BGP Policy Control

ISP Workshops

Last updated 11th May 2021

Acknowledgements

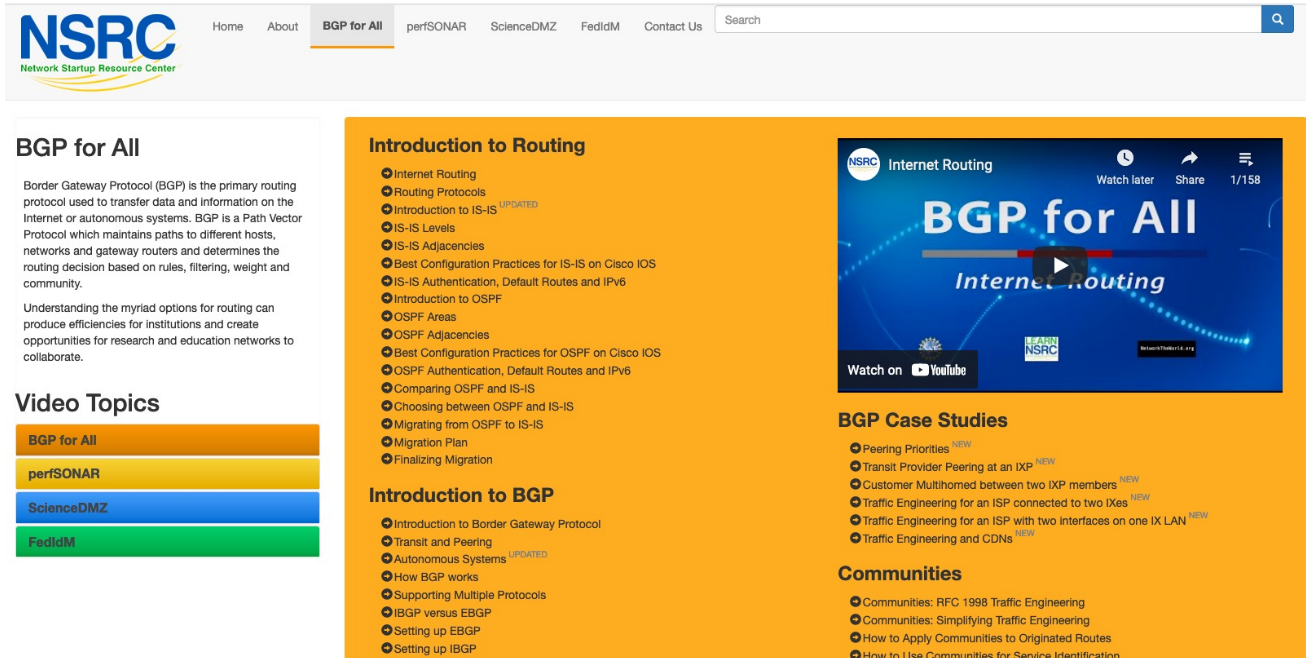
- This material originated from the Cisco ISP/IXP Workshop Programme developed by Philip Smith & Barry Greene
  - Acknowledgements to Patrick Okui for the JunOS examples

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

Philip Smith

BGP Videos

- NSRC has produced a library of BGP presentations (including this one), recorded on video, for the whole community to use
  - https://learn.nsrc.org/bgp



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 EBGP
- Setting up EBGP
- 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

Overview

- Organisations tend to have particular non-technical routing policies
  - A circuit may be preferred because it is cheaper
  - A circuit may be preferred because the traffic by regulation must stay within a certain jurisdiction or country
- BGP in this case is more of a policy tool than the typical routing protocol which just tries to find the best technical route

Overview: Applying Policy with BGP

- You can accept a prefix announcement, meaning that traffic to that destination will flow towards whoever advertised it to you
- You can reject a prefix announcement, meaning that traffic to that destination will not flow towards whoever advertised it to you
- Similarly for prefixes you announce, if they are accepted then traffic to those destinations will flow towards you

Overview: Applying Policy with BGP

- In addition to the prefix itself you can make similar filtering decisions based on the AS_PATH attribute or which communities have been applied to the prefix announcements
- Once you have decided to accept a prefix you can optionally set other BGP attributes that will affect how preferred the announcement will be in your network
- This can be complex or simple and the goal is to influence the router based on the BGP path selection algorithm

Overview: Applying Policy with BGP

- Tools to do this are:
  - Cisco’s “prefix-list” for filtering BGP prefixes
  - Juniper also has prefix-lists but the direct equivalent would be the “route-filter”
  - Cisco’s filter lists for filtering AS-PATHs
  - Juniper has AS-PATH regular expressions
- For more advanced policy requirements:
  - Route-maps for Cisco IOS
  - BGP Policy statements for Juniper

Policy Control – Prefix List

- Incremental configuration
- Applies Inbound or Outbound
- Based upon network numbers (using familiar IP address/mask format)
- Prefix-list ends with an implicit default deny

- Using access-lists in Cisco IOS for filtering prefixes was deprecated long ago
  - **Strongly discouraged!**

- Note: JunOS equivalent is called "route-filter"

Cisco Prefix Lists – Command Syntax

- Syntax:

```
[no] ip[v6] prefix-list list-name [seq value] permit|deny
  network/len [ge value] [le value]
```

network/len:	The prefix and its length
ge *value*:	"greater than or equal to"
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[v6] prefix-list sequence-number` to disable display of sequence numbers

Juniper Route-lists – Command Syntax

- **`route-filter`** ***`prefix match-type`*** **`{`** ***`action;`*** **`}`**
  - ***`prefix`*** is the network and its length we'd like to match
  - ***`match-type`*** is a group of optional keywords that further match prefixes out of the described network
  - ***`{ action; }`*** is an optional set of actions to apply if this route-list matches

Match Type	**Match Condition**
exact	Matches exactly
longer	Matches subnets only
orlonger	Matches prefix and subnets
prefix-length-range **X Y**	Matches subnet sizes **X** through **Y**
upto **Y**	Matches all subnet sizes up to **Y**

Cisco Prefix Lists – Examples

- Deny default route in IPv4

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

- Deny default route in IPv6

```
ipv6 prefix-list EG-v6 deny ::/0
```

- Permit the prefix 35.0.0.0/8

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

- Permit the IPv6 prefix 2001:DB8::/32

```
ipv6 prefix-list EG-v6 permit 2001:DB8::/32
```

Juniper Route-filter – Examples

- Deny default route in IPv4

```
route-filter 0.0.0.0/0 exact { reject; }
```

- Deny default route in IPv6

```
route-filter ::/0 exact { reject; }
```

- Permit the prefix 35.0.0.0/8

```
route-filter 35.0.0.0/8 exact { accept; }
```

- Permit the IPv6 prefix 2001:DB8::/32

```
route-filter 2001:DB8::/32 exact { accept; }
```

Cisco Prefix Lists – Examples

- Deny the prefix 172.16.0.0/12

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

- Deny the IPv6 prefix 3FFE::/16

```
ipv6 prefix-list EG-v6 deny 3FFE::/16
```

- 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.

- In 2000::/3 allow up to /48

```
ipv6 prefix-list EG-v6 permit 2000::/3 le 48
```

Juniper Route-filter – Examples

- Deny the prefix 172.16.0.0/12

```
route-filter 172.16.0.0/12 exact { reject; }
```

- Deny the IPv6 prefix 3FFE::/16

```
route-filter 3FFE::/16 exact { reject; }
```

- In 192/8 allow up to /24

```
route-filter 192.0.0.0/8 upto 24 { accept; }
```

  - 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.

- In 2000::/3 allow up to /48

```
route-filter 2000::/3 upto 48 { accept; }
```

Cisco 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

Juniper Route-filter – Examples

- In 192/8 deny /25 and above

```
route-filter 192.0.0.0/8 prefix-length-range 25 32 { reject; }
```

  - 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

```
route-filter 193.0.0.0/8 prefix-length-range 12 20 { accept; }
```

  - 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

```
route-filter 0.0.0.0/0 orlonger { accept; }
```

  - 0.0.0.0 matches all possible addresses, "/0 orlonger" matches all possible prefix lengths

Cisco Prefix Lists – Full Example

- Example Configuration

```
router bgp 100
 address-family ipv4
  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 – Cisco Filter List

- Filter routes based on AS path
  - Inbound or Outbound
- Referenced in BGP neighbour configuration as:

```
neighbor <addr> filter-list <N> [in|out]
```

- Referenced in main configuration as:

```
ip as-path access-list <N> [permit|deny] ...
```

- The as-path access-list finishes with an implicit default deny

Cisco Filter List – Example

- Example Configuration:

```
router bgp 100
 address-family ipv4
  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 (IOS)

- 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 (JunOS)

- Juniper AS regular expressions are quite similar to IOS except that the entire AS number comprises one term
  - It is not possible to reference individual characters within the AS number, which differs from the POSIX 1003.2 definitions as used in IOS
  - This means:
    - The [] operator works in a different way
    - Some operators have different meanings
    - There are some extra operators

Policy Control – Regular Expressions (JunOS)

Operator	Match Definition
{m,n}	At least *m* and no more than *n* repetitions of the term. *n* must be greater than *m*.
{m}	Exactly *m* repetitions of a term
{m,}	*m* or more repetitions of a term
?	Zero or one repetition of a term, equivalent to {0,1}
[]	Set of AS numbers (rather than individual digits)
^	Character at the start of the regex. This is implicit as all regexes must match the entire AS path so isn't needed
$	Character at the end of the regex. This is also implicit and isn't needed
_	Underscore is not used in JunOS AS regexes since each term is an AS

Policy Control – Regular Expressions (IOS)

- Simple Examples

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

Policy Control – Regular Expressions (JunOS)

- Simple Examples

.*	match anything
.+	match at least one character
"()"	match routes local to this AS
.* 1800	originated by AS1800
1800 .*	received from AS1800
.* 1800 .*	via AS1800
.* 790 1800 .*	via AS1800 and AS790
.* 1800+ .*	multiple AS1800 in sequence (used to match AS-PATH prepends)
.* 65530 .*	via AS65530 (confederations) – no way to match the '('

Policy Control – Regular Expressions (IOS)

- Not so simple Examples

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

Policy Control – Regular Expressions (JunOS)

- Not so simple Examples

.	Match AS_PATH length of one
. .	Match AS_PATH length of two
.? .	Match AS_PATH length of one or two
.? .?	Match AS_PATH length of one or two (will also match zero)
. . .	Match AS_PATH length of three
.* (701|1800) .*	Match anything which has gone through AS701 or AS1800
.* 1849 .* 12163	Match anything of origin AS12163 and passed through AS1849

Policy Control – Cisco's 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

Policy Control – JunOS Policy Framework

- The same general framework is used on Juniper for routing policy as well as firewall filtering
- Like Cisco IOS route-maps there are three components
  - Match condition that select advertisements
  - Actions performed if the criteria match
  - A **`term`** is the actual line/statement that contain the match conditions and actions – there can be many **`term`**s
    - Unlike IOS they are not numbered
    - The **`term`** does not define a "default action" as there isn't a "permit" or a "deny" in the **`term`** line

Route Maps – Rules

- Lines can have multiple set statements
  - All set statements are implemented

```
route-map SAMPLE permit 10
 set community 300:1
 set local-preference 120
!
```

- Lines can have multiple match statements
  - All conditions must match

```
route-map SAMPLE permit 10
 match community MY-COMMUNITY
 match ip address prefix-list MY-LIST
 set local-preference 300
!
```

Route Maps – Rules

- A match statement can have multiple commands
  - At least one command must match

```
route-map SAMPLE permit 10
 match ip address prefix-list MY-LIST OTHER-LIST
 set community 300:10
!
```

- Route-map with only a match statement
  - Only prefixes matching go through, the rest are dropped

```
route-map SAMPLE permit 10
 match ip address prefix-list MY-LIST
!
```

Route Maps – Rules

- Line with only a set statement
  - All prefixes are matched and set
  - Any following lines are ignored

```
route-map SAMPLE permit 10
 set local-preference 120
!
route-map SAMPLE permit 20
 remark This line is ignored
 set community 300:5
!
```

Route Maps – Rules

- Line with a match/set statement and no following lines
  - Only prefixes matching the condition are set, the rest are dropped

```
route-map SAMPLE permit 10
 match ip address prefix-list MY-LIST
 set local-preference 120
!
```

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
 remark Don't forget this
!
```

Route Maps – Matching prefixes

- Example Configuration:

```
router bgp 100
 address-family ipv4
  neighbor 102.10.1.2 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 – Matching prefixes

- Commentary:
  - If address matches HIGH-PREF set local-pref 120, and then exit
  - Otherwise if address matches LOW-PREF, set local-pref 80, and then exit
  - No other condition, so all other prefixes are dropped

Route Maps – AS-PATH filtering

- Example Configuration

```
router bgp 100
 address-family ipv4
  neighbor 102.10.1.2 remote-as 200
  neighbor 102.10.1.2 route-map FILTER-ON-ASPATH in
!
route-map FILTER-ON-ASPATH permit 10
 match as-path 1
 set local-preference 80
!
route-map FILTER-ON-ASPATH 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 filtering

- Commentary:
  - If prefix originated from AS150, then set local-pref to 80, and exit
  - Otherwise if prefix transited AS210 (ie AS210 appears in the path), then set local-pref to 200, and exit
  - No other condition, so all other prefixes are dropped

Route Maps – AS-PATH prepends

- Example configuration of AS-PATH prepend

```
router bgp 100
 address-family ipv4
  network 105.7.0.0 mask 255.255.0.0
  neighbor 102.10.1.2 remote-as 300
  neighbor 102.10.1.2 route-map SETPATH out
!
route-map SETPATH permit 10
 set as-path prepend 100 100
!
```

- Use your **own** AS number when prepending
  - Otherwise BGP loop detection may cause disconnects
  - Deliberate insertion of other ASNs is called "AS PATH poisoning"

Route Maps – Matching Communities

- Example Configuration

```
router bgp 100
 address-family ipv4
  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 MY1
 set local-preference 50
!
route-map FILTER-ON-COMMUNITY permit 20
 match community MY2 exact-match
 set local-preference 200
!
ip community-list standard MY1 permit 150:3 200:5
ip community-list standard MY2 permit 88:6
```

Route Maps – Matching Communities

- Commentary:
  - If prefix belongs to communities 150:3 AND 200:5, then set local-pref to 50, and exit
  - Otherwise if prefix belongs to ONLY community 88:6, then set local-pref to 200, and exit
  - No other condition, so all other prefixes are dropped

Community-List Processing

- Note:
  - When multiple values are configured in the same community list statement, a logical AND condition is created. All community values must match to satisfy an AND condition

```
ip community-list standard MY1 permit 150:3 200:5
```

  - When multiple values are configured in separate community list statements, a logical OR condition is created. The first list that matches a condition is processed

```
ip community-list standard MY1 permit 150:3
ip community-list standard MY1 permit 200:5
```

Route Maps – Setting Communities

- Example Configuration

```
router bgp 100
 address-family ipv4
  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
!
```

Juniper Policy Example Route Filter

```
policy-options {
  policy-statement import-example {
    term some-prefixes {
      from {
        route-filter 0.0.0.0/0 exact { reject; }
        route-filter 192.0.0.0/8 upto 24;
        route-filter 193.0.0.0/8 prefix-length-range 12 20;
      }
      then {
        preference 200;
        accept;
      }
    }
    term default-deny {
      then {
        reject;
      }
    }
  }
}
```

Juniper Policy Example AS-PATH regex

```
policy-options {
  as-path from1800 ".* 1800";
  policy-statement import-example {
    term filter-ases {
      from {
        as-path from1800;
      }
      then {
        preference 10;
      }
    }
  }
}
```

Juniper – applying to BGP session

```
protocols bgp {
  export our-policy-out;
  group upstreams {
    type external;
    export all-upstreams-out;
    import incoming-upstreams;
    neighbor 172.16.2.2 {
      import import-example;
    }
    neighbor 172.20.3.1;
  }
}
```

Order of processing BGP policy in IOS

- For policies applied to a specific BGP neighbour, the following sequence is applied:
  - For inbound updates, the order is:
    1. Route-map
    2. Filter-list
    3. Prefix-list
  - For outbound updates, the order is:
    1. Prefix-list
    2. Filter-list
    3. Route-map

Managing Policy Changes in IOS

- 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 — forgetting results in a hard reset of the BGP session
- **Note:** Cisco IOS does not automatically apply policy changes after they are added to the configuration
  - Most other router operating systems will implement the route-refresh once the policy change has been committed

Managing Policy Changes in IOS

- 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 Policy Control

ISP Workshops