Campus Network Design Workshop

Routing Basics

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Routing Concepts

- IPv6
- IPv4
- Routing
- Forwarding
- Some definitions
- Policy options
- Routing Protocols

IPv4

- Internet still uses IPv4
  - (legacy protocol)
  - Addresses are 32 bits long
  - Addresses are written as decimal with each 8-bit range separated by a "."
  - Range from 1.0.0.0 to 223.255.255.255
  - 0.0.0.0 to 0.255.255.255 and 224.0.0.0 to 255.255.255.255 have special uses
- IPv4 address has a network portion and a host portion

IPv6

- Internet is starting to use IPv6
  - Addresses are 128 bits long
  - Addresses are written as hexadecimal with each 16-bit range separated by ":"
  - Internet addresses range from 2000::/16 to 3FFF::/16
  - The remaining IPv6 range is reserved or has "special" uses
- IPv6 address has a network portion and a host portion

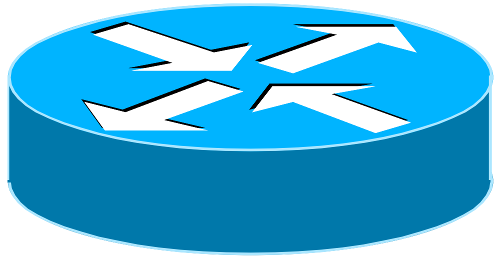
IP address format

- Address and subnet mask
  - IPv4 written as
    - 12.34.56.78 255.255.255.0 or
    - 12.34.56.78/24
  - IPv6 written as
    - 2001:db8::1/126
  - mask represents the number of network bits in the address
    - Usually referred to as the subnet size
  - The remaining bits are the host bits

IP subnets

- IPv4 example – 12.34.56.78/24
  - 32 bits in an IPv4 address
    - 24 bits for the network portion
    - Leaves 8 bits for the host portion
    - 8 bits means there are 2^8 possible hosts on this subnet
- IPv6 example – 2001:db8::1/126
  - 128 bits in an IPv6 address
    - 126 bits for the network portion
    - Leaves 2 bits for the host portion
    - 2 bits means there are 2^2 possible hosts on this subnet

What does a router do?



A day in a life of a router

find path

forward packet, forward packet, forward packet, forward packet…

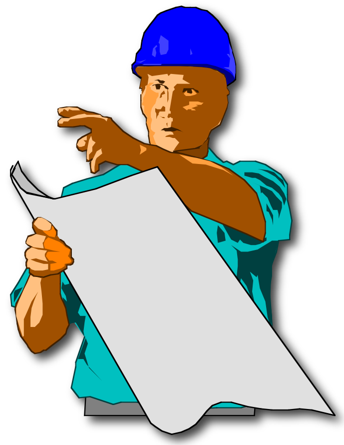
find alternate path

forward packet, forward packet, forward packet, forward packet…

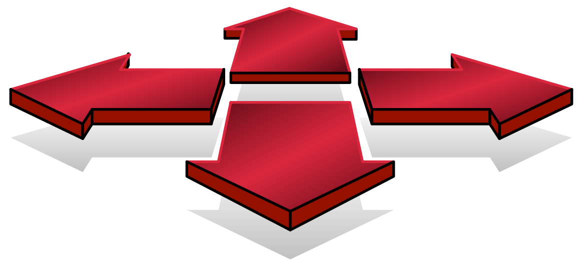
repeat until powered off

Routing versus Forwarding

- Routing = building maps and giving directions



- Forwarding = moving packets between interfaces according to the “directions”



IP Routing – finding the path

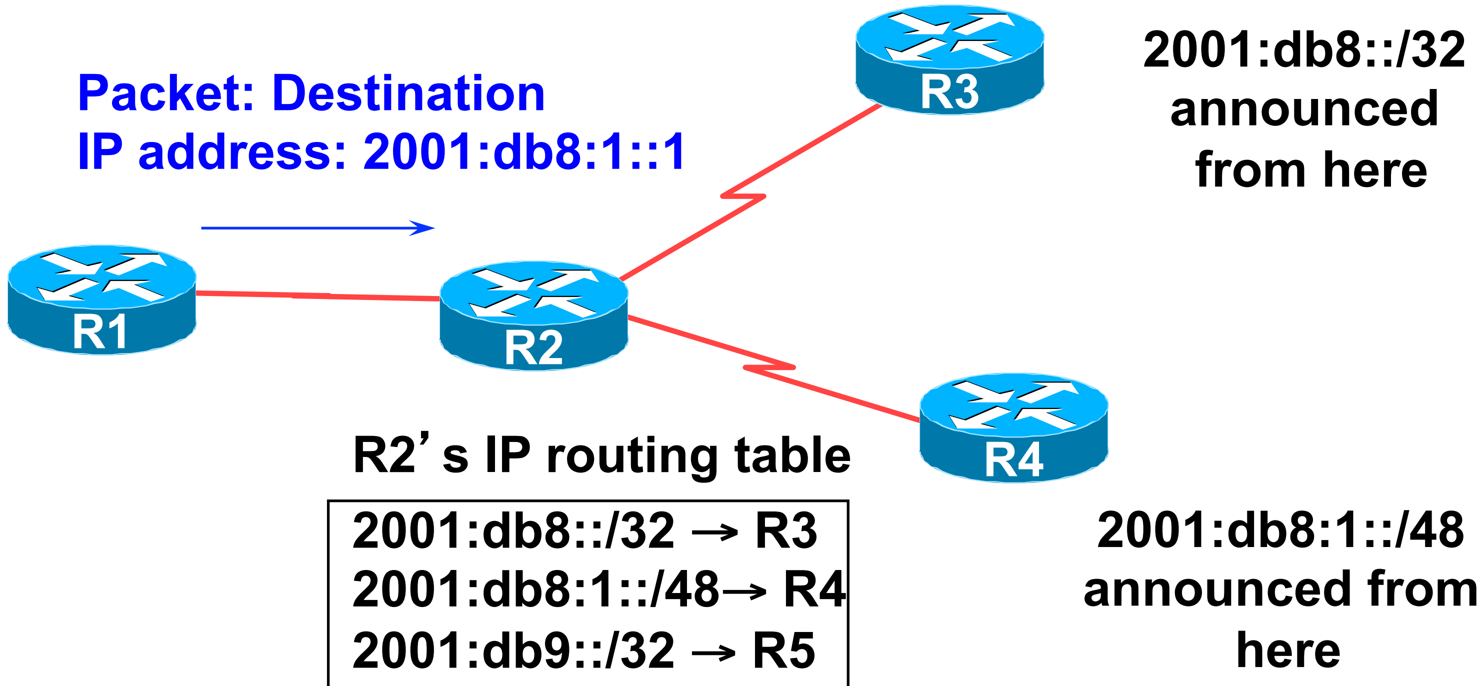
- Path derived from information received from a routing protocol
- Several alternative paths may exist
  - Best path stored in **forwarding** table
- Decisions are updated periodically or as topology changes (event driven)
- Decisions are based on:
  - Topology, policies and metrics (hop count, filtering, delay, bandwidth, etc.)

IP route lookup

- Based on destination IP address
- “longest match” routing
  - More specific prefix preferred over less specific prefix
  - **Example**: packet with destination of 2001:db8:1::1/128 is sent to the router announcing 2001:db8:1::/48 rather than the router announcing 2001:db8::/32.

IP route lookup

- Based on destination IP address



R2's IP routing table

2001:db8::/32 → R3
2001:db8:1::/48→ R4
2001:db9::/32 → R5
2001:dba::/32 → R6
……

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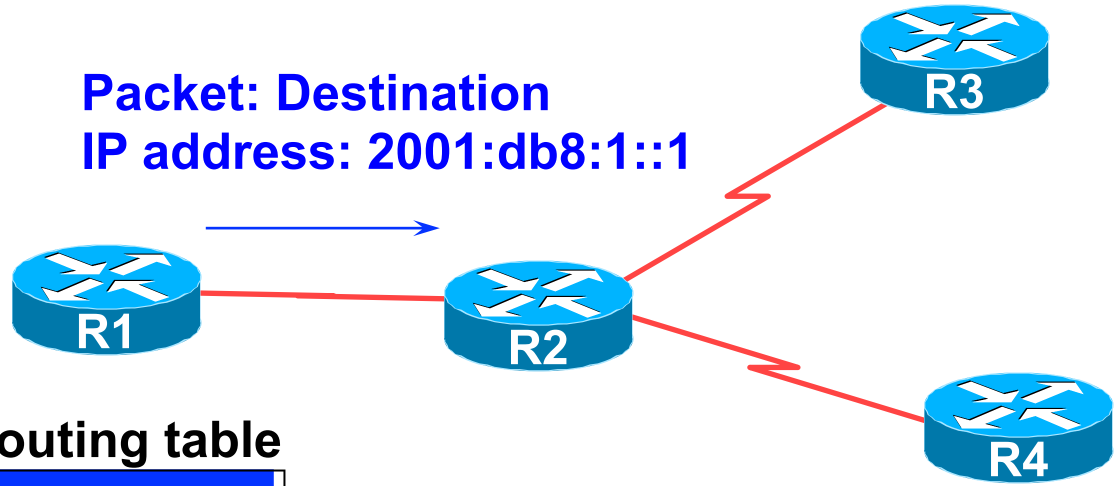
IP route lookup: Longest match routing

- Based on destination IP address

Packet: Destination
IP address: 2001:db8:1::1



2001:db8::/32 announced from here

2001:db8:1::/48 announced from here

R2's IP routing table

2001:db8::/32 → R3
2001:db8:1::/48 → R4
2001:db9::/32 → R5
2001:dba::/32 → R6
……

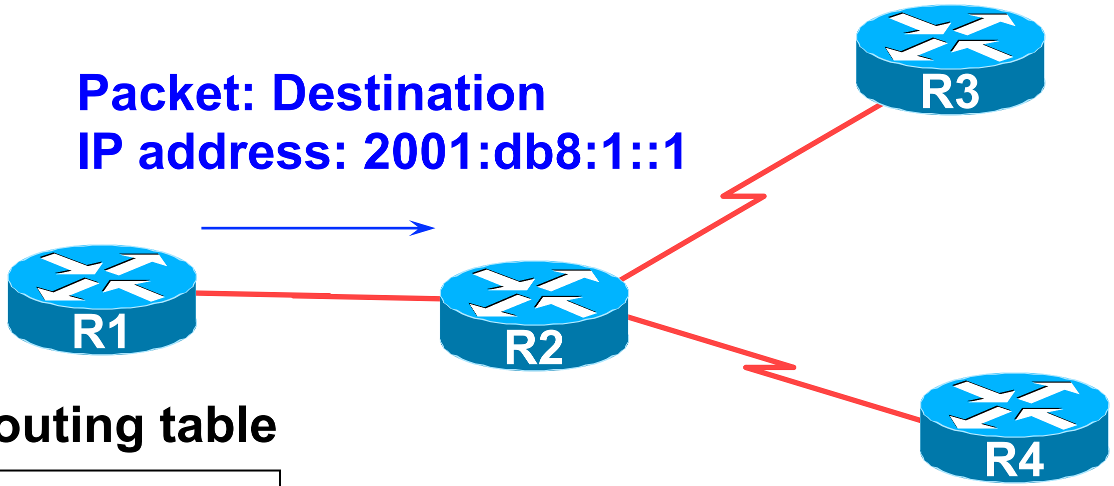
2001:db8:1::1 && ffff:ffff::
vs.
2001:db8:: && ffff:ffff::

Match!

IP route lookup: Longest match routing

- Based on destination IP address

Packet: Destination
IP address: 2001:db8:1::1



2001:db8::/32 announced from here

2001:db8:1::/16 announced from here

R2's IP routing table

2001:db8::/32 → R3
2001:db8:1::/48 → R4
2001:db9::/32 → R5
2001:dba::/32 → R6
……

2001:db8:1::1 && ffff:ffff:ffff::
vs.
2001:db8:1:: && ffff:ffff:ffff::

Match as well!

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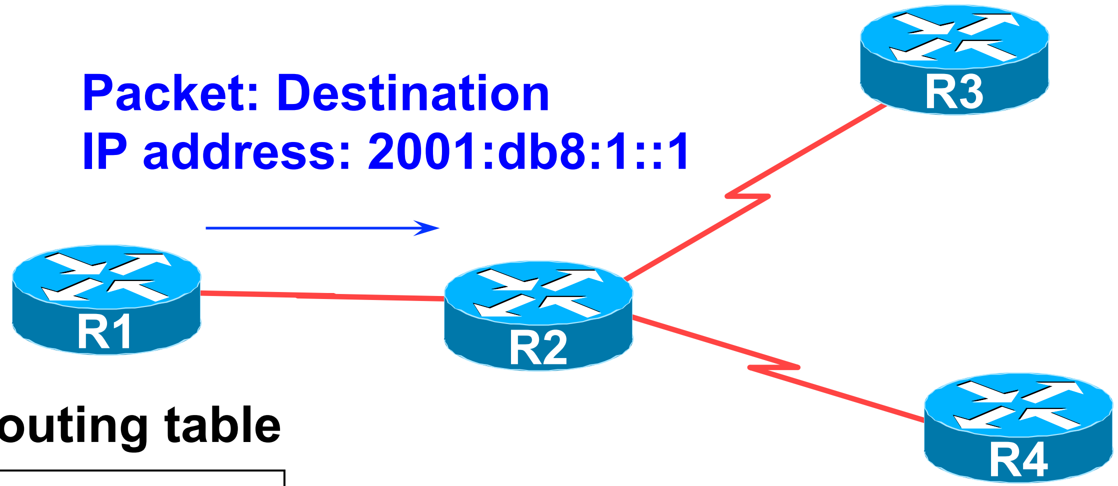
IP route lookup: Longest match routing

- Based on destination IP address

Packet: Destination IP address: 2001:db8:1::1



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R2's IP routing table

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2001:dba::/32 → R6
……

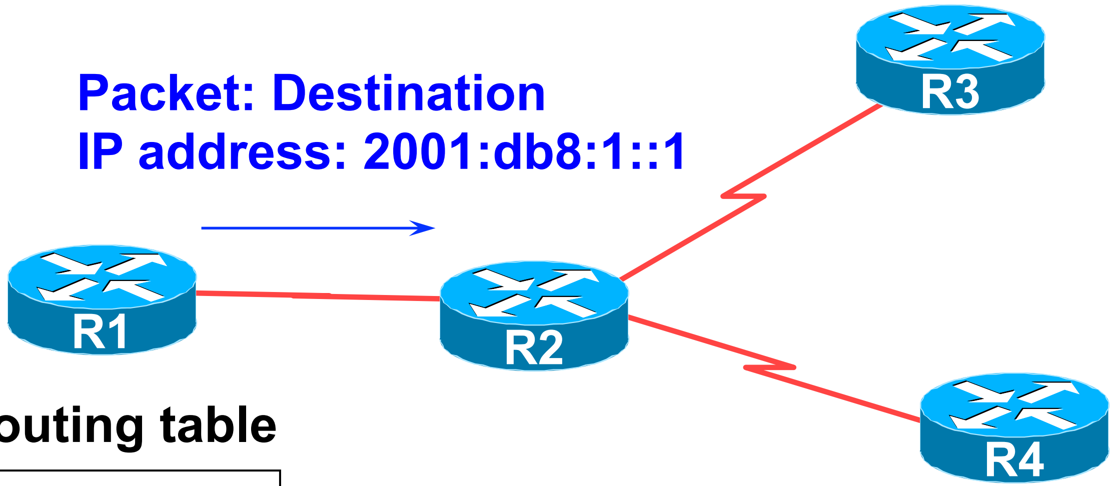
2001:db8:1::1 && ffff:ffff::
vs.
2001:db9:: && ffff:ffff::

Does not match!

IP route lookup: Longest match routing

- Based on destination IP address

Packet: Destination IP address: 2001:db8:1::1



2001:db8::/32 announced from here

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R2's IP routing table

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2001:db8:1::1 && ffff:ffff::
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Does not match!

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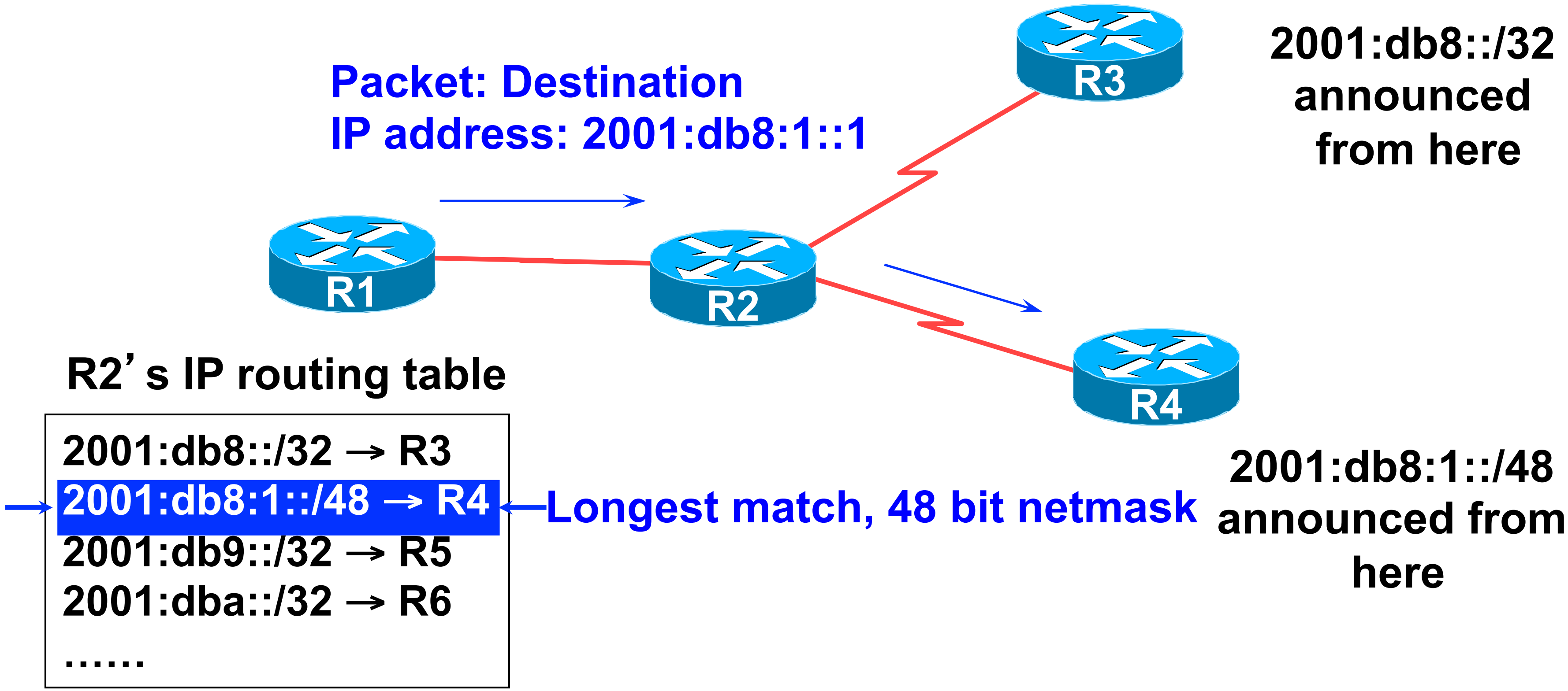
IP route lookup: Longest match routing

- Based on destination IP address



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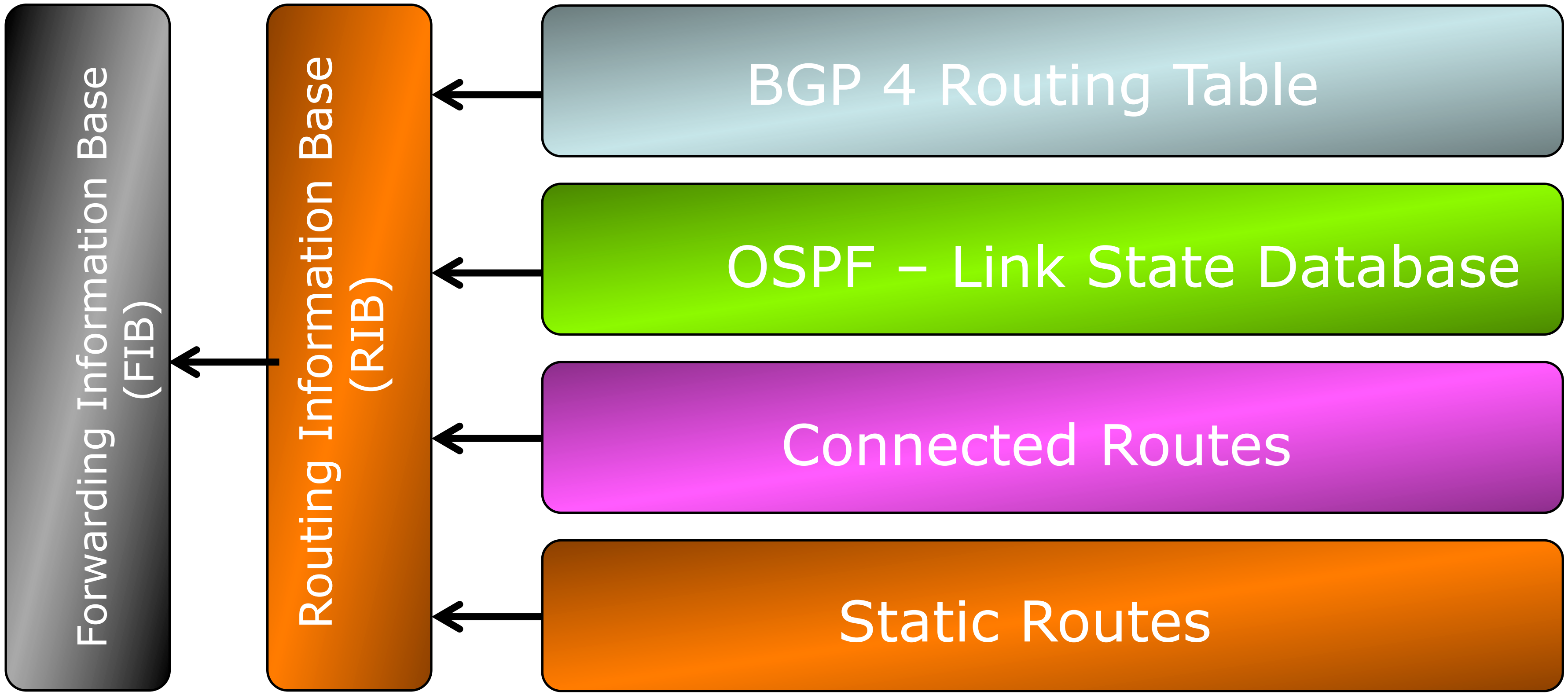
IP Forwarding

- Router decides which interface a packet is sent to
- Forwarding table populated by routing process
- Forwarding decisions:
  - destination address
  - class of service (fair queuing, precedence, others)
  - local requirements (packet filtering)
- Forwarding is usually aided by special hardware

Routing Tables Feed the Forwarding Table



The FIB

- FIB is the Forwarding Table
  - It contains destinations and the interfaces to get to those destinations
  - Used by the router to figure out where to send the packet
  - Careful! Some people still call this a route!
  - Cisco IOS: “show ip cef”

The RIB

- RIB is the Routing Table
  - It contains a list of all the destinations and the various next hops used to get to those destinations – and lots of other information too!
  - One destination can have lots of possible next-hops – only the best next-hop goes into the FIB
  - Cisco IOS: “show ip route”

Explicit versus Default Routing

- Default:
  - Simple, cheap (CPU, memory, bandwidth)
  - No overhead
  - Low granularity (metric games)
- Explicit: (default free zone)
  - Complex, expensive (CPU, memory, bandwidth)
  - High overhead
  - High granularity (every destination known)
- Hybrid:
  - Minimise overhead
  - Provide useful granularity
  - Requires some filtering knowledge

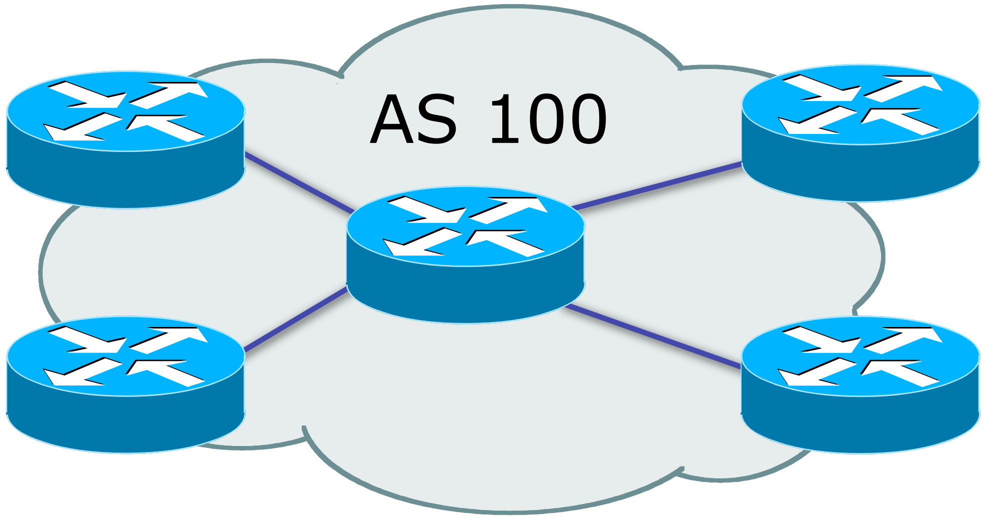
Egress Traffic

- How packets leave your network
- Egress traffic depends on:
  - Route availability (what others send you)
  - Route acceptance (what you accept from others)
  - Policy and tuning (what you do with routes from others)
  - Peering and transit agreements

Ingress Traffic

- How packets get to your network and your customers' networks
- Ingress traffic depends on:
  - What information you send and to whom
  - Based on your addressing and AS's
  - Based on others' policy (what they accept from you and what they do with it)

Autonomous System (AS)

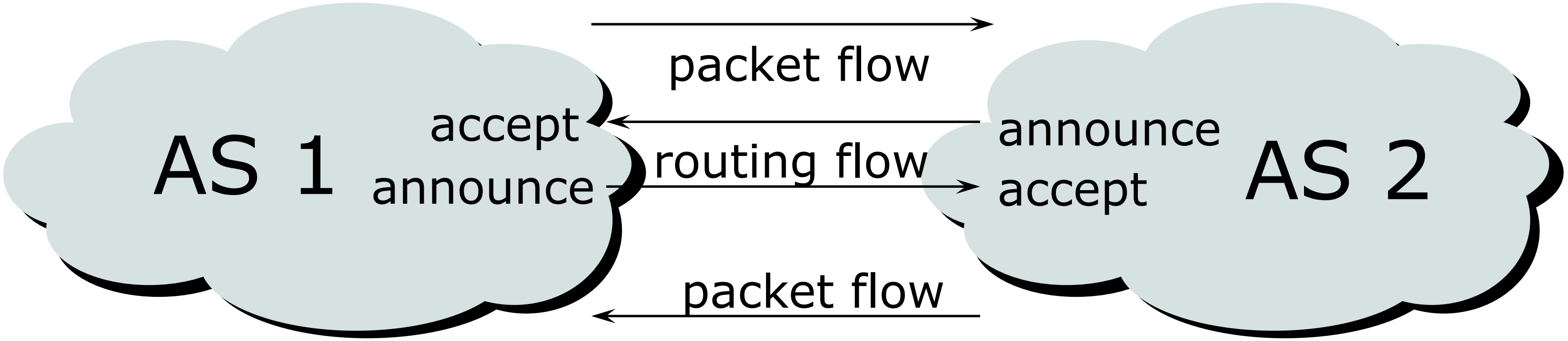


- Collection of networks with same routing policy
- Single routing protocol
- Usually under single ownership, trust and administrative control

Definition of terms

- Neighbours
  - AS's which directly exchange routing information
  - Routers which exchange routing information
- Announce
  - send routing information to a neighbour
- Accept
  - receive and use routing information sent by a neighbour
- Originate
  - insert routing information into external announcements (usually as a result of the IGP)
- Peers
  - routers in neighbouring AS's or within one AS which exchange routing and policy information

Routing flow and packet flow



For networks in AS1 and AS2 to communicate:

AS1 must announce to AS2

AS2 must accept from AS1

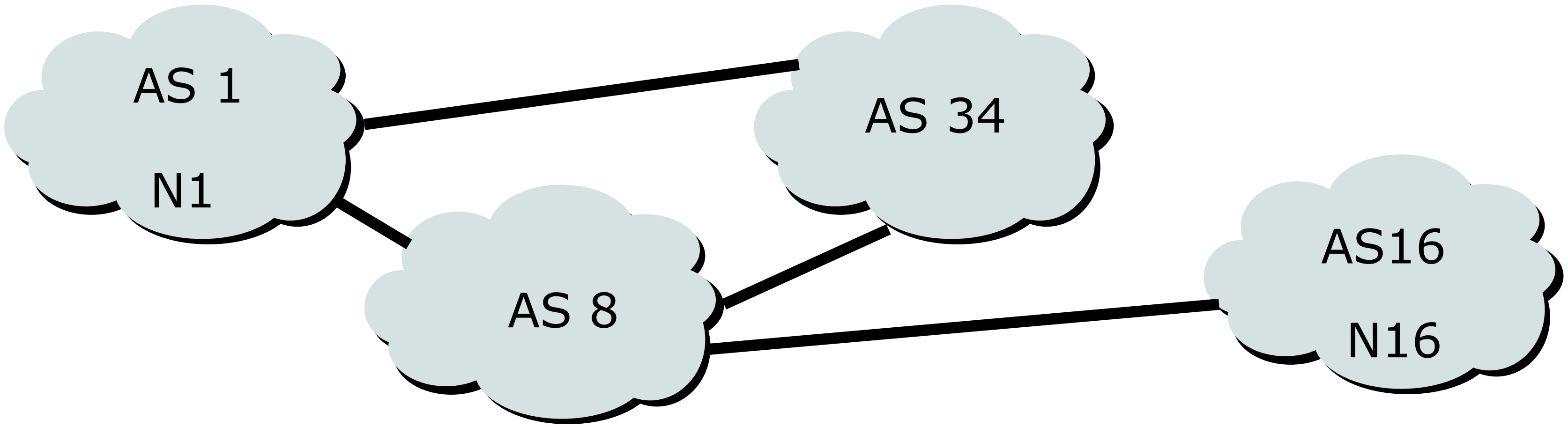
AS2 must announce to AS1

AS1 must accept from AS2

Routing flow and Traffic flow

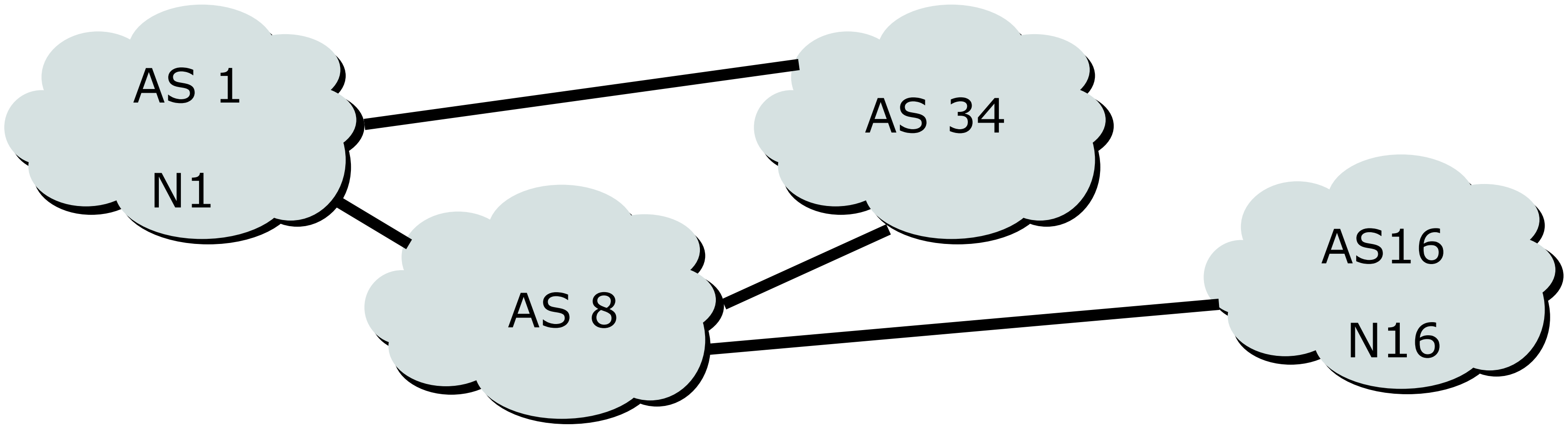
- Traffic flow is always in the opposite direction of the flow of Routing information
  - Filtering outgoing routing information inhibits traffic flow inbound
  - Filtering inbound routing information inhibits traffic flow outbound

Routing Flow/Packet Flow: With multiple ASes



- For net N1 in AS1 to send traffic to net N16 in AS16:
  - AS16 must originate and announce N16 to AS8.
  - AS8 must accept N16 from AS16.
  - AS8 must announce N16 to AS1 or AS34.
  - AS1 must accept N16 from AS8 or AS34.
- For two-way packet flow, similar policies must exist for N1

Routing Flow/Packet Flow: With multiple ASes

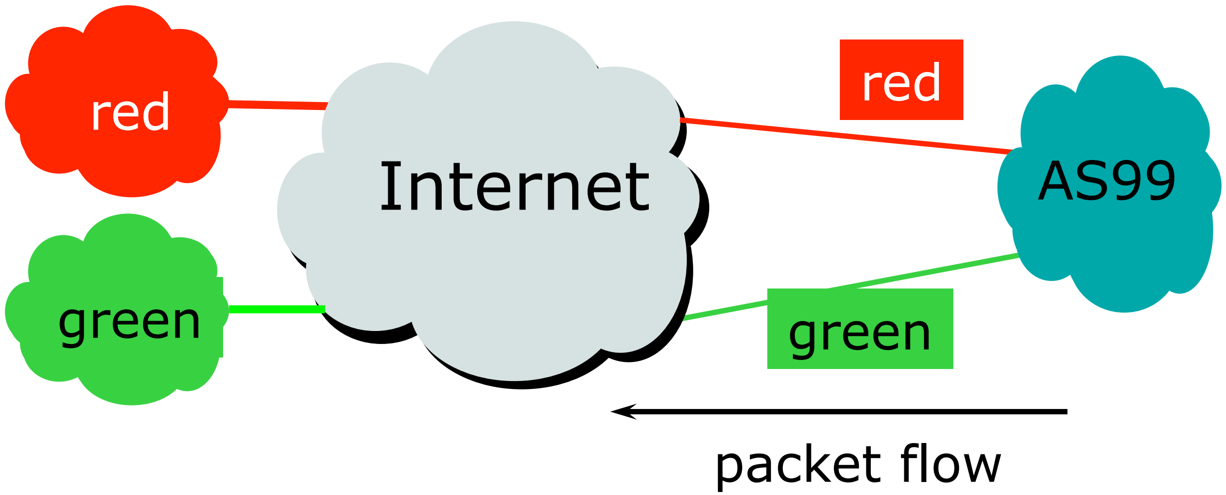


- As multiple paths between sites are implemented it is easy to see how policies can become quite complex.

Routing Policy

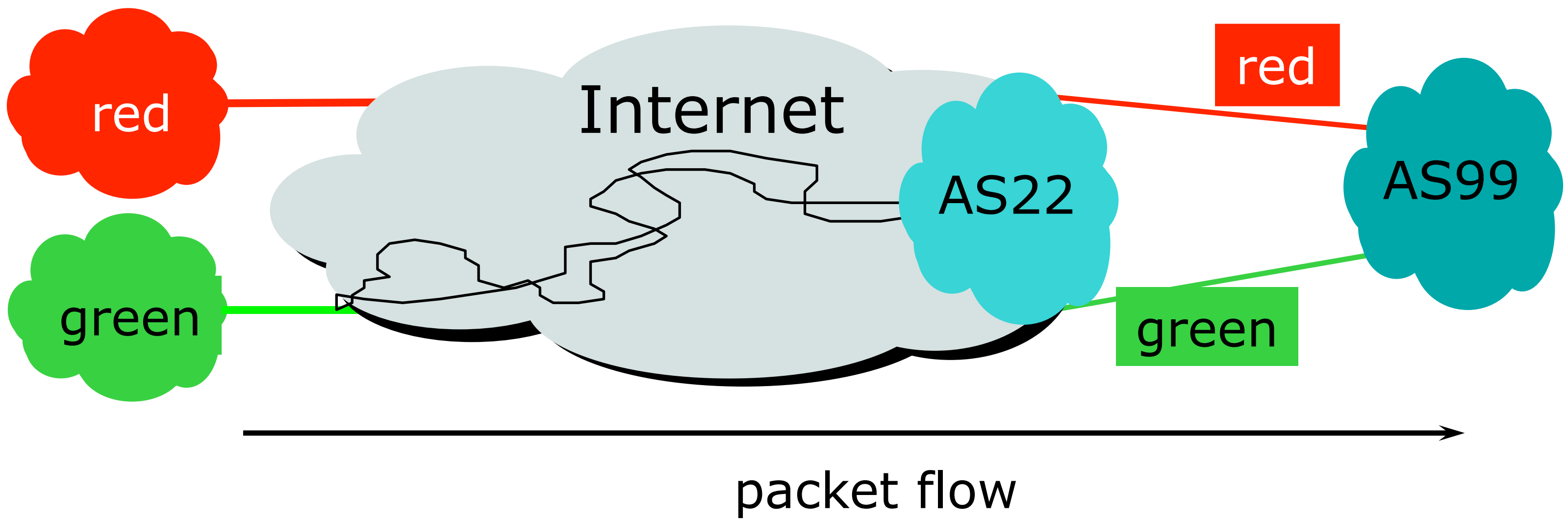
- Used to control traffic flow in and out of an ISP network
- ISP makes decisions on what routing information to accept and discard from its neighbours
  - Individual routes
  - Routes originated by specific ASes
  - Routes traversing specific ASes
  - Routes belonging to other groupings
    - Groupings which you define as you see fit

Routing Policy Limitations



- AS99 uses red link for traffic to the red AS and the green link for remaining traffic
- To implement this policy, AS99 has to:
  - Accept routes originating from the red AS on the red link
  - Accept all other routes on the green link

Routing Policy Limitations



- AS99 would like packets coming from the green AS to use the green link.
- But unless AS22 cooperates in pushing traffic from the green AS down the green link, there is very little that AS99 can do to achieve this aim

Routing Policy Issues

- June 2016:
  - 28700 IPv6 prefixes & 595000 IPv4 prefixes
    - Not realistic to set policy on all of them individually
  - 53900 origin AS’s
    - Too many to try and create individual policies for
- Routes tied to a specific AS or path may be unstable regardless of connectivity
- Solution: Groups of AS’s are a natural abstraction for filtering purposes

Routing Protocols

We now know what routing means…

…but what do the routers get up to?

And why are we doing this anyway?

1: How Does Routing Work?

- Internet is made up of the ISPs who connect to each other's networks
- How does an ISP in Kenya tell an ISP in Japan what customers they have?
- And how does that ISP send data packets to the customers of the ISP in Japan, and get responses back
  - After all, as on a local ethernet, two way packet flow is needed for communication between two devices

2: How Does Routing Work?

- ISP in Kenya could buy a direct connection to the ISP in Japan
  - But this doesn't scale – thousands of ISPs, would need thousands of connections, and cost would be astronomical
- Instead, ISP in Kenya tells his neighbouring ISPs what customers he has
  - And the neighbouring ISPs pass this information on to their neighbours, and so on
  - This process repeats until the information reaches the ISP in Japan

3: How Does Routing Work?

- This process is called “Routing”
- The mechanisms used are called “Routing Protocols”
- Routing and Routing Protocols ensures that
  - The Internet can scale
  - Thousands of ISPs can provide connectivity to each other
  - We have the Internet we see today

4: How Does Routing Work?

- ISP in Kenya doesn't actually tell his neighbouring ISPs the names of the customers
  - (network equipment does not understand names)
- Instead, he has received an IP address block as a member of the Regional Internet Registry serving Kenya
  - His customers have received address space from this address block as part of their "Internet service"
  - And he announces this address block to his neighbouring ISPs – this is called announcing a "route"

Routing Protocols

- Routers use “routing protocols” to exchange routing information with each other
  - **IGP** is used to refer to the process running on routers inside an ISP’s network
  - **EGP** is used to refer to the process running between routers bordering directly connected ISP networks

What Is an IGP?

- **I**nterior **G**ateway **P**rotocol
- Within an Autonomous System
- Carries information about internal infrastructure prefixes
- Two widely used IGPs:
  - OSPF
  - IS-IS

Why Do We Need an IGP?

- ISP backbone scaling
  - Hierarchy
  - Limiting scope of failure
  - Only used for ISP's **infrastructure** addresses, not customers or anything else
  - Design goal is to **minimise** number of prefixes in IGP to aid scalability and rapid convergence

What Is an EGP?

- **E**xterior **G**ateway **P**rotocol
- Used to convey routing information between Autonomous Systems
- De-coupled from the IGP
- Current EGP is BGP

Why Do We Need an EGP?

- Scaling to large network
  - Hierarchy
  - Limit scope of failure
- Define Administrative Boundary
- Policy
  - Control reachability of prefixes
  - Merge separate organisations
  - Connect multiple IGPs

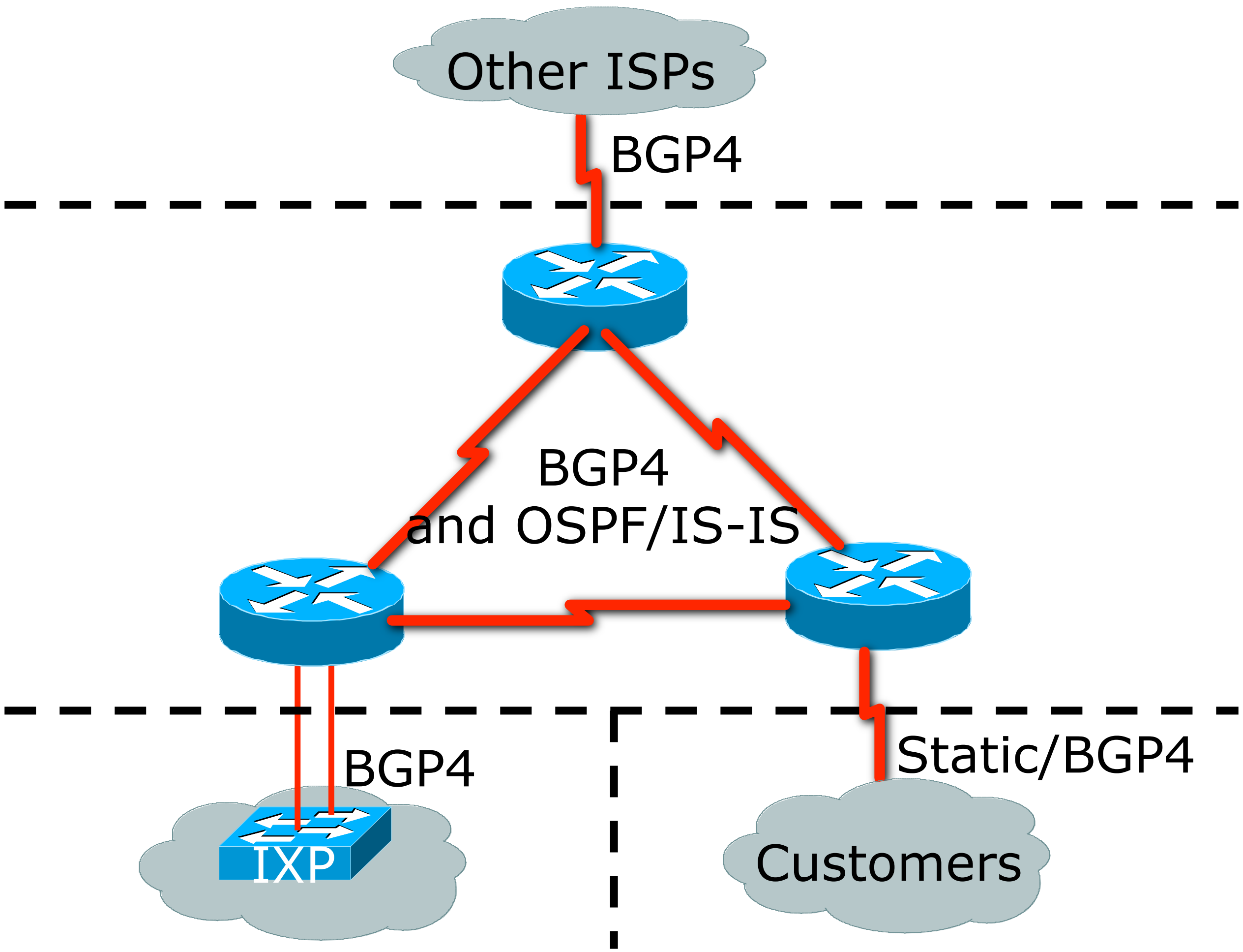
Interior versus Exterior Routing Protocols

- Interior
  - Automatic neighbour discovery
  - Generally trust your IGP routers
  - Prefixes go to all IGP routers
  - Binds routers in one AS together
- Exterior
  - Specifically configured peers
  - Connecting with outside networks
  - Set administrative boundaries
  - Binds AS's together

Interior versus Exterior Routing Protocols

- Interior
  - Carries ISP infrastructure addresses only
  - ISPs aim to keep the IGP small for efficiency and scalability
- Exterior
  - Carries customer prefixes
  - Carries Internet prefixes
  - EGPs are independent of ISP network topology

Hierarchy of Routing Protocols



FYI: Default Administrative Distances

Route Source	Cisco	Juniper	Huawei	Brocade
Connected Interface	**0**	**0**	**0**	**0**
Static Route	**1**	**5**	**60**	**1**
EIGRP Summary Route	5	N/A	?	N/A
External BGP	**20**	**170**	**255**	**20**
Internal EIGRP Route	90	N/A	?	N/A
IGRP	100	N/A	?	N/A
OSPF	**110**	**10**	**10**	**110**
IS-IS	**115**	**18**	**15**	**115**
RIP	120	100	100	120
EGP	140	N/A	N/A	N/A
External EIGRP	170	N/A	?	N/A
Internal BGP	**200**	**170**	**255**	**200**
Unknown	255	255	?	255

Questions?