 activate
!
```

- ip address on ethernet interface
- Local ASN
- Select IPv4 or IPv6
- Remote ASN
- Inbound and outbound filters
- ip address of Router C ethernet interface

Configuring External BGP

- Router C in AS64501

```
interface FastEthernet 1/0
 ip address 102.102.10.1 255.255.255.240
!
router bgp 64501
 address-family ipv4
  network 100.100.64.0 mask 255.255.248.0
  neighbor 102.102.10.2 remote-as 64500
  neighbor 102.102.10.2 prefix-list RouterA-in in
  neighbor 102.102.10.2 prefix-list RouterA-out out
  neighbor 102.102.10.2 activate
!
```

ip address on ethernet interface

Local ASN

Select IPv4 or IPv6

Remote ASN

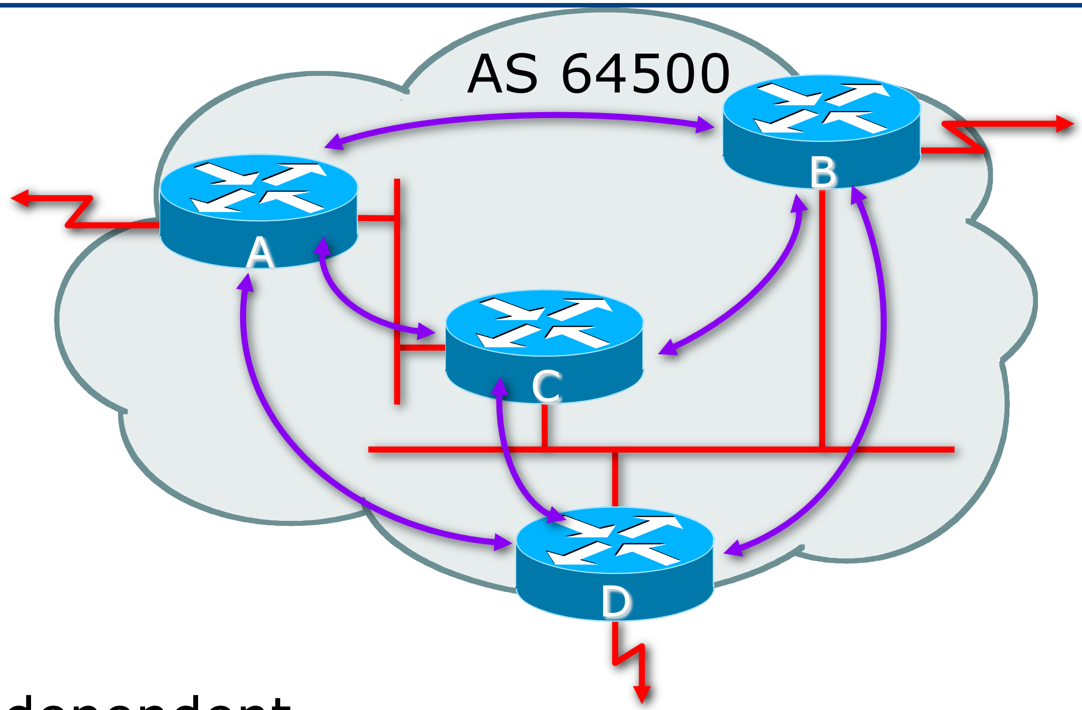
Inbound and outbound filters

ip address of Router A ethernet interface

Internal BGP (IBGP)

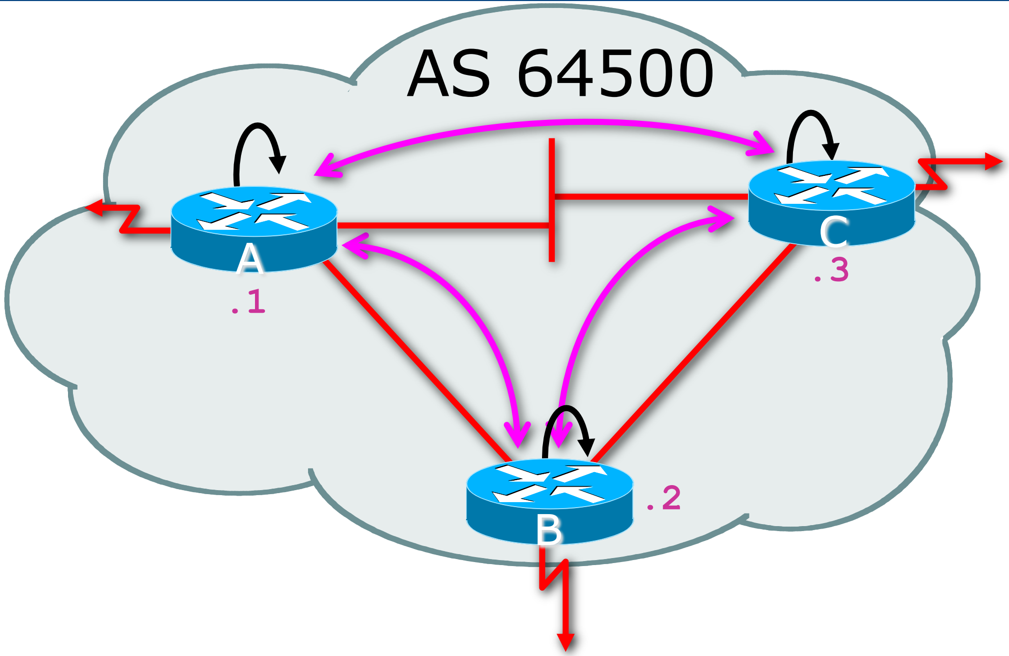
- BGP peer within the same AS
- Not required to be directly connected
  - IGP takes care of inter-BGP speaker connectivity
- IBGP speakers must be fully meshed:
  - They originate connected networks
  - They pass on prefixes learned from outside the AS
  - They do not pass on prefixes learned from other IBGP speakers

Internal BGP Peering (IBGP)



- Topology independent
- Each IBGP speaker must peer with every other IBGP speaker in the AS as per ⟷

Peering between Loopback Interfaces



- Peer with loop-back interface
  - Loop-back interface does not go down – ever!
- Do not want IBGP session to depend on state of a single interface or the physical topology

Configuring Internal BGP

- Router A in AS64500

```
interface loopback 0
 ip address 105.3.7.1 255.255.255.255
!
router bgp 64500
 address-family ipv4
  network 100.100.1.0 mask 255.255.255.0
  neighbor 105.3.7.2 remote-as 64500
  neighbor 105.3.7.2 update-source loopback0
  neighbor 105.3.7.2 activate
  neighbor 105.3.7.3 remote-as 64500
  neighbor 105.3.7.3 update-source loopback0
  neighbor 105.3.7.3 activate
!
```

ip address on loopback interface

Local ASN

Local ASN

ip address of Router B loopback interface

Configuring Internal BGP

- Router B in AS64500

```
interface loopback 0
 ip address 105.3.7.2 255.255.255.255
!
router bgp 64500
 address-family ipv4
  network 100.100.1.0 mask 255.255.255.0
  neighbor 105.3.7.1 remote-as 64500
  neighbor 105.3.7.1 update-source loopback0
  neighbor 105.3.7.1 activate
  neighbor 105.3.7.3 remote-as 64500
  neighbor 105.3.7.3 update-source loopback0
  neighbor 105.3.7.3 activate
!
```

ip address on loopback interface

Local ASN

Local ASN

ip address of Router A loopback interface

Inserting prefixes into BGP

- Two ways to insert prefixes into BGP
  - **redistribute static**
  - **network** command

Inserting prefixes into BGP – redistribute static

- Configuration Example:

```
router bgp 64500
 address-family ipv4
  redistribute static
ip route 100.64.32.0 255.255.254.0 serial0
```

- Static route must exist before redistribute command will work
- Forces origin to be “incomplete”
- Care required!

Inserting prefixes into BGP – redistribute static

- Care required with redistribute!
  - `redistribute` ***`routing-protocol`*** means everything in the named *routing-protocol* will be transferred into the current routing protocol
  - Will not scale if uncontrolled
  - Best avoided if at all possible
  - `redistribute` normally used with route-maps and under tight administrative control

Inserting prefixes into BGP – network command

- Configuration Example

```
router bgp 64500
 address-family ipv4
  network 100.64.32.0 mask 255.255.254.0
ip route 100.64.32.0 255.255.254.0 serial0
```

- A matching route must exist in the routing table before the network is announced
- Forces origin to be “IGP”

Configuring Aggregation

- Three ways to configure route aggregation
  - **`redistribute static`**
  - **`aggregate-address`**
  - **`network`** command

Configuring Aggregation – Redistributing Static

- Configuration Example:

```
router bgp 64500
 address-family ipv4
  redistribute static
ip route 100.64.0.0 255.255.0.0 null0
```

- Static route to "null0" is called a pull up route
  - Packets only sent here if there is no more specific match in the routing table
  - Care required – see previously!

Configuring Aggregation – Network Command

- Configuration Example

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.0.0
ip route 100.64.0.0 255.255.0.0 null0
```

- A matching route must exist in the routing table before the network is announced
- Easiest and best way of generating an aggregate

Configuring Aggregation – aggregate-address command

- Configuration Example:

```
router bgp 64500
 address-family ipv4
  network 100.64.32.0 mask 255.255.252.0
  aggregate-address 100.64.0.0 255.255.0.0 [summary-only]
!
ip route 100.64.32.0 255.255.252.0 null 0
```

- Requires more specific prefix in BGP table before aggregate is announced
- `summary-only` keyword
  - Optional keyword which ensures that only the summary is announced (the more specific routes are suppressed)

Summary
BGP neighbour status (Cisco IOS IPv4)

```
Router6>show ip bgp summary
BGP router identifier 10.0.15.246, local AS number 10
BGP table version is 16, main routing table version 16
7 network entries using 819 bytes of memory
14 path entries using 728 bytes of memory
2/1 BGP path/bestpath attribute entries using 248 bytes of memory
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP using 1795 total bytes of memory
BGP activity 7/0 prefixes, 14/0 paths, scan interval 60 secs

Neighbor        V    AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
10.0.15.241     4    10       9       8       16    0    0 00:04:47        2
10.0.15.242     4    10       6       5       16    0    0 00:01:43        2
10.0.15.243     4    10       9       8       16    0    0 00:04:49        2
...
```

BGP Version

Updates sent and received

Updates waiting

Summary
BGP neighbour status (Cisco IOS IPv6)

```
Router1>sh bgp ipv6 unicast summary
BGP router identifier 10.10.15.224, local AS number 10
BGP table version is 28, main routing table version 28
18 network entries using 2880 bytes of memory
38 path entries using 3040 bytes of memory
9/6 BGP path/bestpath attribute entries using 1152 bytes of memory
4 BGP AS-PATH entries using 96 bytes of memory
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP using 7168 total bytes of memory
BGP activity 37/1 prefixes, 95/19 paths, scan interval 60 secs

Neighbor        V    AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
2001:DB8::2     4    10     185     182       28    0    0 02:36:11       16
2001:DB8::3     4    10     180     181       28    0    0 02:36:08       11
2001:DB8:0:4::1 4    40     153     152       28    0    0 02:05:39        9
```

↑ Neighbour Information ↑ BGP Messages Activity

Summary
BGP neighbour status (JunOS)

```
philip@R6> show bgp summary
Groups: 1 Peers: 14 Down peers: 0
Table          Tot Paths  Act Paths Suppressed    History Damp State    Pending
inet.0                20         20          0          0          0          0
inet6.0               20         20          0          0          0          0

Peer             AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn  State|#Active/Received/Accepted/Damped..
10.0.15.241      10    1067980     202487       0       0 9w1d 4:32:05 Establ   inet.0: 10/10/10/0
10.0.15.242      10     204577    1001705       0       0 9w1d 4:32:09 Establ   inet.0: 3/3/3/0
10.0.15.243      10     277630    1886656       0       0 9w1d 4:32:06 Establ   inet.0: 4/4/4/0
...
2001:DB8::1      10     416832     202568       0       0 9w1d 4:30:46 Establ   inet6.0: 10/10/10/0
2001:DB8::2      10     204605     411166       0       0 9w1d 4:34:47 Establ   inet6.0: 3/3/3/0
2001:DB8::3      10     277568     729073       0       0 9w1d 1:03:31 Establ   inet6.0: 2/2/2/0
...
```

AS Number

Updates sent and received

Updates waiting

Address Family

Summary
BGP Table (Cisco IOS IPv4)

```
Router6>sh ip bgp
BGP table version is 18, 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, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>i 10.0.0.0/26      10.0.15.241              0    100      0 i
 *>i 10.0.0.64/26     10.0.15.242              0    100      0 i
 *>i 10.0.0.128/26    10.0.15.243              0    100      0 i
 *>i 10.0.0.192/26    10.0.15.244              0    100      0 i
 *>i 10.0.1.0/26      10.0.15.245              0    100      0 i
 *>  10.0.1.64/26     0.0.0.0                  0         32768 i
 *>i 10.0.1.128/26    10.0.15.247              0    100      0 i
 *>i 10.0.1.192/26    10.0.15.248              0    100      0 i
 *>i 10.0.2.0/26      10.0.15.249              0    100      0 i
 *>i 10.0.2.64/26     10.0.15.250              0    100      0 i
 *>i 10.0.2.128/26    10.0.15.251              0    100      0 i
 *>i 10.0.2.192/26    10.0.15.252              0    100      0 i
 *>i 10.0.3.0/26      10.0.15.253              0    100      0 i
 *>i 10.0.3.64/26     10.0.15.254              0    100      0 i
```

Summary
BGP Table (Cisco IOS IPv6)

```
Router6>sh bgp ipv6 unicast
BGP table version is 18, 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, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop                 Metric LocPrf Weight Path
 *>i 2001:DB8:1::/48  2001:DB8::1                   0    100      0 i
 *>i 2001:DB8:2::/48  2001:DB8::2                   0    100      0 i
 *>i 2001:DB8:3::/48  2001:DB8::3                   0    100      0 i
 *>i 2001:DB8:4::/48  2001:DB8::4                   0    100      0 i
 *>i 2001:DB8:5::/48  2001:DB8::5                   0    100      0 i
 *>  2001:DB8:6::/48  ::                            0         32768 i
 *>i 2001:DB8:7::/48  2001:DB8::7                   0    100      0 i
 *>i 2001:DB8:8::/48  2001:DB8::8                   0    100      0 i
 *>i 2001:DB8:9::/48  2001:DB8::9                   0    100      0 i
 *>i 2001:DB8:A::/48  2001:DB8::A                   0    100      0 i
 *>i 2001:DB8:B::/48  2001:DB8::B                   0    100      0 i
 *>i 2001:DB8:C::/48  2001:DB8::C                   0    100      0 i
 *>i 2001:DB8:D::/48  2001:DB8::D                   0    100      0 i
 *>i 2001:DB8:E::/48  2001:DB8::E                   0    100      0 i
```

Summary
BGP Table (JunOS)

```
philip@R6> show route protocol bgp terse

inet.0: 14 destinations, 14 routes (14 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

A V Destination        P Prf   Metric 1   Metric 2  Next hop        AS path
  ? 10.0.0.0/26        B 100                                        I
  unverified                              >10.0.15.241
  ? 10.0.0.64/26       B 100                                        I
  unverified                              >10.0.15.241
...
  ? 10.1.0.0/24        B 100                                        20 I
  unverified                              >10.0.15.242
  ? 10.4.0.0/24        B 100                                        20 I
  unverified                              >10.0.15.241
...
inet6.0: 14 destinations, 14 routes (14 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

A V Destination        P Prf   Metric 1   Metric 2  Next hop        AS path
  ? 2001:DB8:1::/48    B 100                                        I
  unverified                              >fe80::82ac:acff:fed2:ea88
  ? 2001:DB8:2::/48    B 100                                        I
  unverified                              >fe80::82ac:acff:fed2:ea88
...
  ? 2001:DB9::/32      B 100                                        20 I
  unverified                              >fe80::224e:71ff:fe90:2500
  ? 2001:DB9::/32      B 100                                        20 I
  unverified                              >fe80::82ac:acff:fed2:ea88
...
```

Summary

- BGP – path vector protocol
- Multi-protocol (IPv4 & IPv6)
- IBGP versus EBGP
- Stable IBGP – peer with loopbacks
- Announcing prefixes & aggregates

Introduction to BGP

ISP/IXP Workshops