

Remotely Triggered Black Hole Filtering

ISP 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*

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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>

The screenshot shows the NSRC (Network Startup Resource Center) website. The navigation bar includes links for Home, About, BGP for All (highlighted), perfSONAR, ScienceDMZ, FedIdM, and Contact Us, along with a search bar. The main content area is divided into several sections:

- BGP for All:** A text-based introduction to BGP, explaining its role as the primary routing protocol for the Internet and autonomous systems. It also mentions that understanding routing options can lead to efficiencies for institutions and research/education networks.
- Video Topics:** A list of video topics with color-coded buttons: BGP for All (orange), perfSONAR (yellow), ScienceDMZ (blue), and FedIdM (green).
- Introduction to Routing:** A list of 17 topics including Internet Routing, Routing Protocols, Introduction to IS-IS, 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, and Finalizing Migration.
- Introduction to BGP:** A list of 7 topics including Introduction to Border Gateway Protocol, Transit and Peering, Autonomous Systems, How BGP works, Supporting Multiple Protocols, IBGP versus EBGP, Setting up EBGP, and Setting up IBGP.
- BGP Case Studies:** A list of 5 case studies, each marked as 'NEW', including Peering Priorities, Transit Provider Peering at an IXP, Customer Multihomed between two IXPs, Traffic Engineering for an ISP connected to two IXes, and Traffic Engineering for an ISP with two interfaces on one IX LAN.
- Communities:** A list of 4 topics including Communities: RFC 1998 Traffic Engineering, Communities: Simplifying Traffic Engineering, How to Apply Communities to Originated Routes, and How to Use Communities for Service Identification.

A video player is embedded in the center, showing a video titled "BGP for All" with the subtitle "Internet Routing". The video player includes controls for "Watch later", "Share", and "1/158". A "Watch on YouTube" button is visible at the bottom left of the video player.

Remotely Triggered Black Hole Filtering

- ❑ A simple technique whereby the Network Operator can use their entire backbone router infrastructure to block mischievous traffic to or from a specific address targeting their network or their customers' network
- ❑ Powerful tool to help with mitigating Distributed Denial of Service (DDoS) Attacks

Remotely Triggered Black Hole Filtering

- Well documented around the Internet, including:
 - Chris Morrow's presentation at NANOG 30 in 2004 describing the technique:
 - <https://www.nanog.org/meetings/nanog30/presentations/morrow.pdf>
 - Cisco whitepaper from 2005:
 - https://www.cisco.com/c/dam/en_us/about/security/intelligence/blackhole.pdf
 - Informational RFC from the IETF in 2009:
 - <https://tools.ietf.org/html/rfc5635>

Defending against DDoS

- ❑ Link bandwidths from ISPs to their customers are usually quite small
- ❑ Link bandwidths from ISPs to their upstreams are usually quite large
- ❑ DDoS attacks nowadays are usually multi-Gbps
 - Significant burden for transit providers to handle
 - Completely swamps the end user link

Defending against DDoS

- Packet filters at the customer side are no good
 - The packets have already traversed the link
 - The link is already swamped
- Packet filters at the ISP side could help
 - Requires human intervention
 - Requires serious CPU power on the ISP access router doing the filtering
 - ISP access router has become the target now
 - Doesn't scale!

Defending against DDoS

- Wouldn't it be better to have all the ISP's routers dealing with the DDoS ?
- Manual solution:
 - Customer phones ISP and asks them to null route all traffic to the address under attack
 - Which means the ISP has to change router configurations across the backbone; in the middle of the day / outside maintenance
- Automatic solution:
 - Remotely Triggered Black Hole (RTBH) Filtering

Defending against DDoS

- DDoS against a local target
 - Where traffic appears to be coming from “everywhere” targeting a single IP address hosted locally
 - Traditional RTBH filtering implementation

- DDoS from a single source
 - Where traffic is coming from one external source targeting a range of local addresses (e.g. scanning)
 - Use Source RTBH filtering to handle

RTBH: Two Implementation Methods

1. Network Operator implements the RTBH function at the customer's request
 - Appropriate for statically connected customers
2. Customer triggers the RTBH function via their BGP session with their ISP
 - Using a specific RTBH BGP Community (RFC7999)
 - Appropriate for BGP customers of the Network Operator

RTBH: Method 1

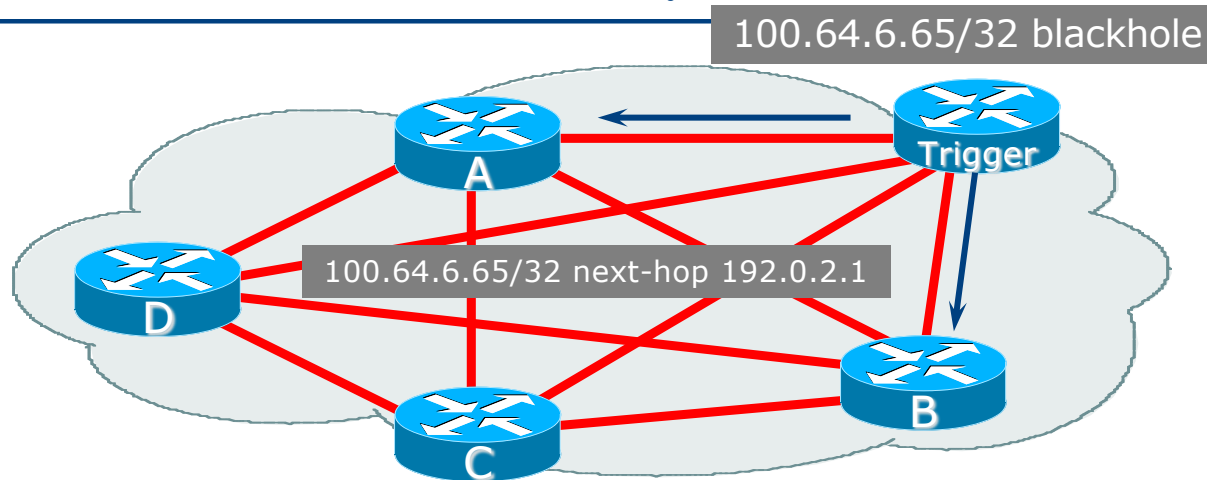


Network Operator Deploys RTBH Filtering
and Trigger Router within their backbone

RTBH – How it works

- Network Operator deploys:
 - RTBH support across their entire backbone
 - Simply a null route for a specific next-hop address
 - (Router Null interfaces simply discard packets sent to them – negligible overhead in modern hardware)
 - A trigger router (usually in the NOC)
 - Talks IBGP with the rest of the backbone (typically as a client of route-reflectors in the core)
 - Used to trigger a blackhole route activity for any address under attack, as requested by a customer

Blackhole Community



□ How it works:

- Operator flags the prefix to be Null routed
- Trigger router sets *next-hop* to 192.0.2.1
- 192.0.2.1 is routed to Null interface on all routers within the Autonomous System
- All traffic to 100.64.6.65 is Null routed

RTBHv4 – Backbone Configuration

- Network Operator sets up a null route for the 192.0.2.1 address on all the backbone routers which participate in BGP

```
ip route 192.0.2.1 255.255.255.255 null0 254
```

- 192.0.2.1 is part of 192.0.2.0/24, the TEST-NET, one of the reserved IPv4 address blocks
 - <http://www.iana.org/assignments/iana-ipv4-special-registry>
 - It is not used or routed on the public Internet

RTBHv6 – Backbone Configuration

- Network Operator sets up a null route for the 100::<1 address on all the backbone routers which participate in BGP

```
ipv6 route 100::<1/128 null0 254
```

- 100::<1 is part of 100::- <http://www.iana.org/assignments/iana-ipv6-special-registry>
- It is not used or routed on the public Internet

RTBH – Trigger Router (1)

- Create a route-map to catch routes which need to be blackholed
 - Static routes can be tagged in Cisco IOS – we will tag routes to be blackholed with the value of 666
 - Set origin to be IBGP
 - Set local-preference to be 1000
 - Higher than any other local-preference set in the backbone
 - Set community to be *no-export* and RTBH community (65535:666)
 - Don't want prefix to leak outside the AS
 - Set next-hop to 192.0.2.1 (IPv4) or 100::1 (IPv6)

RTBHv4 – Trigger Router (2)

□ The whole route-map:

```
route-map v4blackhole-trigger permit 10
  description Look for Route 666
  match tag 666
  set local-preference 1000
  set origin igp
  set community no-export 65535:666
  set ip next-hop 192.0.2.1
!
route-map v4blackhole-trigger deny 20
  description Nothing else gets through
```

RTBHv6 – Trigger Router (2)

□ The whole route-map:

```
route-map v6blackhole-trigger permit 10
  description Look for Route 666
  match tag 666
  set local-preference 1000
  set origin igp
  set community no-export 65535:666
  set ipv6 next-hop 100::1
!
route-map v6blackhole-trigger deny 20
  description Nothing else gets through
```

RTBHv4 – Trigger Router (3)

- Then introduce the route-map into the BGP configuration
 - **NB:** the IBGP on the trigger router cannot use “next-hop-self” – Cisco IOS overwrites the route-map originated next-hop with “next-hop-self”

```
router bgp 64500
  address-family ipv4
    redistribute static route-map v4blackhole-trigger
    neighbor 100.65.0.2 remote-as 64500
    neighbor 100.65.0.2 description IBGP with RR1
    neighbor 100.65.0.2 update-source Loopback 0
    neighbor 100.65.0.2 send-community
    neighbor 100.65.0.3 remote-as 64500
    neighbor 100.65.0.3 description IBGP with RR2
    neighbor 100.65.0.3 update-source Loopback 0
    neighbor 100.65.0.3 send-community
!
```

RTBHv6 – Trigger Router (3)

- Then introduce the route-map into the BGP configuration
 - **NB:** the IBGP on the trigger router cannot use “next-hop-self” – Cisco IOS overwrites the route-map originated next-hop with “next-hop-self”

```
router bgp 64500
  address-family ipv6
    redistribute static route-map v6blackhole-trigger
    neighbor 2001:DB8::2 remote-as 64500
    neighbor 2001:DB8::2 description IBGP with RR1
    neighbor 2001:DB8::2 update-source Loopback 0
    neighbor 2001:DB8::2 send-community
    neighbor 2001:DB8::3 remote-as 64500
    neighbor 2001:DB8::3 description IBGP with RR2
    neighbor 2001:DB8::3 update-source Loopback 0
    neighbor 2001:DB8::3 send-community
!
```

RTBHv4 – Trigger Router (4)

- To implement the trigger, simply null route whatever address or address block needs to be blackholed

- With Tag 666

```
ip route 50.62.124.1 255.255.255.255 null0 tag 666
```

- And this ensures that (for example) 50.62.124.1/32 is announced to the entire backbone with next-hop 192.0.2.1 set

RTBHv6 – Trigger Router (4)

- To implement the trigger, simply null route whatever address or address block needs to be blackholed

- With Tag 666

```
ipv6 route 2001:DB8:F::E0/128 null0 tag 666
```

- And this ensures that (for example) 2001:DB8:F::E0/128 is announced to the entire backbone with next-hop 100::1 set

RTBHv4 – End Result

- Prefixes which need to be null routed will come from the trigger router and look like this in the BGP table:

```
*>i 50.62.124.1/32 192.0.2.1 0 1000 0 i
```

- Routing entry for 50.62.124.1 is this:

```
cr1>sh ip route 50.62.124.1
Routing entry for 50.62.124.1/32
  Known via "bgp 64500", distance 200, metric 0, type internal
  Last update from 1.2.0.1 7w0d ago
  Routing Descriptor Blocks:
  * 192.0.2.1, from 1.2.0.1, 7w0d ago
    Route metric is 0, traffic share count is 1
    AS Hops 0
    MPLS label: none
```

RTBHv4 – End Result

- Routing entry for 192.0.2.1 is this:

```
cr1>sh ip route 192.0.2.1
Routing entry for 192.0.2.1/32
  Known via "static", distance 1, metric 0 (connected)
  Routing Descriptor Blocks:
    * directly connected, via Null0
      Route metric is 0, traffic share count is 1
```

- Traffic to 50.62.124.1 is sent to null interface

RTBHv6 – End Result

- Prefixes which need to be null routed will come from the trigger router and look like this in the BGP table:

```
*>i 2001:DB8:F::E0/128 100::1 0 1000 0 i
```

- Routing entry for 2001:DB8:F::E0 is this:

```
cr1>sh ipv6 route 2001:DB8:F::E0
Routing entry for 2001:DB8:F::E0/128
  Known via "bgp 64500", distance 200, metric 0, type internal
  Route count is 1/1, share count 0
  Routing paths:
    100::1
      MPLS label: no-label
      Last updated 00:00:03 ago
```

RTBHv6 – End Result

- Routing entry for 100::1 is this:

```
cr1>sh ipv6 route 100::1
Routing entry for 100::1/128
  Known via "static", distance 1, metric 0
  Route count is 1/1, share count 0
  Routing paths:
    directly connected via Null0
    Last updated 00:05:21 ago
```

- Traffic to 2001:DB8:F::E0 is sent to null interface

RTBH: Method 2

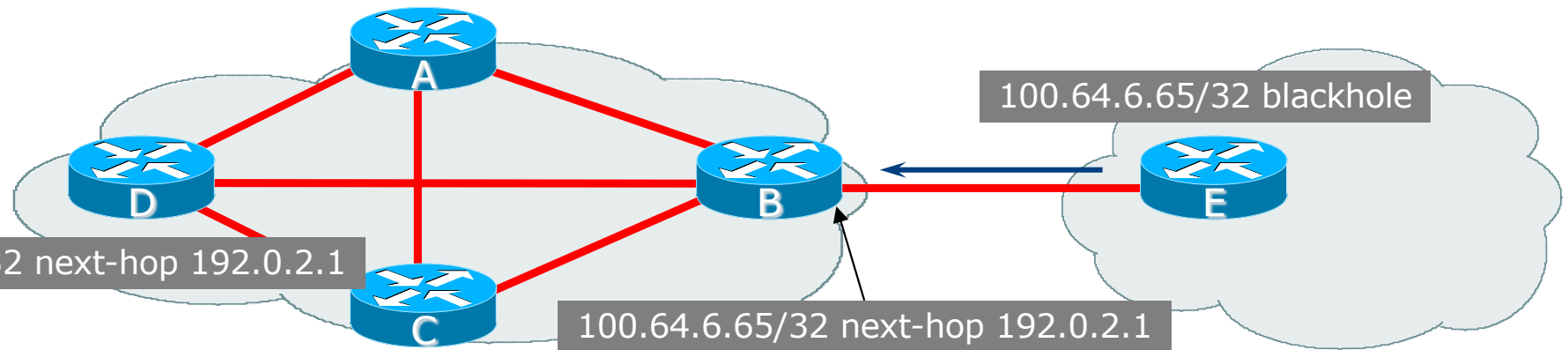


Network Operator Deploys RTBH Filtering across their backbone, and supplies BGP community for their customer

RTBH – How it works

- Customer uses BGP to announce the IP address being attacked to their upstream provider
 - Prefix is tagged with a special community
- Upstream provider sees the prefix with special community from their customer
 - This flags their BGP speaking routers to set the next-hop to the Null interface
 - All traffic to the customer address is discarded

Blackhole Community



□ How it works:

- Router E sets *blackhole* community
- Router B detects *blackhole* community on incoming EBGP announcements and sets *next-hop* to 192.0.2.1
- 192.0.2.1 is routed to Null interface on all routers within the Autonomous System
- All traffic to 100.64.6.65 is Null routed

RTBH – Customer Configuration (1)

- Create a route-map to tag routes which need to be blackholed by upstream
 - Routes tagged with 666 need to be blackholed
 - Set origin to be IBGP
 - Set community to the well-known RTBH community (RFC7999)

```
route-map blackhole-trigger permit 10
  description Look for Route 666
  match tag 666
  set origin igp
  set community 65535:666
!
route-map blackhole-trigger deny 20
```

RTBHv4 – Customer Configuration (2)

- Then introduce the route-map into the BGP configuration
 - We will tag static routes with “666” to indicate they are blackhole routes
- And use it on the EBGP with the upstream:

```
router bgp 64511
  address-family ipv4
    redistribute static route-map blackhole-trigger
  neighbor 100.65.1.1 remote-as 64500
  neighbor 100.65.1.1 description Transit ISP
  neighbor 100.65.1.1 prefix-list upstream-in in
  neighbor 100.65.1.1 prefix-list my-prefixes out
  neighbor 100.65.1.1 send-community
!
```

RTBHv6 – Customer Configuration (2)

- Then introduce the route-map into the BGP configuration
 - We will tag static routes with “666” to indicate they are blackhole routes
- And use it on the EBGP with the upstream:

```
router bgp 64511
  address-family ipv6
    redistribute static route-map blackhole-trigger
  neighbor 2001:db8:1::1 remote-as 64500
  neighbor 2001:db8:1::1 description Transit ISP
  neighbor 2001:db8:1::1 prefix-list upstreamv6-in in
  neighbor 2001:db8:1::1 prefix-list my-v6prefixes out
  neighbor 2001:db8:1::1 send-community
!
```


RTBHv4 – Customer Configuration (3)

- To implement the trigger, simply null route whatever address or address block needs to be blackholed

- With Tag 666

```
ip route 50.62.124.1 255.255.255.255 null0 tag 666
```

- And this ensures that (for example) 50.62.124.1/32 is announced to the upstream provider with community 65535:666 set

RTBHv6 – Customer Configuration (3)

- To implement the trigger, simply null route whatever address or address block needs to be blackholed

- With Tag 666

```
ipv6 route 2001:DB8:F::E0/128 null0 tag 666
```

- And this ensures that (for example) 2001:DB8:F::E0/128 is announced to the upstream provider with community 65535:666 set

RTBHv4 – Upstream Configuration (1)

- Upstream provider sets up route-map to look for trigger community from their BGP customers
 - Need to set next hop for non-blackhole routes to be loopback of local router

```
ip community-list standard RTBH permit 65535:666
!
route-map ibgpv4-policy permit 10
  description Look for Blackhole Routes
  match community RTBH
  set local-preference 1000
  set ip next-hop 192.0.2.1
  set community no-export
!
route-map ibgpv4-policy permit 20
  description Let everything else through
  set ip next-hop 100.65.0.1
!
```

RTBHv6 – Upstream Configuration (1)

- Upstream provider sets up route-map to look for trigger community from their BGP customers
 - Need to set next hop for non-blackhole routes to be loopback of local router

```
ip community-list standard RTBH permit 65535:666
!
route-map ibgpv6-policy permit 10
  description Look for Blackhole Routes
  match community RTBH
  set local-preference 1000
  set ipv6 next-hop 100::1
  set community no-export
!
route-map ibgpv6-policy permit 20
  description Let everything else through
  set ipv6 next-hop 2001:DB8::1
!
```

RTBHv4 – Upstream Configuration (2)

- The route-map is now applied to the iBGP neighbours of this edge router
 - Note the absence of “next-hop-self” – this is now done in the route-map

```
router bgp 64500
  address-family ipv4
    neighbor 100.65.0.2 remote-as 64500
    neighbor 100.65.0.2 description IBGP with RR1
    neighbor 100.65.0.2 update-source Loopback 0
    neighbor 100.65.0.2 send-community
    neighbor 100.65.0.2 route-map ibgpv4-policy out
    neighbor 100.65.0.3 remote-as 64500
    neighbor 100.65.0.3 description IBGP with RR2
    neighbor 100.65.0.3 update-source Loopback 0
    neighbor 100.65.0.3 send-community
    neighbor 100.65.0.3 route-map ibgpv4-policy out
!
```

RTBHv6 – Upstream Configuration (2)

- The route-map is now applied to the iBGP neighbours of this edge router
 - Note the absence of “next-hop-self” – this is now done in the route-map

```
router bgp 64500
  address-family ipv6
    neighbor 2001:DB8::2 remote-as 64500
    neighbor 2001:DB8::2 description IBGP with RR1
    neighbor 2001:DB8::2 update-source Loopback 0
    neighbor 2001:DB8::2 send-community
    neighbor 2001:DB8::2 route-map ibgpv6-policy out
    neighbor 2001:DB8::3 remote-as 64500
    neighbor 2001:DB8::3 description IBGP with RR2
    neighbor 2001:DB8::3 update-source Loopback 0
    neighbor 2001:DB8::3 send-community
    neighbor 2001:DB8::3 route-map ibgpv6-policy out
!
```

RTBHv4 – Upstream Configuration (3)

- Upstream provider then sets up a null route for the 192.0.2.1 address on all the backbone routers which participate in BGP

```
ip route 192.0.2.1 255.255.255.255 null0 254
```

- Note: It is NOT possible in Cisco IOS to change the next-hop of the blackhole route as it arrives on the IPv4 EBGP session
 - Which is why the policy to change the next-hop to 192.0.2.1 is applied on the IBGP sessions

RTBHv6 – Upstream Configuration (3)

- Upstream provider then sets up a null route for the 100::1 address on all the backbone routers which participate in BGP

```
ipv6 route 100::1/128 null0 254
```

- Note: It is NOT possible in Cisco IOS to change the next-hop of the blackhole route as it arrives on the IPv6 EBGP session
 - Which is why the policy to change the next-hop to 100::1 is applied on the IBGP sessions

RTBH – End Result

- Prefixes which need to be null routed coming from the customer will look like this in the BGP table:

```
*>i 50.62.124.1/32 192.0.2.1 0 1000 0 64511 i
```

- Routing entry for 50.62.124.1 is this:

```
cr1>sh ip route 50.62.124.1
Routing entry for 50.62.124.1/32
  Known via "bgp 64500", distance 200, metric 0, type internal
  Last update from 1.2.0.4 7w0d ago
  Routing Descriptor Blocks:
  * 192.0.2.1, from 1.2.0.4, 7w0d ago
    Route metric is 0, traffic share count is 1
    AS Hops 0
    MPLS label: none
```

RTBH – End Result

- Routing entry for 192.0.2.1 is this:

```
cr1>sh ip route 192.0.2.1
Routing entry for 192.0.2.1/32
  Known via "static", distance 1, metric 0 (connected)
  Routing Descriptor Blocks:
    * directly connected, via Null0
      Route metric is 0, traffic share count is 1
```

- Traffic to 50.62.124.1 is sent to null interface

S/RTBH



Source-based Remotely Triggered
Blackhole Filtering

S/RTBH

- ❑ We already have the infrastructure in place to implement RTBH
- ❑ To implement S/RTBH, we need one simple amendment
 - Take advantage of the loose uRPF feature on the router
- ❑ Reminder:
 - Loose uRPF drops the incoming packet if the source address is not in the FIB, or the source address is Null routed
- ❑ Which means if we introduce the source address via our trigger router, loose uRPF will drop all packets with that source address

S/RTBH – Implementation

- Introduce the attacking source address via our existing trigger router as we did before:

```
ip route 50.62.124.1 255.255.255.255 null0 tag 666
```

- And then on external facing (transit & peering) interfaces:

```
ip verify unicast source reachable-via any
```

- The Routing Table (RIB) will have two entries:
 - One for the real route heard by BGP from upstream or peers
 - One pointing to the Null interface created by our trigger router

S/RTBH – Outcome

- The Routing Table populates the FIB:
 - If the prefix lengths are the same, the locally generated route goes in the FIB (the Null route created by the Trigger Router)
 - If the prefix lengths are different, the FIB gets both entries, and shortest match routing wins (again the Null route created by the Trigger Router)
- Loose uRPF drops the source packet if the FIB entry doesn't exist or if the address is routed to Null
- We have routed the attacking address (/32 in IPv4, /128 in IPv6) to Null
 - Which means this host route is the best
 - Thus, loose uRPF drops the source of the attack

RTBH – Conclusion



RTBH – Conclusion

- Very effective method of dealing with DDoS attacks
 - Can deal with DDoS aimed at local address (own or customer)
 - Can deal with DDoS from a remote address (S/RTBH)
- Implementation:
 - Automatically enlist the support of upstream ISP
 - Lightweight on resources
 - Null interface is a discard interface, takes negligible CPU on the line card, negligible CPU on control plane
 - Uses a BGP Community for signalling between customer and transit provider

RTBH – Recommendations

- Recommendation 1:
 - Only buy Internet transit from an operator who supports RTBH filtering

- Recommendation 2:
 - Provide the RTBH filtering feature to all your customers

RTBH – Other hints

- ❑ Single host addresses are usually what are announced by RTBH Trigger routers
 - /32 for IPv4 and /128 for IPv6
- ❑ Websites are usually the most frequent targets
 - Good idea to keep the DNS TTL very low for websites (few minutes)
 - If under DDoS attack:
 - ❑ Announce the host address from Trigger router
 - ❑ Change the IP address of the website on the host and in the DNS
 - ❑ End-users can access web-site again
 - If attacker changes the target address to the new IP address, then repeat the above

RTBH – Other hints

- What can be used as the Trigger Router?
 - Anything that runs modern BGP
 - Trigger router simply announces prefixes into the operator's IBGP mesh
 - Minimal CPU requirements
 - No packeting forwarding requirements
 - Minimal RAM requirements
 - Trigger router could be:
 - FRR/BIRD/OpenBGPD running on a VM or container
 - Old/retired routing hardware
 - Tiny hardware running BGP daemon

Remotely Triggered Black Hole Filtering



ISP Workshops