Multihoming: Outbound Traffic Engineering

ISP/IXP Workshops

Last updated 4th April 2025

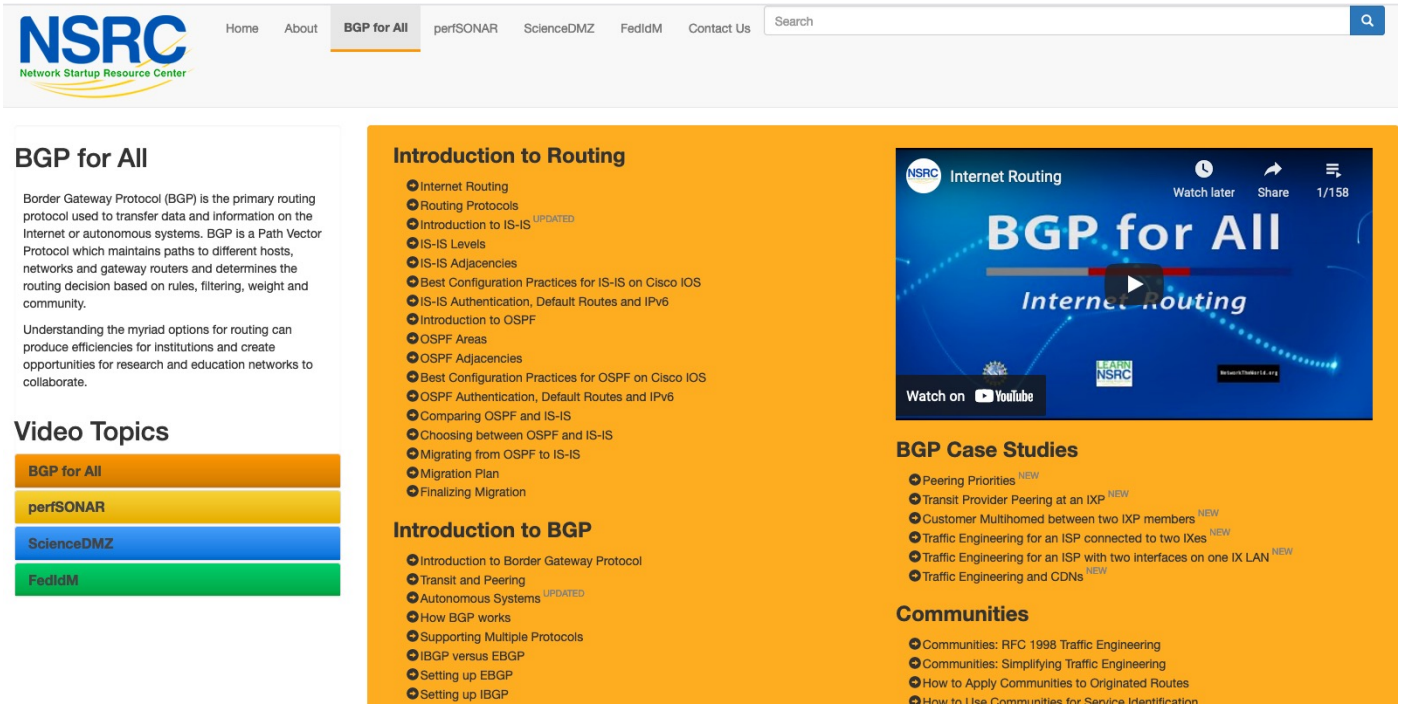
Acknowledgements

- 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#multi-homing



Service Provider Multihoming

- Previous examples dealt with loadsharing inbound traffic
  - Of primary concern at Internet edge
  - What about outbound traffic?
- Transit Providers strive to balance traffic flows in both directions
  - Balance link utilisation
  - Try and keep most traffic flows symmetric
  - Some edge networks try and do this too
- The original "Traffic Engineering"

Service Provider Multihoming

- Balancing outbound traffic requires inbound routing information
  - Common solution is "full routing table"
  - Rarely necessary
    - Why use the "routing mallet" to try solve loadsharing problems?
  - "Keep It Simple" is often easier (and $$$ cheaper) than carrying N-copies of the full routing table

Service Provider Multihoming MYTHS!!

Common MYTHS

1. You need the full routing table to multihome
   - People who sell router memory would like you to believe this
   - Only true if you are a transit provider
   - Full routing table can be a significant hindrance to multihoming
2. You need a BIG router to multihome
   - Router size is related to data rates, not running BGP
   - In reality, to multihome, your router needs to:
     - Have two interfaces,
     - Be able to talk BGP to at least two peers,
     - Be able to handle BGP attributes,
     - Handle at least one prefix
3. BGP is complex
   - In the wrong hands, yes it can be! Keep it Simple!

Service Provider Multihoming: Some Strategies

- Take the prefixes you need to aid traffic engineering
  - Look at NetFlow data for popular sites
- Prefixes originated by your immediate neighbours and their neighbours will do more to aid load balancing than prefixes from ASNs many hops away
  - Concentrate on local destinations
- Use default routing as much as possible
  - Or use the full routing table with care

Service Provider Multihoming

- Examples
  - One upstream, one local peer
  - One upstream, local exchange point
  - Two upstreams, one local peer
  - Three upstreams, unequal link bandwidths
- Require BGP and a public ASN
- Examples assume that the local network has their own /19 IPv4 address block

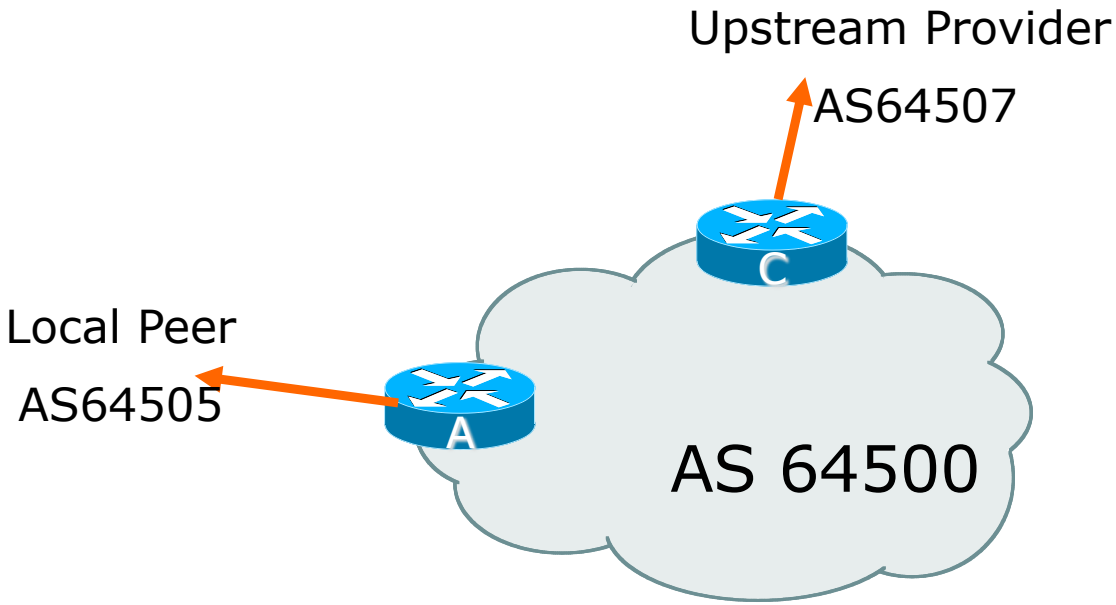
Service Provider Multihoming

One upstream, one local peer

One Upstream, One Local Peer

- Very common situation in many regions of the Internet
- Connect to upstream transit provider to see the "Internet"
- Connect to the local competition so that local traffic stays local
  - Saves spending valuable $ on upstream transit costs for local traffic

One Upstream, One Local Peer

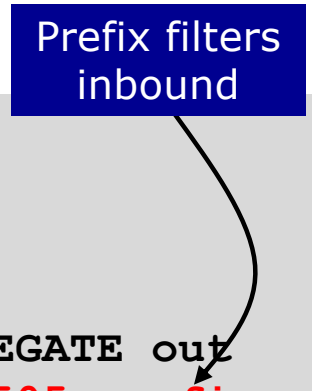


One Upstream, One Local Peer

- Announce /19 aggregate on each link
- Accept default route only from upstream
  - Either 0.0.0.0/0 or a network which can be used as default
- Accept all routes the local peer originates

One Upstream, One Local Peer

- Router A Configuration




```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.2 remote-as 64505
  neighbor 100.66.10.2 prefix-list AGGREGATE out
  neighbor 100.66.10.2 prefix-list AS64505-prefixes in
  neighbor 100.66.10.2 activate
!
ip prefix-list AS64505-prefixes permit 122.5.16.0/19
ip prefix-list AS64505-prefixes permit 121.240.0.0/20
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
!
ip route 100.64.0.0 255.255.224.0 null0 250
```

One Upstream, One Local Peer

- Router A – Alternative Configuration

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.2 remote-as 64505
  neighbor 100.66.10.2 prefix-list AGGREGATE out
  neighbor 100.66.10.2 filter-list 10 in
  neighbor 100.66.10.2 activate
!
ip as-path access-list 10 permit ^(64505_)+$
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
!
ip route 100.64.0.0 255.255.224.0 null0
```

AS Path filters – more "trusting"

One Upstream, One Local Peer

- Router C Configuration

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.1 remote-as 64507
  neighbor 100.66.10.1 prefix-list DEFAULT in
  neighbor 100.66.10.1 prefix-list AGGREGATE out
  neighbor 100.66.10.1 activate
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
ip prefix-list DEFAULT permit 0.0.0.0/0
!
ip route 100.64.0.0 255.255.224.0 null0
```

One Upstream, One Local Peer

- Two configurations possible for Router A
  - Filter-lists assume peer knows what they are doing
  - Prefix-list higher maintenance, but safer
  - Some network operators use both
- Local traffic goes to and from local peer, everything else goes to upstream provider

Aside: Configuration Recommendations

- Private Peers
  - The peering Network Operators exchange prefixes they originate
  - Sometimes they exchange prefixes from neighbouring ASes too
- Be aware that the private peer EBGP router should carry only the prefixes you want the private peer to receive
  - Otherwise, they could point a default route to you and unintentionally transit your backbone

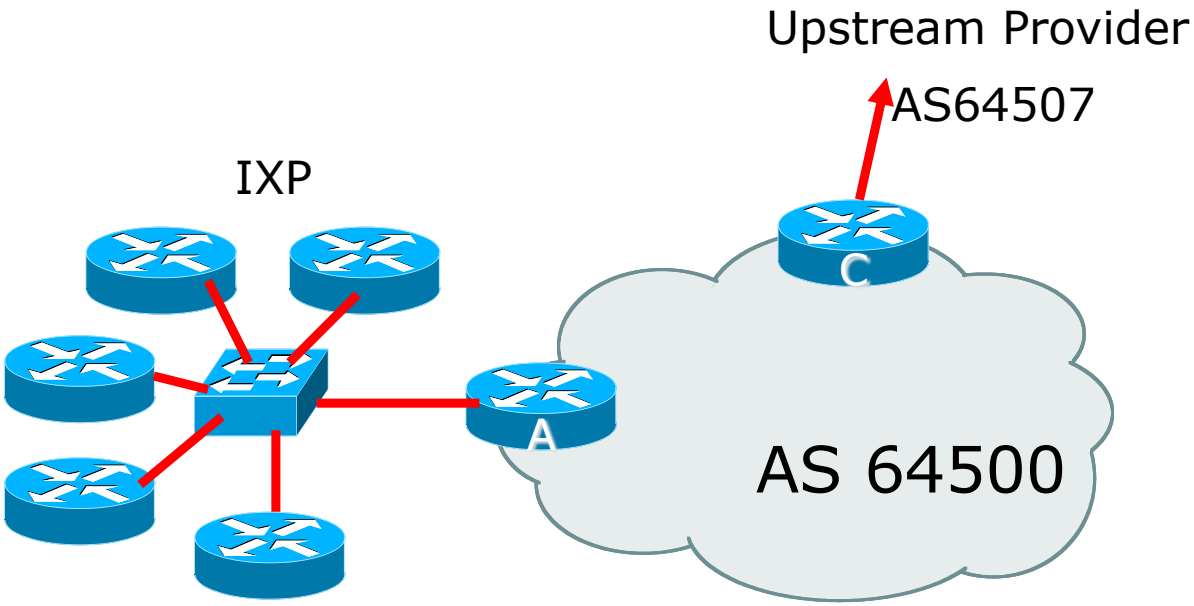
Service Provider Multihoming

One upstream, Local Exchange Point

One Upstream, Local Exchange Point

- Very common situation in many regions of the Internet
- Connect to upstream transit provider to see the "Internet"
- Connect to the local Internet Exchange Point so that local traffic stays local
  - Saves spending valuable $ on upstream transit costs for local traffic
- This example is a scaled up version of the previous one

One Upstream, Local Exchange Point



One Upstream, Local Exchange Point

- Announce /19 aggregate to every neighbouring AS
- Accept default route only from upstream
  - Either 0.0.0.0/0 or a network which can be used as default
- Accept all routes originated by IXP peers

One Upstream, Local Exchange Point

- Router A Configuration

```
interface GigabitEthernet0/0/0
 description Internet Exchange Point Public LAN
 ip address 100.127.10.1 mask 255.255.255.0
!
router bgp 64500
 address-family ipv4
  neighbor IXP-PEERS peer-group
  neighbor IXP-PEERS prefix-list AGGREGATE out
  neighbor IXP-PEERS remove-private-AS
  neighbor IXP-PEERS send-community
  neighbor IXP-PEERS route-map SET-LOCAL-PREF in
!
```

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One Upstream, Local Exchange Point

```
neighbor 100.127.10.2 remote-as 65540
neighbor 100.127.10.2 peer-group IXP-PEERS
neighbor 100.127.10.2 prefix-list PEER65540 in
neighbor 100.127.10.2 activate
neighbor 100.127.10.3 remote-as 65541
neighbor 100.127.10.3 peer-group IXP-PEERS
neighbor 100.127.10.3 prefix-list PEER65541 in
neighbor 100.127.10.3 activate
neighbor 100.127.10.4 remote-as 65542
neighbor 100.127.10.4 peer-group IXP-PEERS
neighbor 100.127.10.4 prefix-list PEER65542 in
neighbor 100.127.10.4 activate
neighbor 100.127.10.5 remote-as 65543
neighbor 100.127.10.5 peer-group IXP-PEERS
neighbor 100.127.10.5 prefix-list PEER65543 in
neighbor 100.127.10.5 activate
```

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One Upstream, Local Exchange Point

```
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
ip prefix-list PEER65540 permit 100.65.0.0/19
ip prefix-list PEER65541 permit 100.66.0.0/19
ip prefix-list PEER65542 permit 100.67.0.0/19
ip prefix-list PEER65543 permit 100.68.128.0/19
!
route-map SET-LOCAL-PREF permit 10
 description Set local preference on all routes to 250
 set local-preference 250
!
```

One Upstream, Local Exchange Point

- Note that Router A does not generate the aggregate for AS64500
  - If Router A becomes disconnected from backbone, then the aggregate is no longer announced to the IX
  - BGP failover works as intended
- Note the inbound route-map which sets the local preference higher than the default
  - This is a visual reminder that BGP Best Path for local traffic will be across the IXP
  - (And allows for future case where operator may need to take BGP routes from their upstream(s) or other peers)

One Upstream, Local Exchange Point

- Router C Configuration

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.1 remote-as 64507
  neighbor 100.66.10.1 prefix-list DEFAULT in
  neighbor 100.66.10.1 prefix-list AGGREGATE out
  neighbor 100.66.10.1 activate
!
ip prefix-list AGGREGATE description AS64500's aggregate route
ip prefix-list AGGREGATE permit 100.64.0.0/19
ip prefix-list DEFAULT description The IPv4 Default route
ip prefix-list DEFAULT permit 0.0.0.0/0
!
ip route 100.64.0.0 255.255.224.0 null0
```

One Upstream, Local Exchange Point

- Note Router A configuration:
  - Prefix-list filtering is strongly recommended
    - Higher maintenance, but safer!
  - No generation of AS64500 aggregate
- IXP traffic goes to and from local IXP, everything else goes to upstream

Aside: IXP Configuration Recommendations

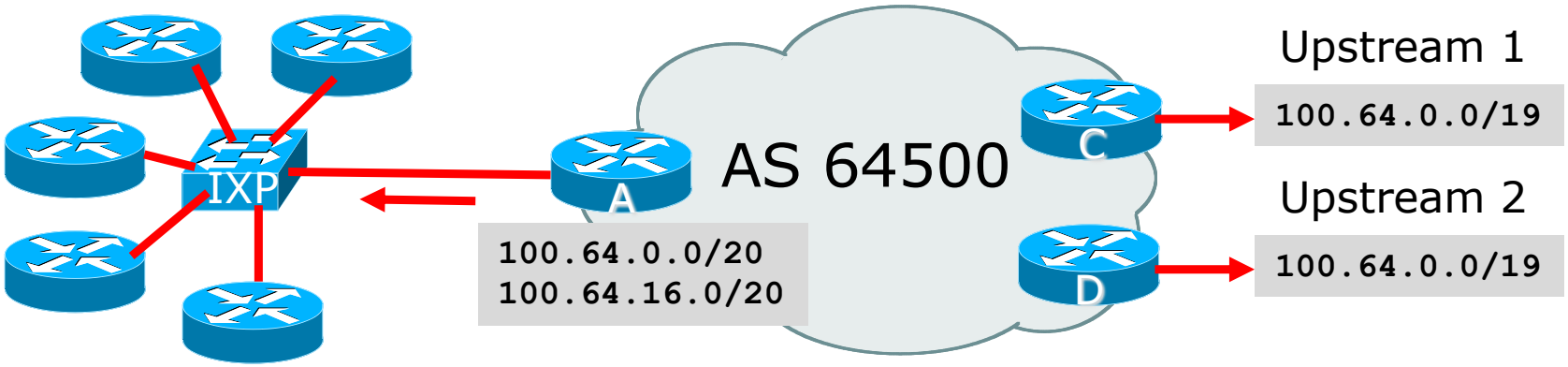
- IXP peers
  - The peering Network Operators at the IXP exchange prefixes they originate
  - Sometimes they exchange prefixes from neighbouring ASes too
- Be aware that the IXP border router should carry only the prefixes you want the IXP peers to receive and the destinations you want them to be able to reach
  - Otherwise, they could point a default route to you and unintentionally transit your backbone
- If IXP router is at IX, and distant from your backbone
  - Don't originate your address block at your IXP router

Aside: BGP recommendations (1)

- For more sophisticated situations (e.g. two upstreams):
  - For Upstreams: default received, aggregates and subnets announced (for inbound traffic engineering)
  - For IXP peers: prefixes received, aggregates and subnets announced
  - It is critically important to ensure that all prefixes (subnets) announced to upstreams are also announced to all peers (IXP and private)
    - Traffic always follows the most specific route – failure to announce subnets to peers will result in peering traffic using transit links!
  - Common strategy is to create one outbound prefix filter policy and apply it on all EBGP sessions

Aside: BGP recommendations (2)

- Many operators use the following strategy:
  1. Announce aggregates to transits only
  2. Split aggregates in half, and announce the halves to peers (IXP and private) – the aggregates themselves are not announced
  - Which means:
    - Peering traffic will always use peering links (as more specific route available)
    - Leaks of IX announced prefixes easy to see in default free zone
    - Avoids situations where IXP peers prefer path via their upstream using local preference!



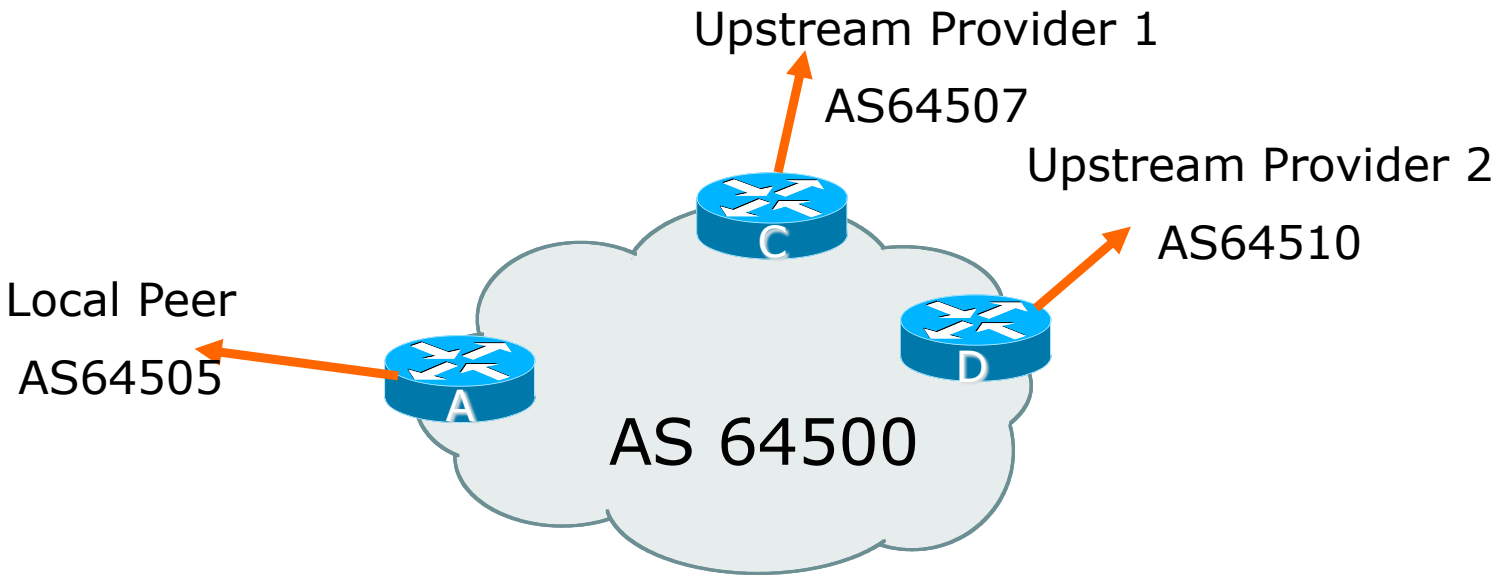
Service Provider Multihoming

Two upstreams, one local peer

Two Upstreams, One Local Peer

- Connect to both upstream transit providers to see the "Internet"
  - Provides external redundancy and diversity – the reason to multihome
- Connect to the local peer so that local traffic stays local
  - Saves spending valuable $ on upstream transit costs for local traffic
- (Situation is similar for IXP as well)

Two Upstreams, One Local Peer



Two Upstreams, One Local Peer

- Announce /19 aggregate on each link
- Accept default route only from upstreams
  - Either 0.0.0.0/0 or a network which can be used as default
- Accept all routes originated by local peer
- Note separation of Router C and D
  - Single edge router means no redundancy
- Router A
  - Same routing configuration as in example with one upstream and one local peer

Two Upstreams, One Local Peer

- Router C Configuration

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.1 remote-as 64507
  neighbor 100.66.10.1 prefix-list DEFAULT in
  neighbor 100.66.10.1 prefix-list AGGREGATE out
  neighbor 100.66.10.1 activate
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
ip prefix-list DEFAULT permit 0.0.0.0/0
!
ip route 100.64.0.0 255.255.224.0 null0
```

Two Upstreams, One Local Peer

- Router D Configuration

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.5 remote-as 64510
  neighbor 100.66.10.5 prefix-list DEFAULT in
  neighbor 100.66.10.5 prefix-list AGGREGATE out
  neighbor 100.66.10.5 activate
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
ip prefix-list DEFAULT permit 0.0.0.0/0
!
ip route 100.64.0.0 255.255.224.0 null0
```

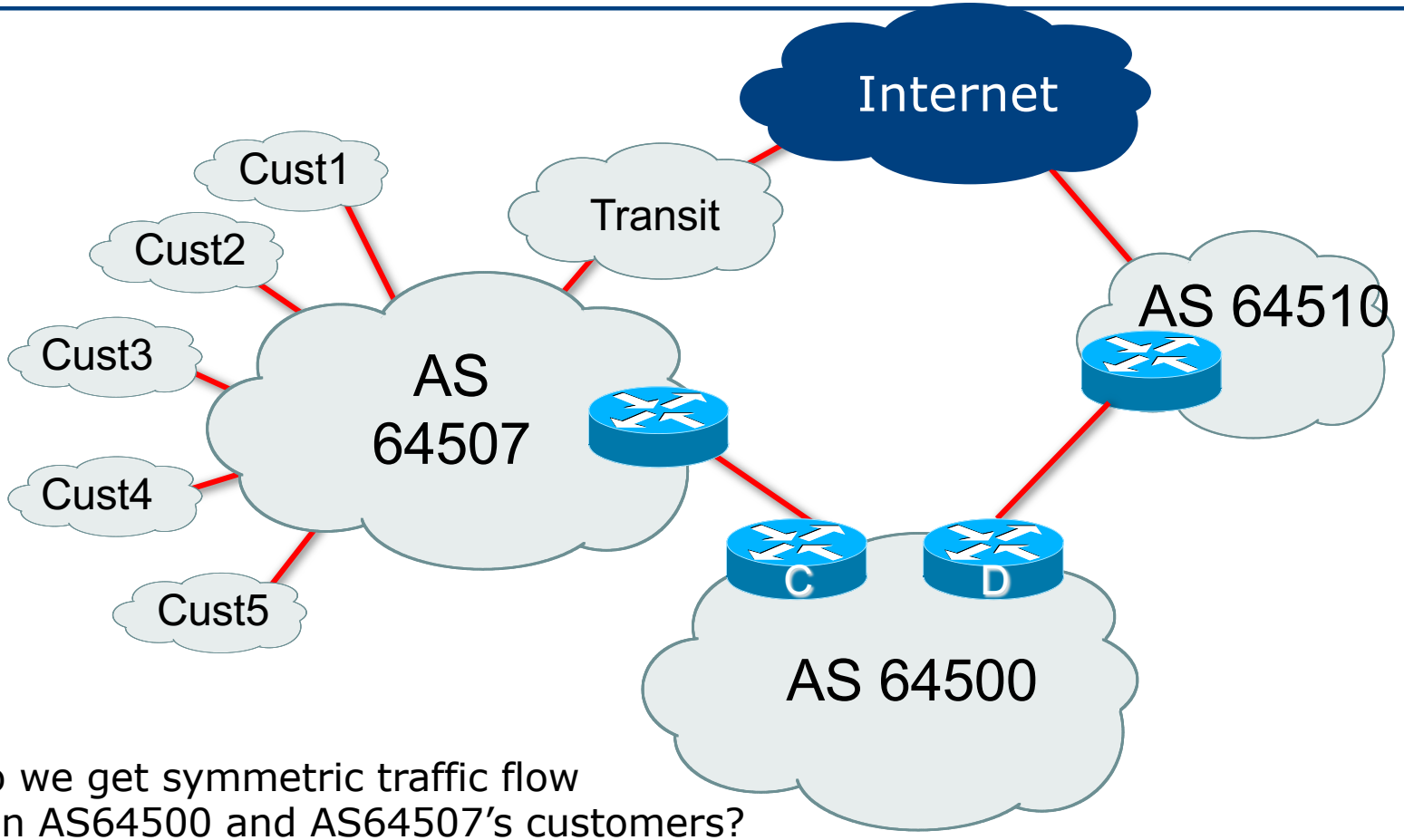
Two Upstreams, One Local Peer

- This is the simple configuration for Router C and D
- Traffic out to the two upstreams will take nearest exit
  - Inexpensive routers required
  - This is not useful in practice especially for international links
  - Loadsharing needs to be better

Two Upstreams, One Local Peer

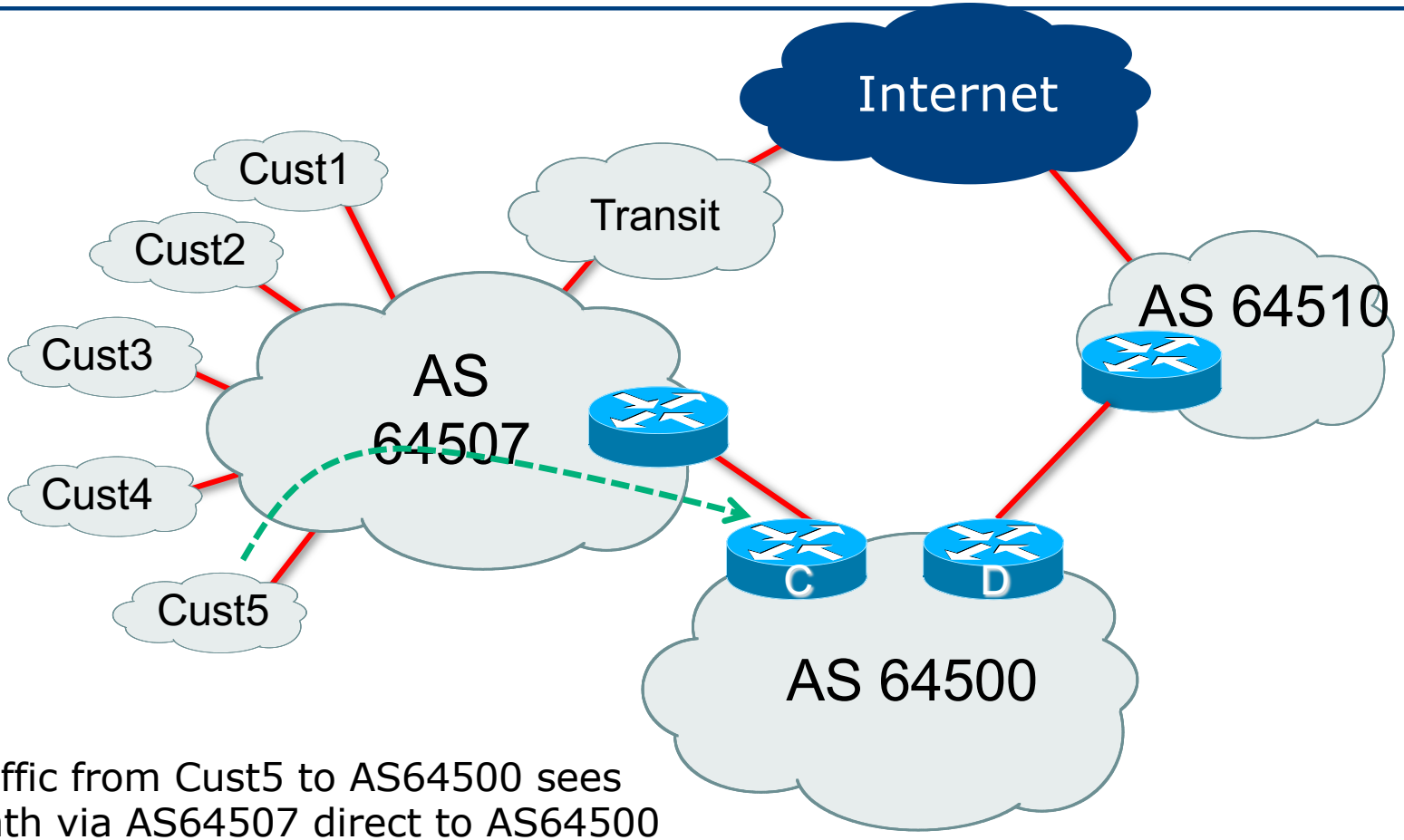
- Better configuration options:
  - Accept full routing from both upstreams
    - **Expensive & unnecessary!**
  - Accept default from one upstream and some routes from the other upstream (partial routes)
    - **The way to go!**
  - Next slides will look at both scenarios
    - And show why "partial routes" is far more manageable and scalable

Loadsharing with different ASes

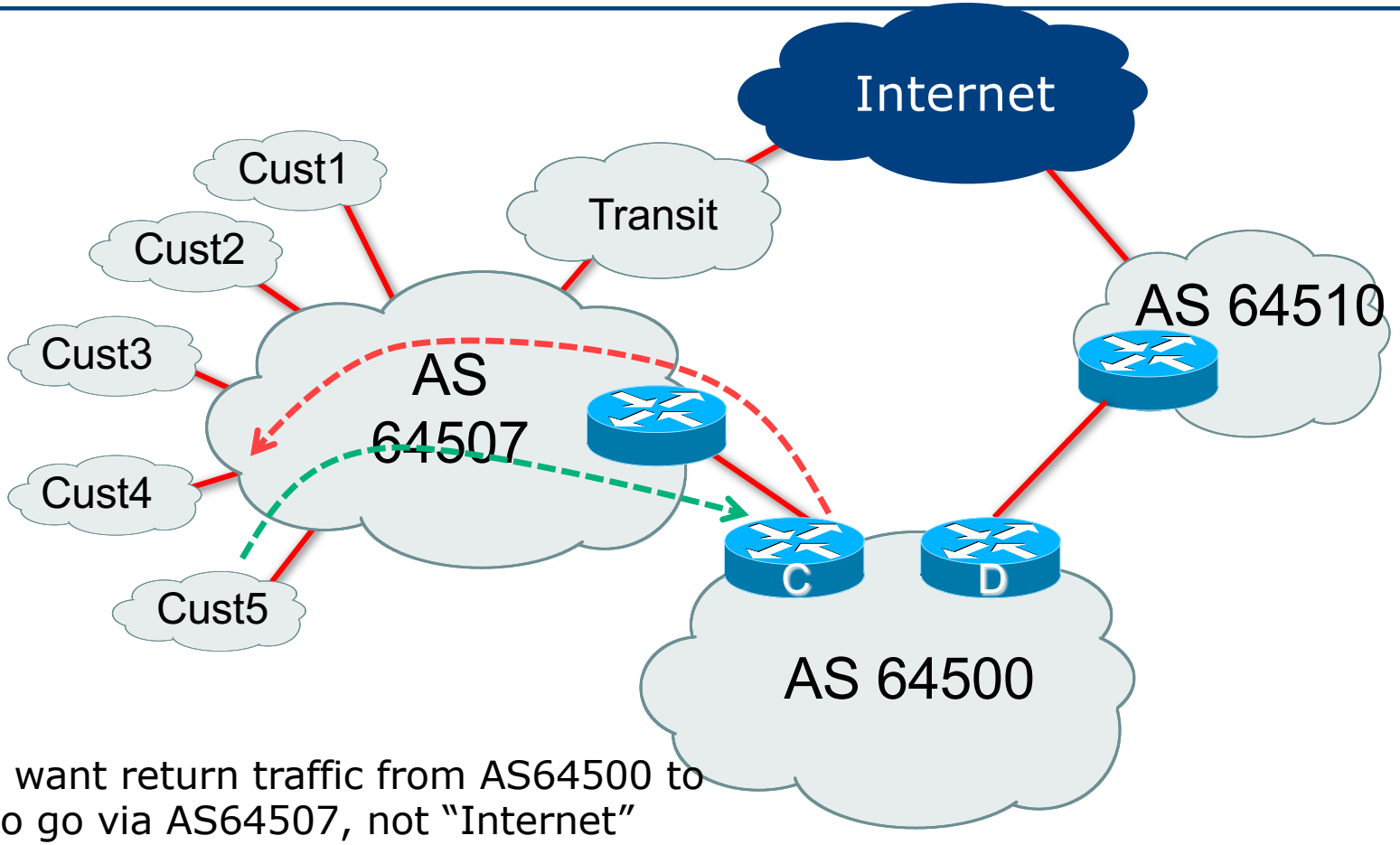


How do we get symmetric traffic flow between AS64500 and AS64507's customers?

Loadsharing with different ASes



Loadsharing with different ASes



We want return traffic from AS64500 to Cust5 to go via AS64507, not "Internet"

Two Upstreams, One Local Peer
Full Routes

- Strategy:
  - Accept full routes from both upstreams
  - Attempt to load balance with those full tables received
    - Consumes large amounts of router control plane CPU and memory
    - Policy changes result in route-refresh for the entire BGP feed, impacting the EBGP peer control plane CPU too 😬
  - Not very sophisticated
    - (The "big hammer" approach which gets harder and harder to manage as the Global IPv4 routing table gets larger and larger)

Two Upstreams, One Local Peer
Full Routes

- Router C Configuration

Allow all prefixes apart from RFC6890 blocks

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.1 remote-as 64507
  neighbor 100.66.10.1 prefix-list RFC6890-deny in
  neighbor 100.66.10.1 prefix-list AGGREGATE out
  neighbor 100.66.10.1 route-map AS64507-loadshare in
  neighbor 100.66.10.1 activate
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
!
! See http://tools.ietf.org/html/rfc6890

...next slide
```

Two Upstreams, One Local Peer
Full Routes

```
ip route 100.64.0.0 255.255.224.0 null0
!
ip as-path access-list 10 permit ^(64507_)+$
ip as-path access-list 10 permit ^(64507_)+_[0-9]+$
!
route-map AS64507-loadshare permit 10
 match ip as-path 10
 set local-preference 120
!
route-map AS64507-loadshare permit 20
 set local-preference 80
!
```

Two Upstreams, One Local Peer
Full Routes

- Router D Configuration

Allow all prefixes apart from RFC6890 blocks

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.5 remote-as 64510
  neighbor 100.66.10.5 prefix-list RFC6890-deny in
  neighbor 100.66.10.5 prefix-list AGGREGATE out
  neighbor 100.66.10.5 activate
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
!
! See http://tools.ietf.org/html/rfc6890
```

Two Upstreams, One Local Peer Full Routes

- Router C configuration:
  - Accept full routes from AS64507
  - Tag prefixes originated by AS64507 and AS64507's neighbouring ASes with local preference 120
    - Traffic to those ASes will go over AS64507 link
  - Remaining prefixes tagged with local preference of 80
    - Traffic to other all other ASes will go over the link to AS64510
- Router D configuration same as Router C without the route-map

Two Upstreams, One Local Peer
Full Routes

- Full routes from upstreams
  - Summary of routes received:

ASN	Full Routes		Partial Routes	
AS64510	970000	@lp 100		
AS64507	30000 970000	@lp 120 @lp 80		
Total	1940000			

Two Upstreams, One Local Peer
Full Routes

- Full routes from upstreams
  - Expensive – needs lots of memory and CPU
  - Need to play preference games
  - Previous example is only an example – real life will need improved fine-tuning!
  - Previous example doesn't consider inbound traffic – see earlier in presentation for examples

Two Upstreams, One Local Peer
Partial Routes: Strategy

- Ask one upstream for a default route
  - Easy to originate default towards a BGP neighbour
- Ask other upstream for a full routing table
  - Then filter this routing table based on neighbouring ASN
  - For example, you want traffic to their neighbours to go over the link to that AS
  - Most of what upstream sends is thrown away
  - Easier than asking the upstream to set up custom BGP filters for you

Two Upstreams, One Local Peer Partial Routes

- Router C Configuration

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.1 remote-as 64507
  neighbor 100.66.10.1 prefix-list RFC6890-deny in
  neighbor 100.66.10.1 prefix-list AGGREGATE out
  neighbor 100.66.10.1 filter-list 10 in
  neighbor 100.66.10.1 route-map TAG-DEFAULT-low in
  neighbor 100.66.10.1 activate
!
```

Allow all prefixes apart from RFC6890 blocks

AS filter-list filters prefixes based on origin ASN

Two Upstreams, One Local Peer
Partial Routes

```
ip prefix-list AGGREGATE permit 100.64.0.0/19
ip prefix-list DEFAULT permit 0.0.0.0/0
!
ip route 100.64.0.0 255.255.224.0 null0
!
ip as-path access-list 10 permit ^(64507_)+$
ip as-path access-list 10 permit ^(64507_)+_[0-9]+$
!
route-map TAG-DEFAULT-low permit 10
 description Default route gets local pref 80
 match ip address prefix-list DEFAULT
 set local-preference 80
!
route-map TAG-DEFAULT-low permit 20
 description All other routes are untouched
!
```

Two Upstreams, One Local Peer Partial Routes

- Router D Configuration

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.5 remote-as 64510
  neighbor 100.66.10.5 prefix-list DEFAULT in
  neighbor 100.66.10.5 prefix-list AGGREGATE out
  neighbor 100.66.10.5 activate
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
ip prefix-list DEFAULT permit 0.0.0.0/0
!
ip route 100.64.0.0 255.255.224.0 null0
```

Two Upstreams, One Local Peer Partial Routes

- Router C configuration:
  - Accept full routes from AS64507
    - (or get them to send less)
  - Filter ASNs so only AS64507 and AS64507's neighbouring ASes are accepted
  - Allow default, and set it to local preference 80
  - Traffic to those ASes will go over AS64507 link
  - Traffic to other all other ASes will go over the link to AS64510
  - If AS64510 link fails, backup via AS64507 – and vice-versa

Two Upstreams, One Local Peer Partial Routes

- Partial routes from upstreams
  - Summary of routes received:

ASN	Full Routes		Partial Routes	
AS64510	970000	@lp 100	1	@lp 100
AS64507	30000 970000	@lp 120 @lp 80	30000 1	@lp 100 @lp 80
Total	1940000		30002	

Distributing Default route with IGP

- Router C IGP Configuration

```
router ospf 64500
 default-information originate metric 30
!
```

- Router D IGP Configuration

```
router ospf 64500
 default-information originate metric 10
!
```

- Primary path is via Router D, with backup via Router C
  - Preferred over carrying default route in IBGP
- See the “BGP Case Studies” presentation for more details

Two Upstreams, One Local Peer Partial Routes

- Partial routes from upstreams
  - Not expensive – only carry the routes necessary for loadsharing
  - Need to filter on AS paths
  - Previous example is only an example – real life will need improved fine-tuning!
  - Previous example doesn't consider inbound traffic – see earlier in presentation for examples

Aside: Configuration Recommendation

- When distributing internal default by IBGP or OSPF/ISIS
  - Make sure that routers connecting to private peers or to IXPs do **NOT** carry the default route
  - Otherwise those peers could point a default route to you and unintentionally transit your backbone
  - Simple fix for Private Peer/IXP routers:

```
ip route 0.0.0.0 0.0.0.0 null0
ipv6 route ::/0 null0
```

Service Provider Multihoming

Three upstreams, unequal bandwidths

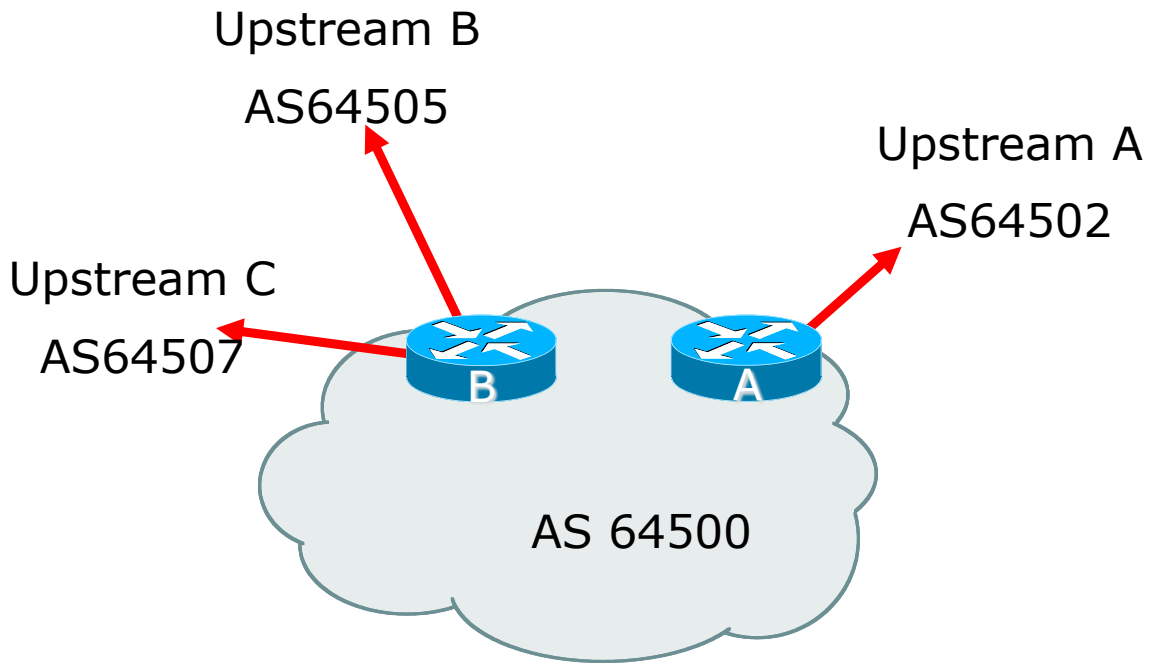
Three upstreams, unequal bandwidths

- This example based on real life complex 3-upstream configuration
- Autonomous System has three upstreams
  - 2.5Gbps to Upstream A
  - 1Gbps to Upstream B
  - 622Mbps to Upstream C
- What is the strategy here?
  - One option is full table from each
    - 3x 970k prefixes ⇒ 2910k paths
  - Other option is partial table and defaults from each
    - How??

Strategy

- Two external routers (gives router redundancy)
  - Do NOT need three routers for this
- Connect biggest bandwidth to one router
  - Most of inbound and outbound traffic will go here
- Connect the other two links to the second router
  - Provides maximum backup capacity if primary link fails
- Use the biggest link as default
  - Most of the inbound and outbound traffic will go here
- Do the traffic engineering on the two smaller links
  - Focus on regional traffic needs

Diagram



- Router A has 2.5Gbps link to Upstream A
- Router B has 1Gbps and 622Mbps links to Upstreams B&C

Outbound load-balancing strategy

- Available BGP feeds from Transit providers:
  - Full table
  - Customer prefixes and default
  - Default Route
- These are the common options on Internet today
  - Very rare for any provider to offer anything different
  - Very rare for any provider to customise BGP feed for a customer

Outbound load-balancing strategy

- Accept only a default route from the provider with the largest connectivity, Upstream A
  - Because most of the traffic is going to use this link
- If Upstream A won't provide a default:
  - Still run BGP with them, but discard all prefixes
  - Point static default route to the upstream link
  - Distribute the default in the IGP
- Request the full table from Upstream B & C
  - Most of this will be thrown away
  - ("Default plus customers" is not enough)

Outbound load-balancing strategy

- How to decide what to keep and what to discard from Upstreams B & C?
  - Most traffic will use Upstream A link — so we need to find a good/useful subset
- Discard prefixes transiting the global transit providers
  - Global transit providers generally appear in most non-local or regional AS-PATHs
- Discard prefixes with Upstream A's ASN in the path
  - Makes more sense for traffic to those destinations to go via the link to Upstream A

Outbound load-balancing strategy

- Global Transit (Tier-1) Providers at the time of this exercise

ASN	Operator (Today)	Operator (Then)
209	Lumen	Qwest
701	Verizon	UUNET
1239	Softbank	Sprint
1299	Arelion	
2914	NTT	NTT/Verio
3549	Lumen	Level3 / GlobalCrossing
3356	Lumen	Level 3
3561	Lumen	SAVVIS / C&W
7018	AT&T	AT&T

Upstream B peering Inbound AS-PATH filter

```
ip as-path access-list 1 deny _209_
ip as-path access-list 1 deny _701_
ip as-path access-list 1 deny _1239_
ip as-path access-list 1 deny _3356_
ip as-path access-list 1 deny _3549_
ip as-path access-list 1 deny _3561_
ip as-path access-list 1 deny _2914_
ip as-path access-list 1 deny _7018_
!
ip as-path access-list 1 deny _ISPA_
ip as-path access-list 1 deny _ISPC_
!
ip as-path access-list 1 permit _ISPB$
ip as-path access-list 1 permit _ISPB_[0-9]+$
ip as-path access-list 1 permit _ISPB_[0-9]+_[0-9]+$
ip as-path access-list 1 permit _ISPB_[0-9]+_[0-9]+_[0-9]+$
ip as-path access-list 1 deny   .*
```

Don’t need Upstream A and Upstream C prefixes via Upstream B

Outbound load-balancing strategy: Upstream B peering configuration

- Part 1: Dropping Global Transit Provider prefixes
  - This can be fine-tuned if traffic volume is not sufficient
  - (More prefixes in = more traffic out)
- Part 2: Dropping prefixes transiting Upstream A & C network
- Part 3: Permitting prefixes from Upstream B, their BGP neighbours, and their neighbours, and their neighbours
  - More AS_PATH permit clauses, the more prefixes allowed in, the more egress traffic
  - Too many prefixes in will mean more outbound traffic than the link to Upstream B can handle

Outbound load-balancing strategy

- Similar AS-PATH filter can be built for the Upstream C BGP peering
- If the same prefixes are heard from both Upstream B and C, then establish proximity of their origin AS to Upstream B or C
  - e.g. Upstream B might be in Japan, with the neighbouring ASN in Europe, yet Upstream C might be in Europe
  - Transit to the ASN via Upstream C makes more sense in this case

Inbound load-balancing strategy

- The largest outbound link should announce just the aggregate
- The other links should announce:
  - The aggregate with AS-PATH prepend
  - Subprefixes of the aggregate, chosen according to traffic volumes to those subprefixes, and according to the services on those subprefixes
- Example:
  - Link to Upstream B could be used just for Broadband customers — so number all such customers out of one contiguous subprefix
  - Link to Upstream C could be used just for Residential customers — so number all such customers out of one contiguous subprefix

Router A: EBGP Configuration Example

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.1 remote 110
  neighbor 100.66.10.1 prefix-list DEFAULT in
  neighbor 100.66.10.1 prefix-list AGGREGATE out
  neighbor 100.66.10.1 activate
!
ip prefix-list DEFAULT permit 0.0.0.0/0
ip prefix-list AGGREGATE permit 100.64.0.0/19
!
```

Router B: EBGP Configuration Example

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.1.1 remote 64505
  neighbor 100.66.1.1 filter-list 1 in
  neighbor 100.66.1.1 prefix-list ISP-B out
  neighbor 100.66.1.1 route-map to-ISP-B out
  neighbor 100.66.1.1 activate
  neighbor 100.67.2.1 remote 64507
  neighbor 100.67.2.1 filter-list 2 in
  neighbor 100.67.2.1 prefix-list ISP-C out
  neighbor 100.67.2.1 route-map to-ISP-C out
  neighbor 100.67.2.1 activate
!
ip prefix-list AGGREGATE permit 100.64.0.0/19
!
```

...next slide

Router B: EBGP Configuration Example

```
ip prefix-list ISP-B permit 100.64.0.0/19
ip prefix-list ISP-B permit 100.64.0.0/21
!
ip prefix-list ISP-C permit 100.64.0.0/19
ip prefix-list ISP-C permit 100.64.28.0/22
!
route-map to-ISP-B permit 10
 match ip address prefix-list AGGREGATE
 set as-path prepend 64500
!
route-map to-ISP-B permit 20
!
route-map to-ISP-C permit 10
 match ip address prefix-list AGGREGATE
 set as-path prepend 64500 64500
!
route-map to-ISP-C permit 20
```

/21 to ISP B "broadband customers"

/22 to ISP C "residential customers"

e.g. Single prepend on ISP B link

e.g. Dual prepend on ISP C link

What about outbound backup?

- We have:
  - Default route from Upstream A by EBGP
  - Mostly discarded full table from Upstreams B&C
- Strategy:
  - Originate default route by OSPF on Router A (with metric 10) — link to Upstream A
  - Originate default route by OSPF on Router B (with metric 20) — links to Upstreams B & C
  - Plus on Router B:
    - Static default route to Upstream B with distance 240
    - Static default route to Upstream C with distance 245
  - When link goes down, static route is withdrawn

Outbound backup: steady state

- Steady state (all links up and active):
  - Default route is to Router A — OSPF metric 10
  - (Because default learned by EBGP ⇒ default is in RIB ⇒ OSPF will originate default)
  - Backup default is to Router B — OSPF metric 20
  - EBGP prefixes learned from upstreams distributed by IBGP throughout backbone
  - (Default can be filtered in IBGP to avoid "RIB failure" error)

Outbound backup: failure examples

- Link to Upstream A down, to Upstreams B&C up:
  - Default route is to Router B — OSPF metric 20
  - (EBGP default gone from RIB, so OSPF on Router A withdraws the default)
- Above is true if link to B or C is down as well
- Link to Upstreams B & C down, link to Upstream A is up:
  - Default route is to Router A — OSPF metric 10
  - (static defaults on Router B removed from RIB, so OSPF on Router B withdraws the default)
- See the "BGP Case Studies" for a more detailed example

Other considerations

- Default route should not be propagated to devices terminating non-transit peers and customers
- Rarely any need to carry default in IBGP
  - Best to filter out default in IBGP mesh peerings
  - Or tag default route with **`no-advertise`** community when learned on EBGP peerings
- Still carry other EBGP prefixes across IBGP mesh
  - Otherwise routers will follow default route rules resulting in suboptimal traffic flow
  - Not a big issue because not carrying full table

Router A: IBGP Configuration Example

- Filtering default route out of IBGP sessions

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor IBGP peer-group
  neighbor IBGP remote-as 64500
  neighbor IBGP prefix-list IBGP-FILTER out
  neighbor 100.64.0.2 peer-group IBGP
  neighbor 100.64.0.2 activate
  neighbor 100.64.0.3 peer-group IBGP
  neighbor 100.64.0.3 activate
!
ip prefix-list IBGP-FILTER deny 0.0.0.0/0
ip prefix-list IBGP-FILTER permit 0.0.0.0/0 le 32
!
```

Router A: EBGP Configuration Example

- Preferred! Tag default route with **no-advertise** community

```
router bgp 64500
 address-family ipv4
  network 100.64.0.0 mask 255.255.224.0
  neighbor 100.66.10.1 remote 64502
  neighbor 100.66.10.1 route-map AS64502-in in
  neighbor 100.66.10.1 prefix-list AGGREGATE out
  neighbor 100.66.10.1 activate
!
ip prefix-list DEFAULT permit 0.0.0.0/0
ip prefix-list AGGREGATE permit 100.64.0.0/19
!
route-map AS64502-in permit 10
 match ip address prefix-list DEFAULT
 set community no-advertise
!
```

Three upstreams, unequal bandwidths: Summary

- Example based on many deployed working multihoming/loadbalancing topologies
- Many variations possible — this one is:
  - Easy to tune
  - Light on border router resources
  - Light on backbone router infrastructure
  - Sparse BGP table ⇒ faster convergence

Multihoming: Outbound Traffic Engineering

ISP/IXP Workshops