

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

The screenshot displays the NSRC (Network Startup Resource Center) website. The header includes the NSRC logo, navigation links (Home, About, BGP for All, perfSONAR, ScienceDMZ, FedIdM, Contact Us), and a search bar. The main content area is divided into three columns. The left column features the 'BGP for All' title, a descriptive paragraph about BGP, and a 'Video Topics' section with color-coded buttons for BGP for All, perfSONAR, ScienceDMZ, and FedIdM. The middle column, titled 'Introduction to Routing', lists various topics such as Internet Routing, Routing Protocols, and IS-IS Levels. The right column features a large video player for 'BGP for All' with a play button and a 'Watch on YouTube' link. Below the video player, there are sections for 'BGP Case Studies' and 'Communities'.

NSRC Network Startup Resource Center

Home About **BGP for All** perfSONAR ScienceDMZ FedIdM Contact Us Search

BGP for All

Border Gateway Protocol (BGP) is the primary routing protocol used to transfer data and information on the Internet or autonomous systems. BGP is a Path Vector Protocol which maintains paths to different hosts, networks and gateway routers and determines the routing decision based on rules, filtering, weight and community.

Understanding the myriad options for routing can produce efficiencies for institutions and create opportunities for research and education networks to collaborate.

Video Topics

- BGP for All
- perfSONAR
- ScienceDMZ
- FedIdM

Introduction to Routing

- Internet Routing
- Routing Protocols
- Introduction to IS-IS UPDATED
- IS-IS Levels
- IS-IS Adjacencies
- Best Configuration Practices for IS-IS on Cisco IOS
- IS-IS Authentication, Default Routes and IPv6
- Introduction to OSPF
- OSPF Areas
- OSPF Adjacencies
- Best Configuration Practices for OSPF on Cisco IOS
- OSPF Authentication, Default Routes and IPv6
- Comparing OSPF and IS-IS
- Choosing between OSPF and IS-IS
- Migrating from OSPF to IS-IS
- Migration Plan
- Finalizing Migration

Introduction to BGP

- Introduction to Border Gateway Protocol
- Transit and Peering
- Autonomous Systems UPDATED
- How BGP works
- Supporting Multiple Protocols
- IBGP versus EBG
- Setting up EBG
- Setting up IBGP

BGP Case Studies

- Peering Priorities NEW
- Transit Provider Peering at an IXP NEW
- Customer Multihomed between two IXP members NEW
- Traffic Engineering for an ISP connected to two IXes NEW
- Traffic Engineering for an ISP with two interfaces on one IX LAN NEW
- Traffic Engineering and CDNs NEW

Communities

- Communities: RFC 1998 Traffic Engineering
- Communities: Simplifying Traffic Engineering
- How to Apply Communities to Originated Routes
- How to Use Communities for Service Identification

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

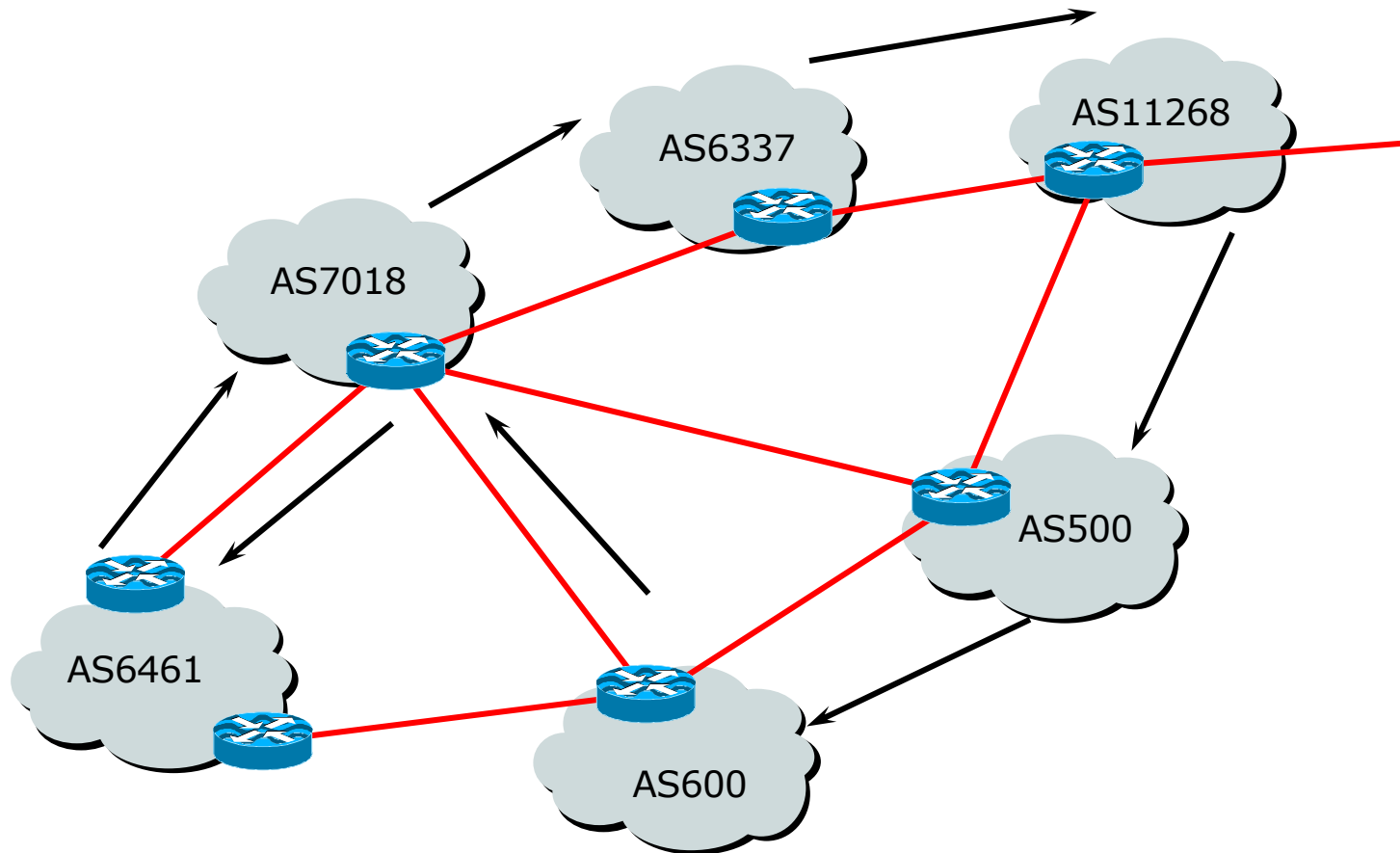
Path Vector Protocol

- 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

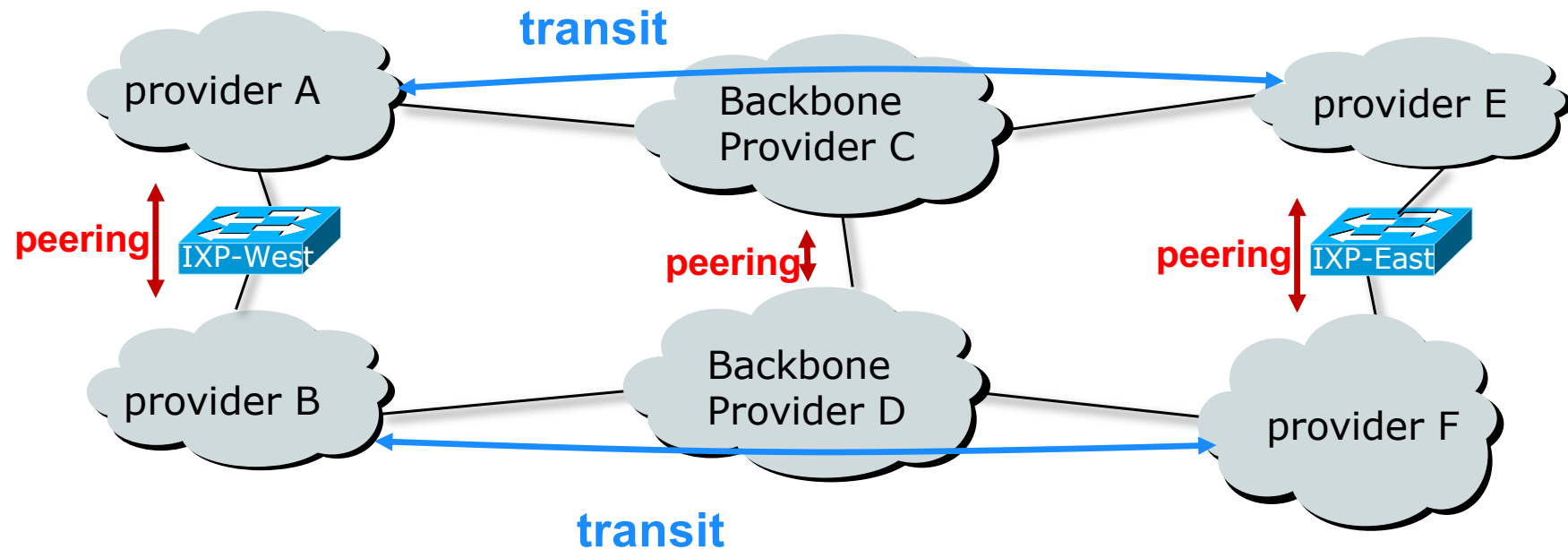
- **Transit** – carrying traffic across a network
 - (Commercially: for a fee)
- **Peering** – exchanging routing information and traffic
 - (Commercially: between similar sized networks, and for no fee)
- **Default** – where to send traffic when there is no explicit match in the routing table

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

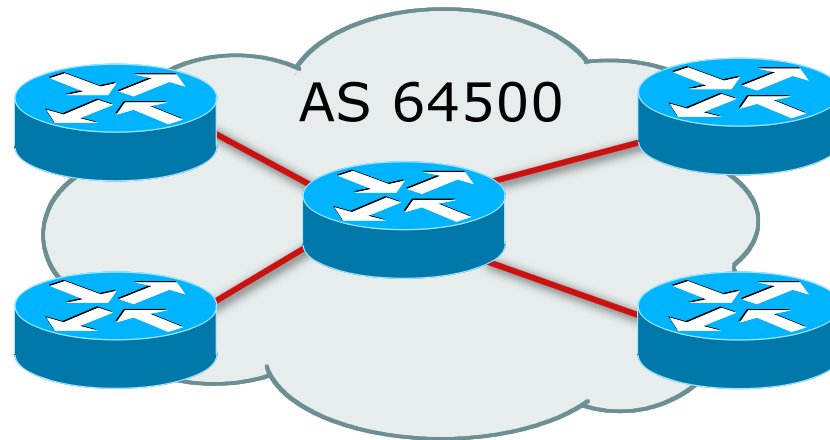
NB: is not related to where a network operator is in the hierarchy

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 38400 16-bit ASNs are visible on the Internet
 - (this number is dropping as 32-bit ASN announcements increase)
- Each RIR has also received a block of 32-bit ASNs
 - Out of 47100 assignments, around 38700 are visible on the Internet (August 2025)
- 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:

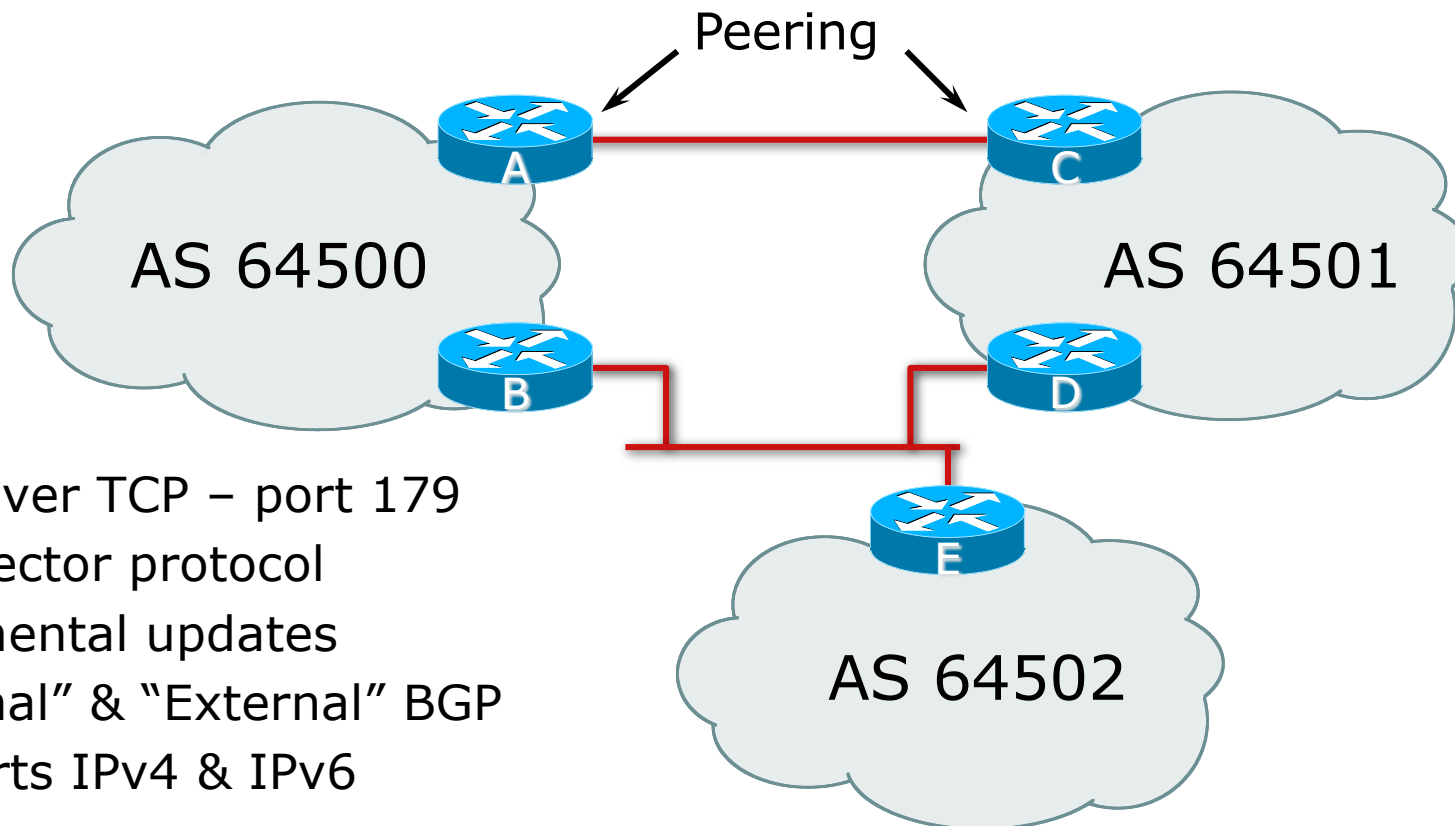
```
edit protocols bgp
```

- JunOS displays ASNs in plain notation by default

- Dot notation is optional (and **NOT** recommended):

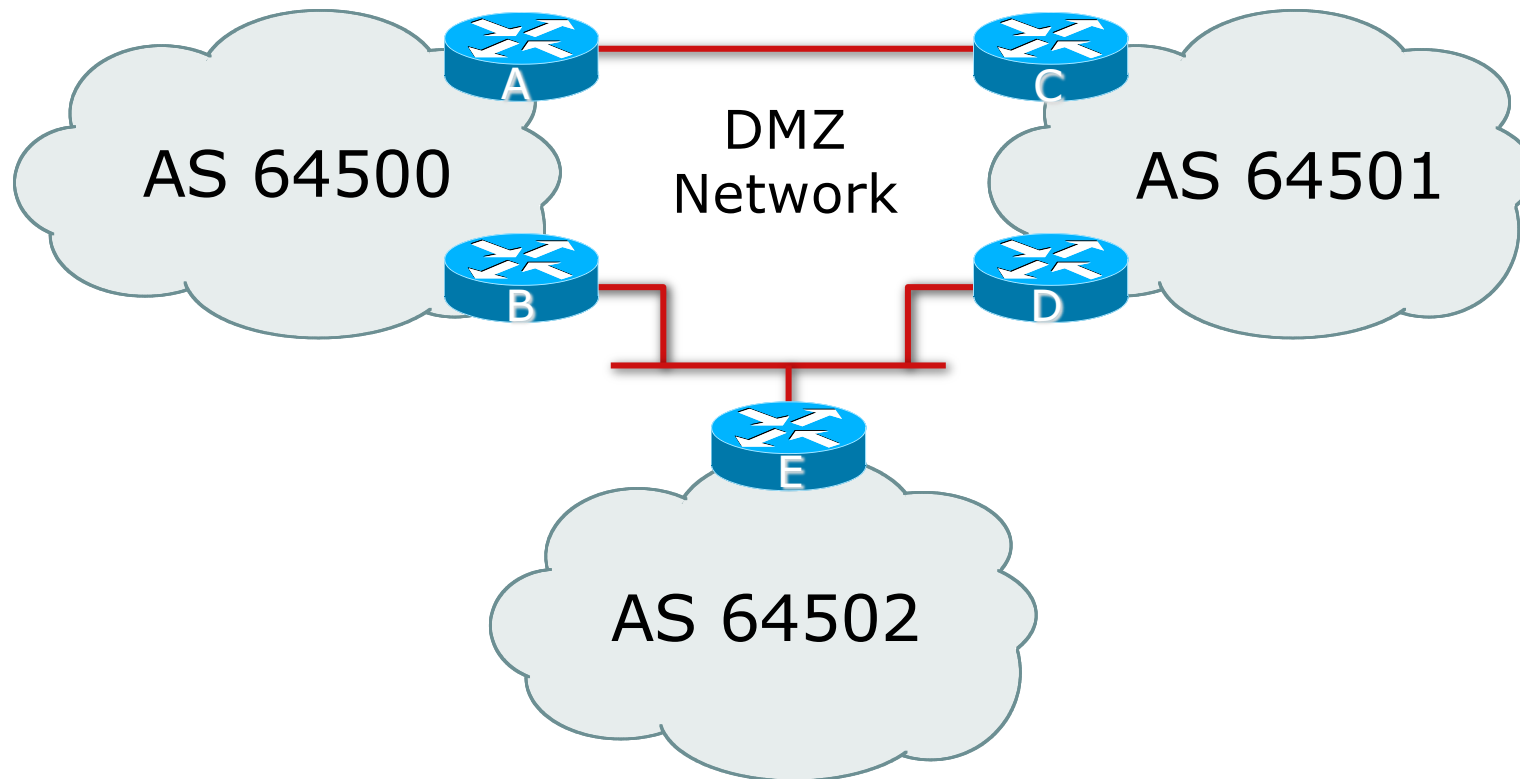
```
set routing-options autonomous-system asdot-notation 2.4
```

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

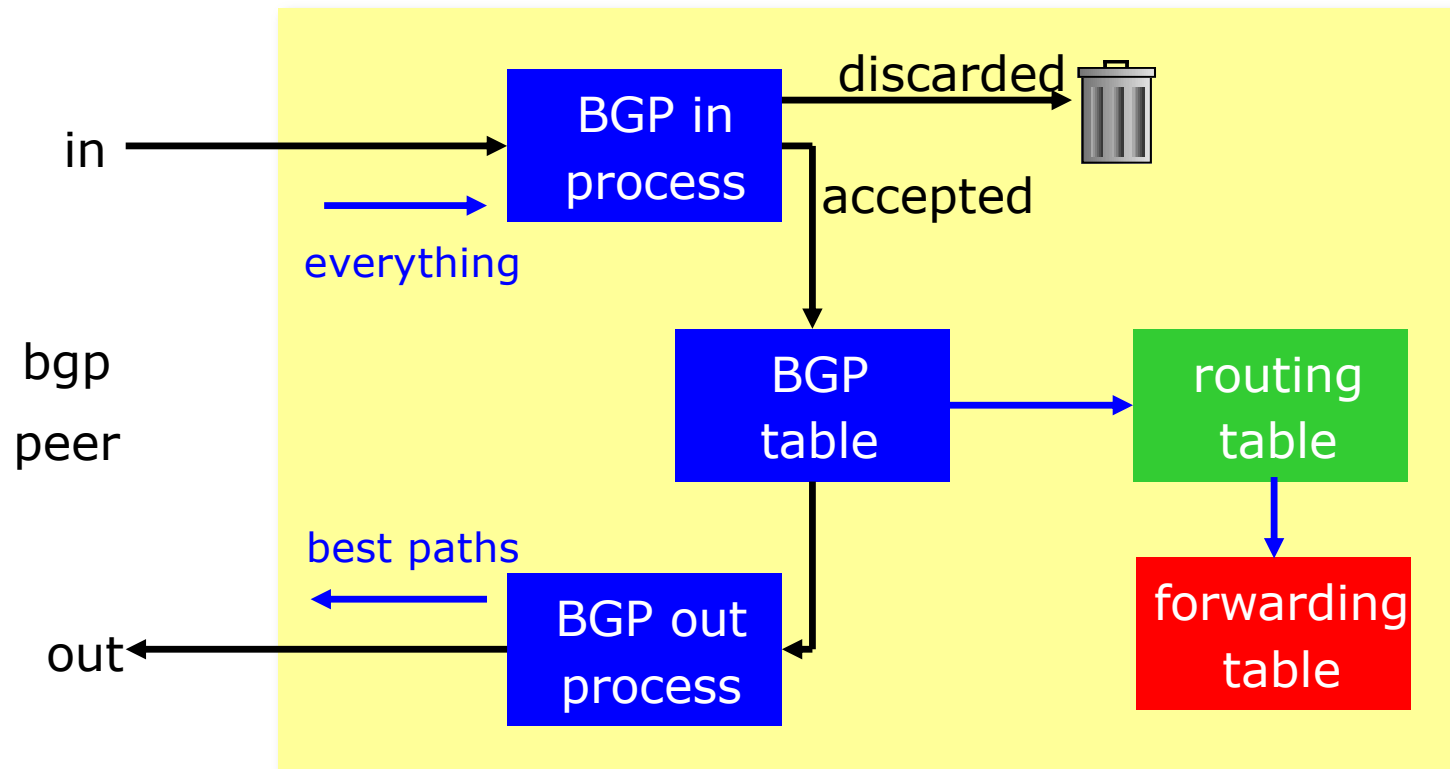
BGP General Operation

- ❑ 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
```

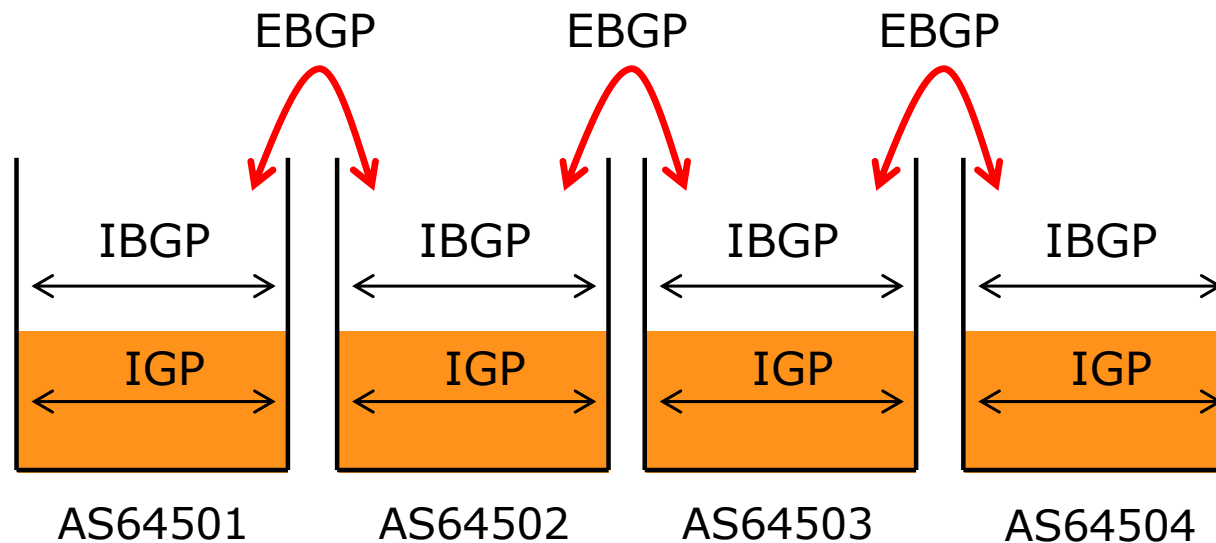
- ❑ For operational simplicity, the desire is for:
 - IPv4 neighbours to exchange IPv4 unicast prefixes
 - IPv6 neighbours to exchange IPv6 unicast prefixes
- ❑ Failure to do this results in:
 - IPv6 neighbours appearing to be set up to exchange IPv4 unicast prefixes
 - Cluttered configuration
 - Confusing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

EBGP & IBGP

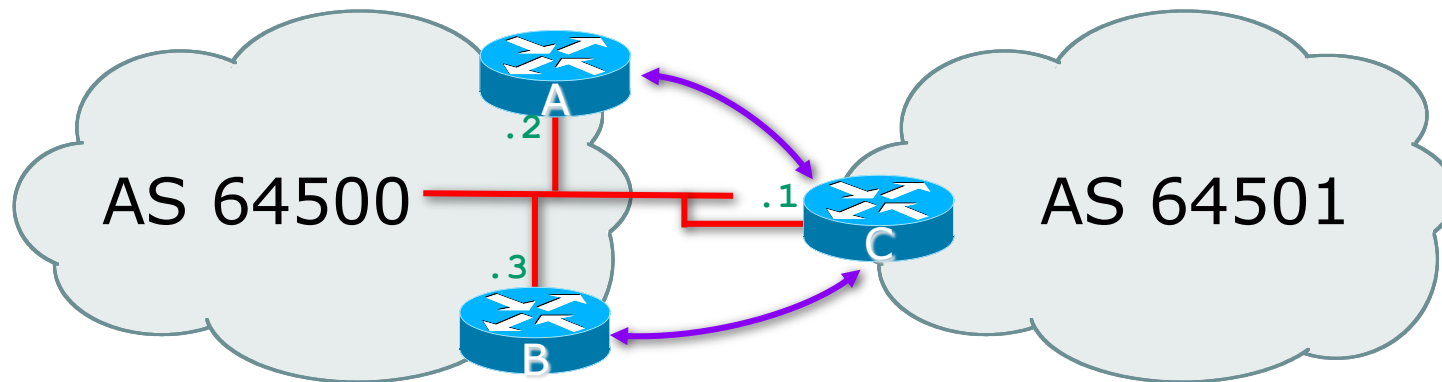
- BGP is used
 - Internally (IBGP)
 - Externally (EBGP)
- IBGP used to carry
 - Some/all Internet prefixes across network operator backbone
 - ISP's customer prefixes
- EBGP used to
 - Exchange prefixes with other ASes
 - Implement routing policy

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 GigabitEthernet 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 GigabitEthernet 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

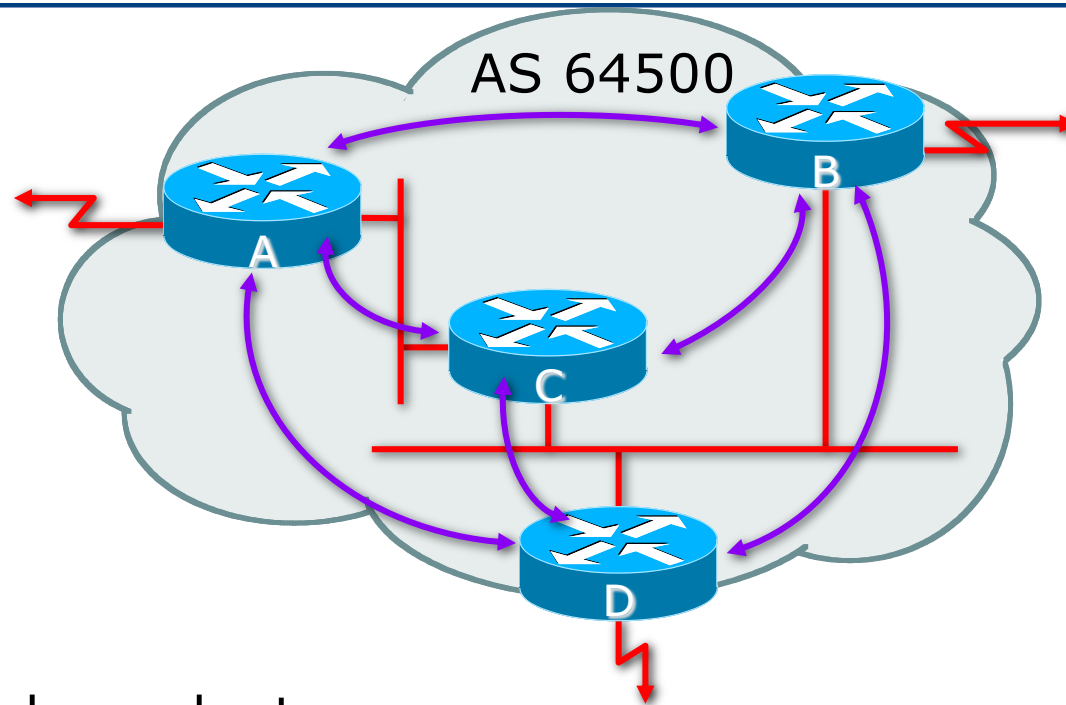
Inbound and
outbound filters

ip address of Router A
ethernet interface

Internal BGP (IBGP)

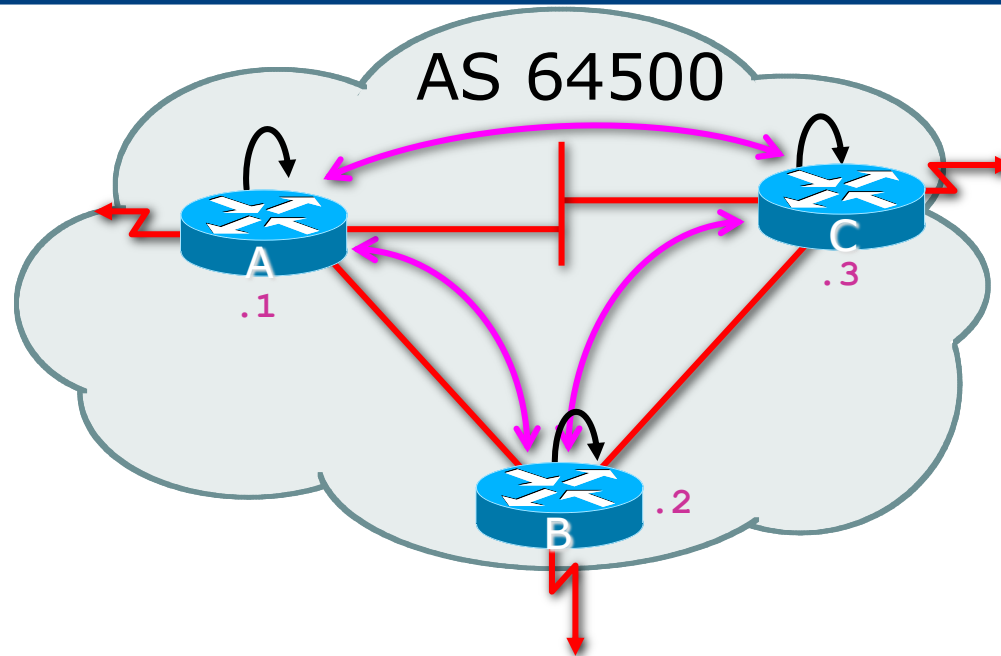
- ❑ BGP peer within the same AS
- ❑ Not required to be directly connected
 - IGP takes care of inter-BGP speaker connectivity
- ❑ IBGP speakers must be fully meshed:
 - They originate connected networks
 - They pass on prefixes learned from outside the AS
 - They do not pass on prefixes learned from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

Internal BGP Peering (IBGP)



- ❑ Topology independent
- ❑ Each IBGP speaker must peer with every other IBGP speaker in the AS as per $\longleftrightarrow$

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