

# Routing Basics

## ISP Workshops



These materials are licensed under the Creative Commons Attribution-NonCommercial 4.0 International license (<http://creativecommons.org/licenses/by-nc/4.0/>)

Last updated 12<sup>th</sup> December 2018

# 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

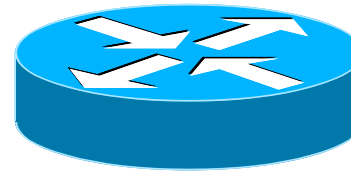
# Routing Concepts

---

- Routers
- Routing
- Forwarding
- Some definitions
- Policy options
- Routing Protocols

# What is a Router?

---



- A router is a layer 3 device
- Used for interconnecting networks at layer 3
- A router generally has at least two interfaces
  - With VLANs a router can have only one interface (known as “router on a stick”)
- A router looks at the destination address in the IP packet, and decides how to forward it

# The Routing Table

---

- ❑ Each router/host has a *routing table*, indicating the path or the next hop for a given destination host or a network
- ❑ The router/host tries to match the destination address of a packet against entries in the routing table
- ❑ If there is a match, the router forwards it to the corresponding gateway router or directly to the destination host
- ❑ Default route is taken if no other entry matches the destination address

# The Routing Table

---

<b>Destination</b>	<b>Next-Hop</b>	<b>Interface</b>
10.40.0.0/16	192.248.40.60	Ethernet0
192.248.0.140/30	Directly connected	Serial1
192.248.40.0/26	Directly connected	Ethernet0
192.248.0.0/17	192.248.0.141	Serial1
203.94.73.202/32	192.248.40.3	Ethernet0
203.115.6.132/30	Directly connected	Serial0
Default	203.115.6.133	Serial0

Typical routing table on a simple edge router

# IP Routing – finding the path

---

- ❑ Routing table entry (the path) is created by the administrator (static) or received from a routing protocol (dynamic)
- ❑ More than one routing protocol may run on a router
  - Each routing protocol builds its own routing table (Local RIB)
- ❑ Several alternative paths may exist
  - Best path selected for the router's Global routing table (RIB)
- ❑ 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

---

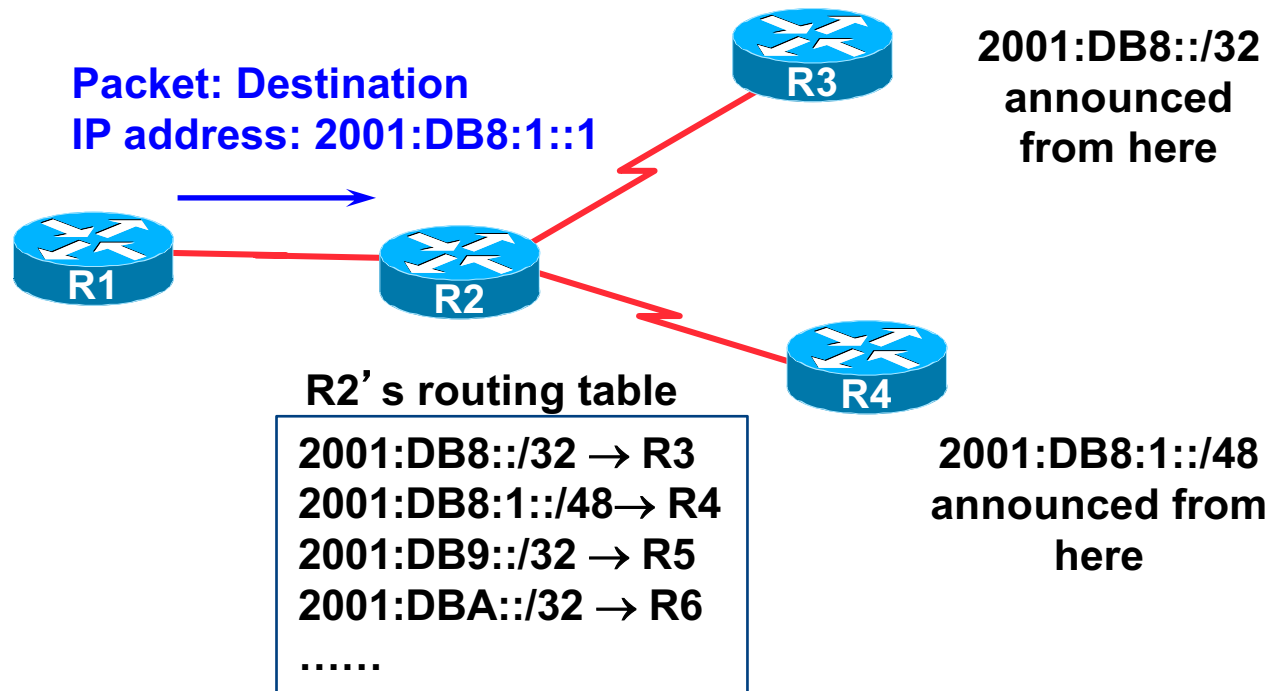
- Based on destination IP address
- “longest match” routing
  - More specific prefix preferred over less specific prefix
  - **Example:** packet with destination of 2001:DB8:1::1/128 is sent to the router announcing 2001:DB8:1::/48 rather than the router announcing 2001:DB8::/32.



# IP route lookup

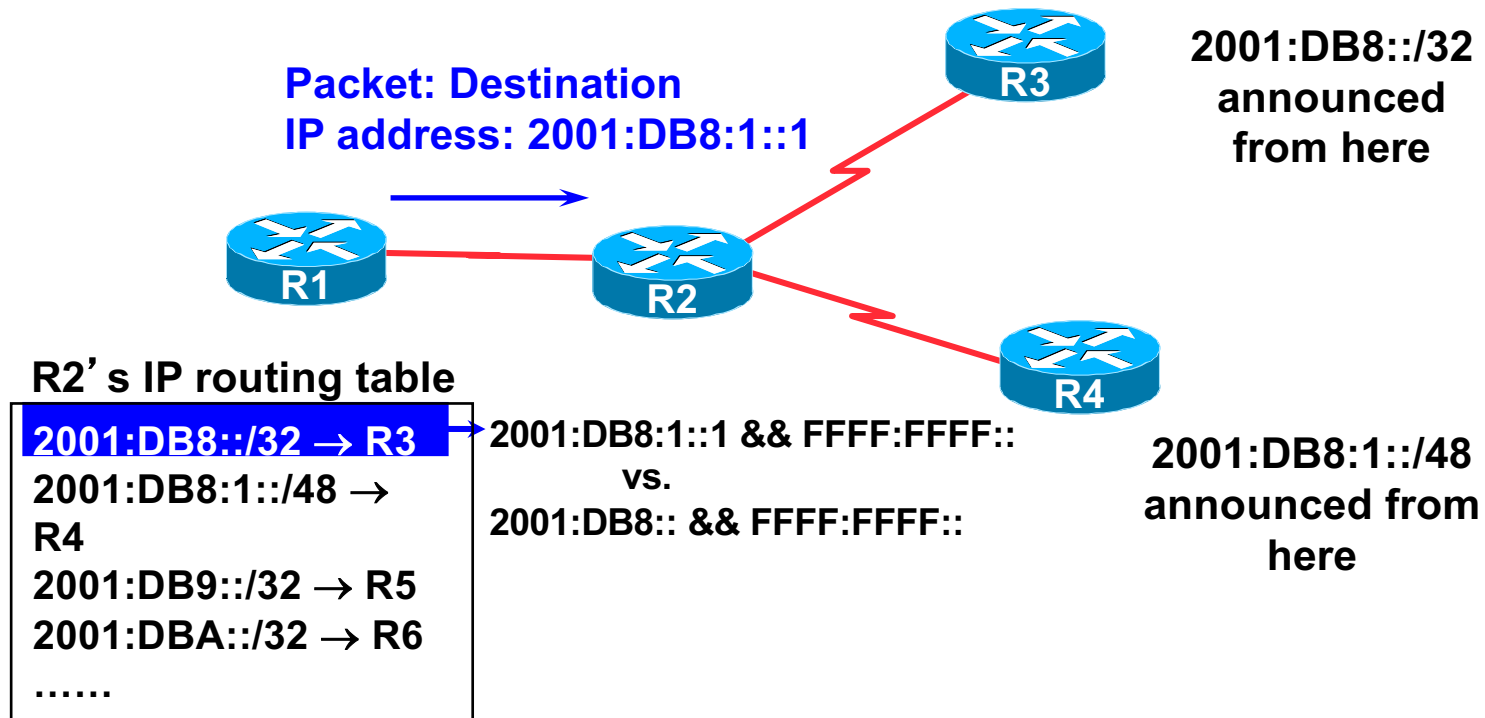
---

- Based on destination IP address



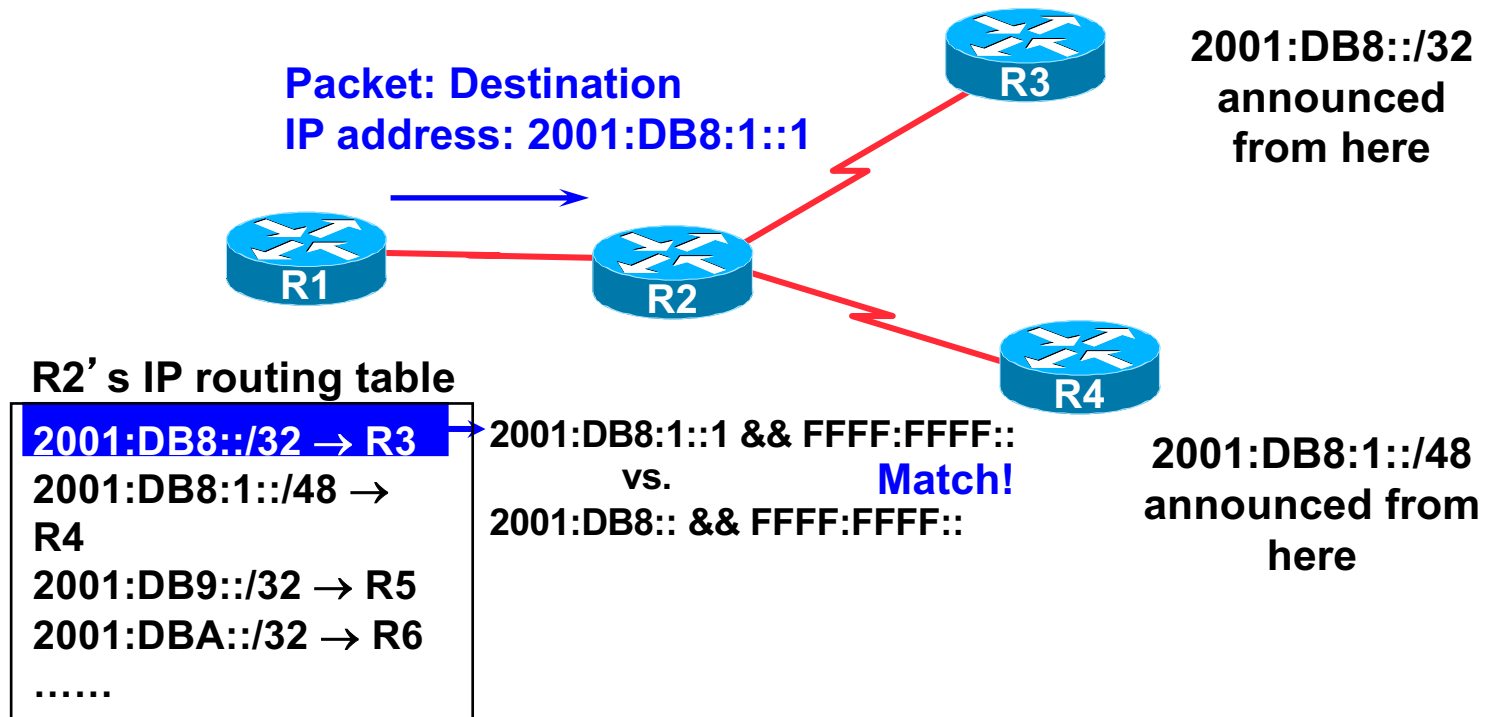
# IP route lookup: Longest match routing

- Based on destination IP address



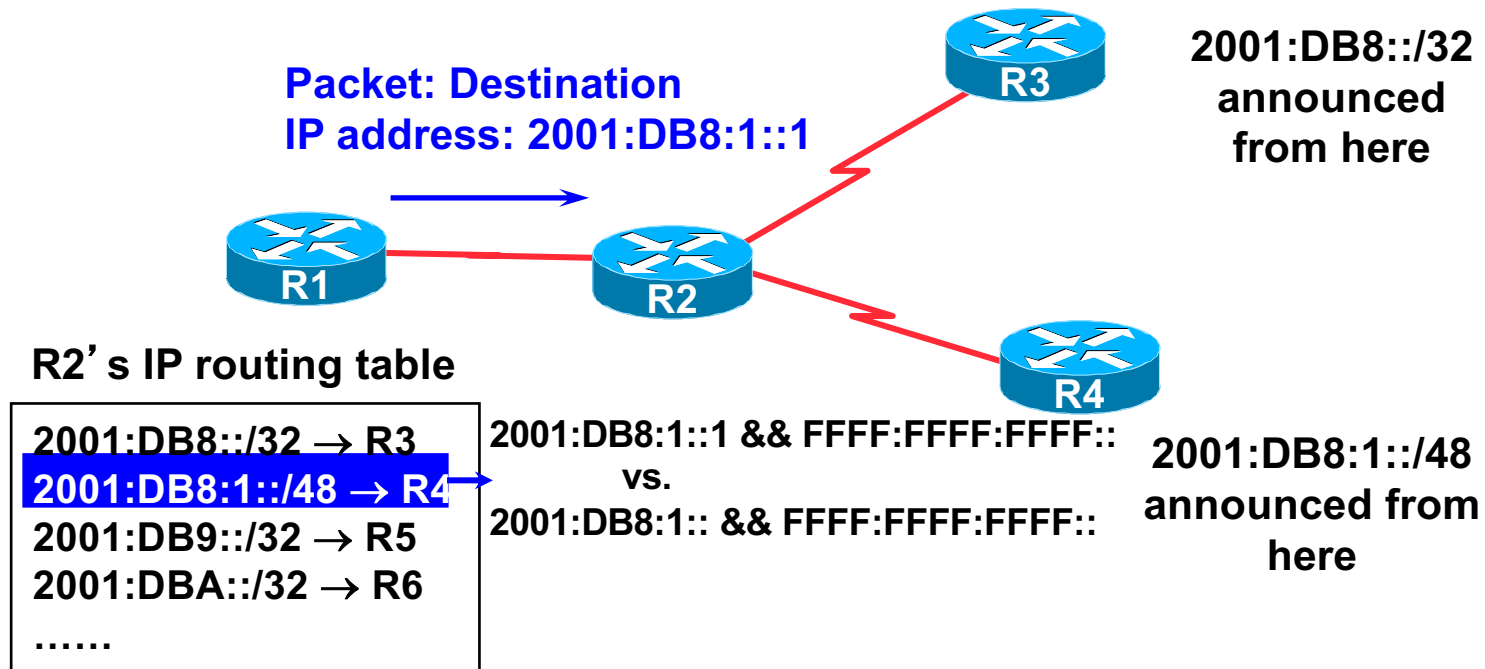
# IP route lookup: Longest match routing

- Based on destination IP address



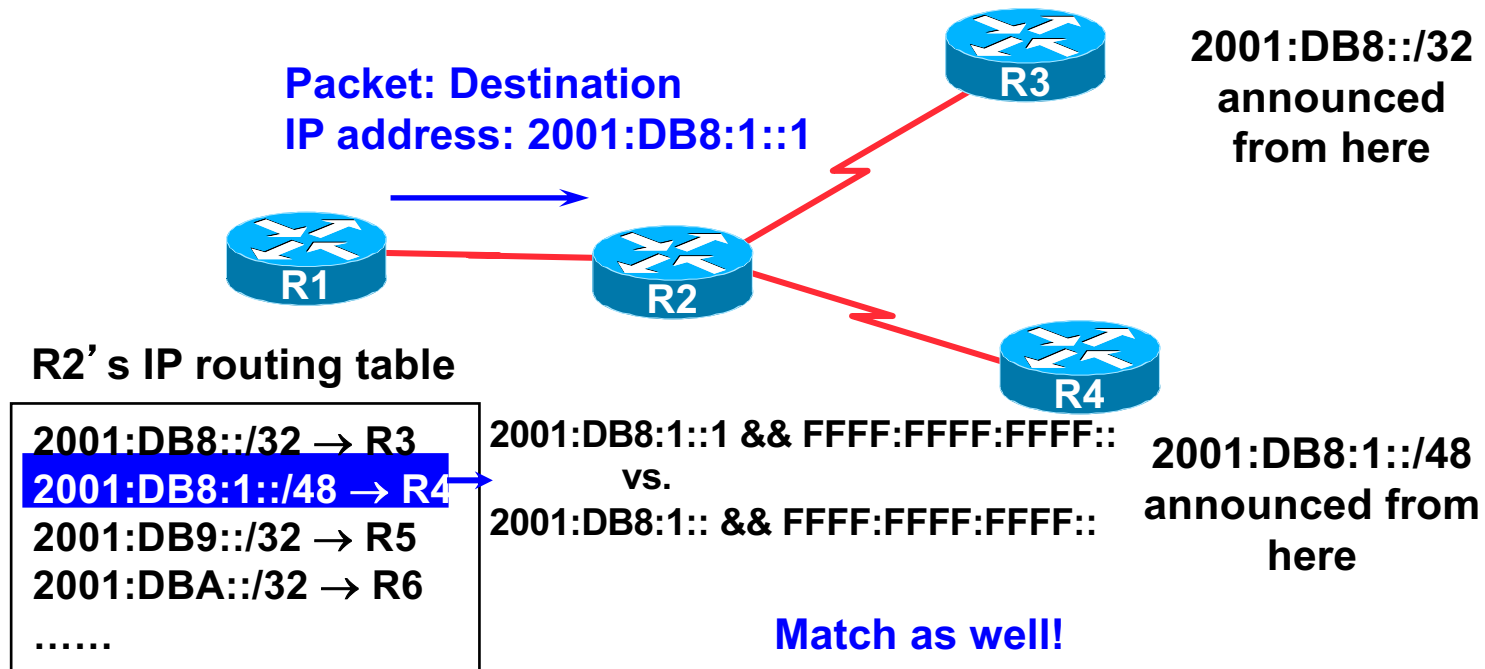
# IP route lookup: Longest match routing

- Based on destination IP address



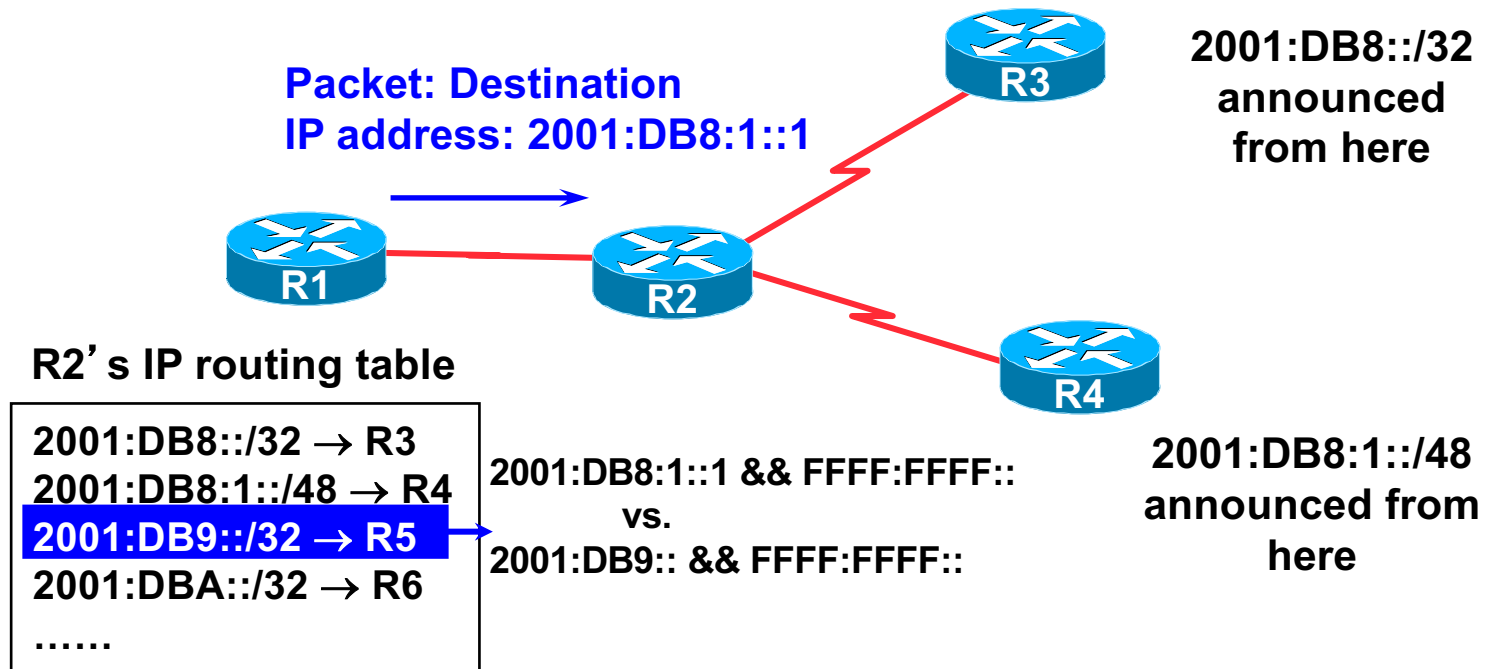
# IP route lookup: Longest match routing

- Based on destination IP address



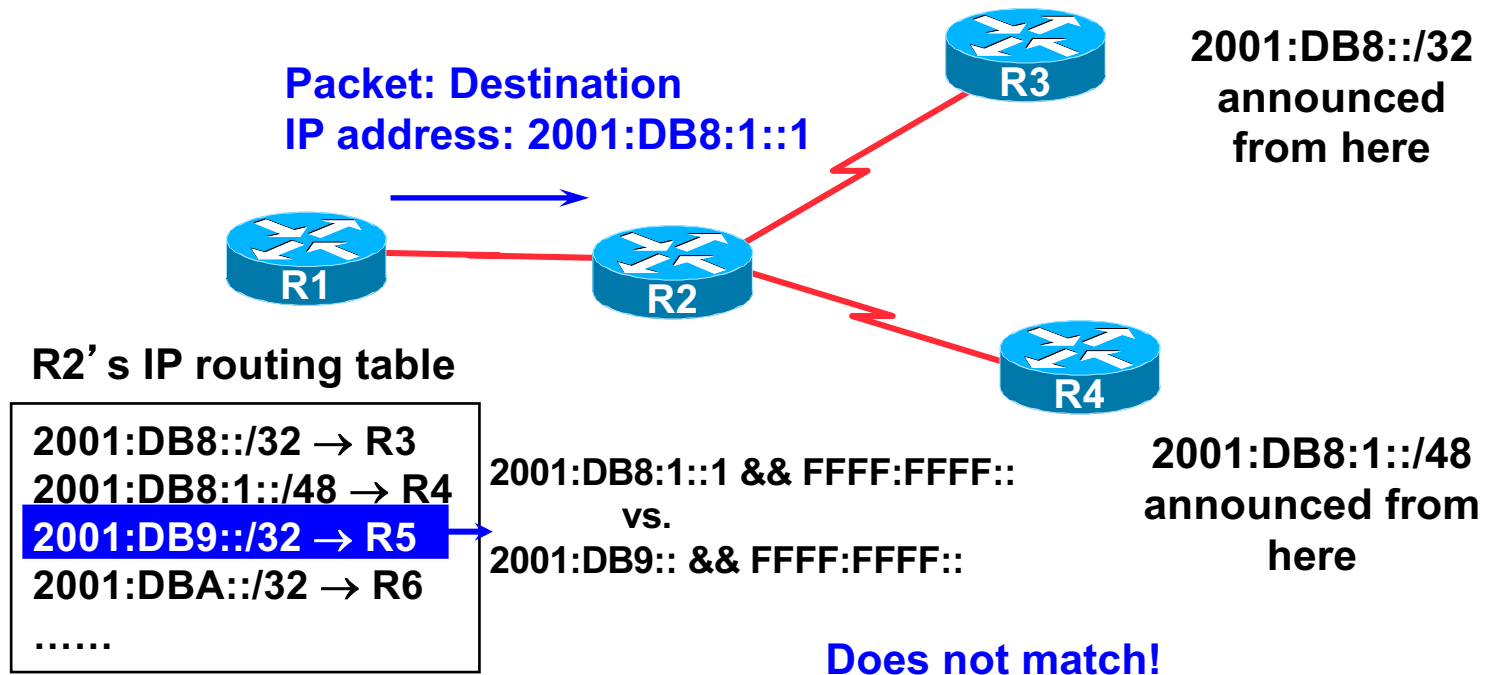
# IP route lookup: Longest match routing

- Based on destination IP address



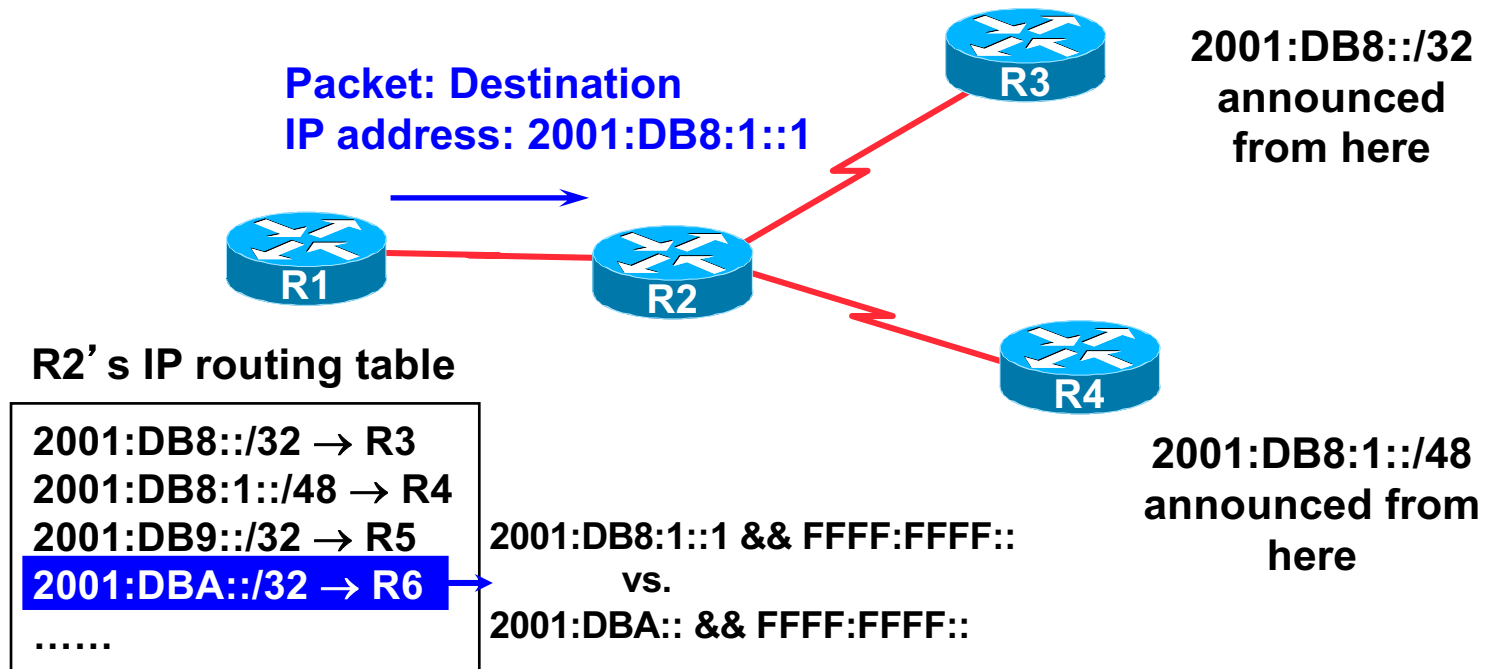
# IP route lookup: Longest match routing

- Based on destination IP address



# IP route lookup: Longest match routing

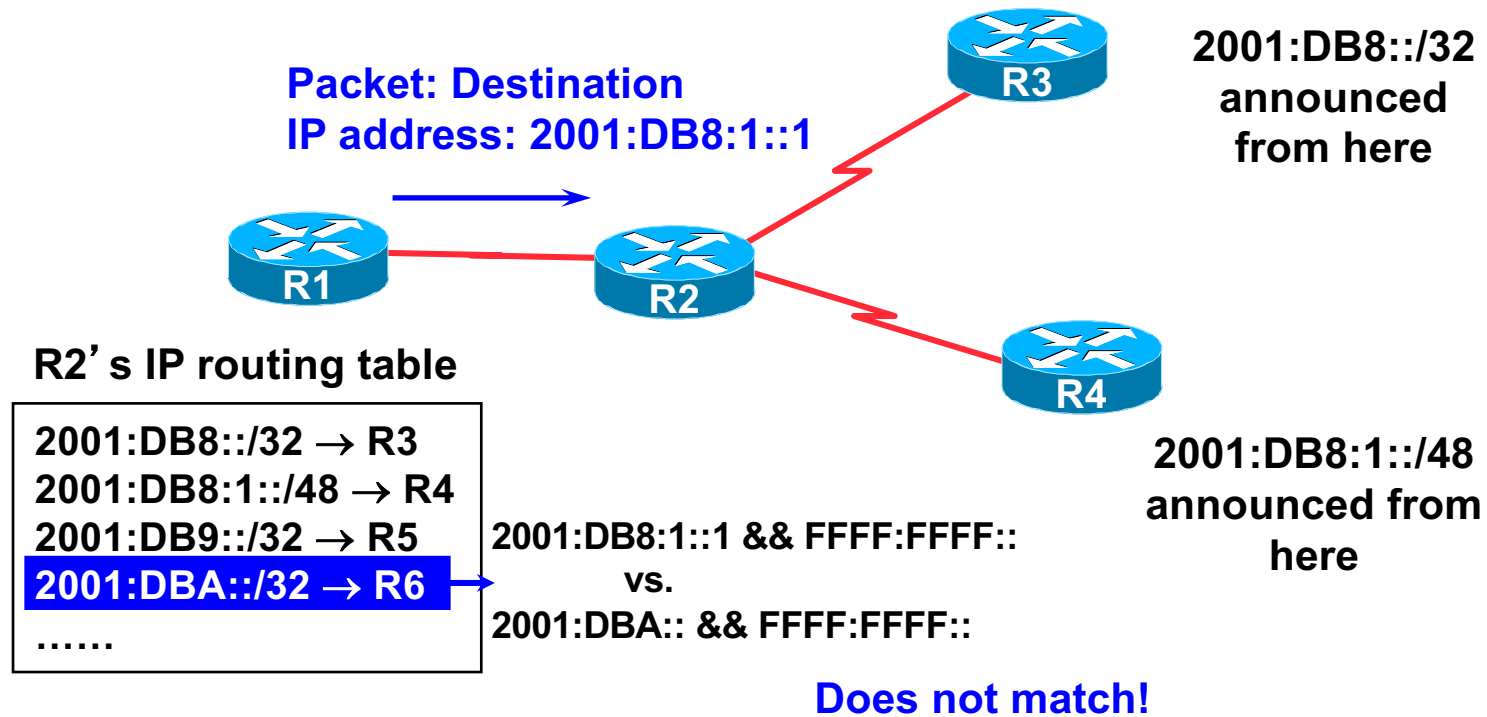
- Based on destination IP address





# IP route lookup: Longest match routing

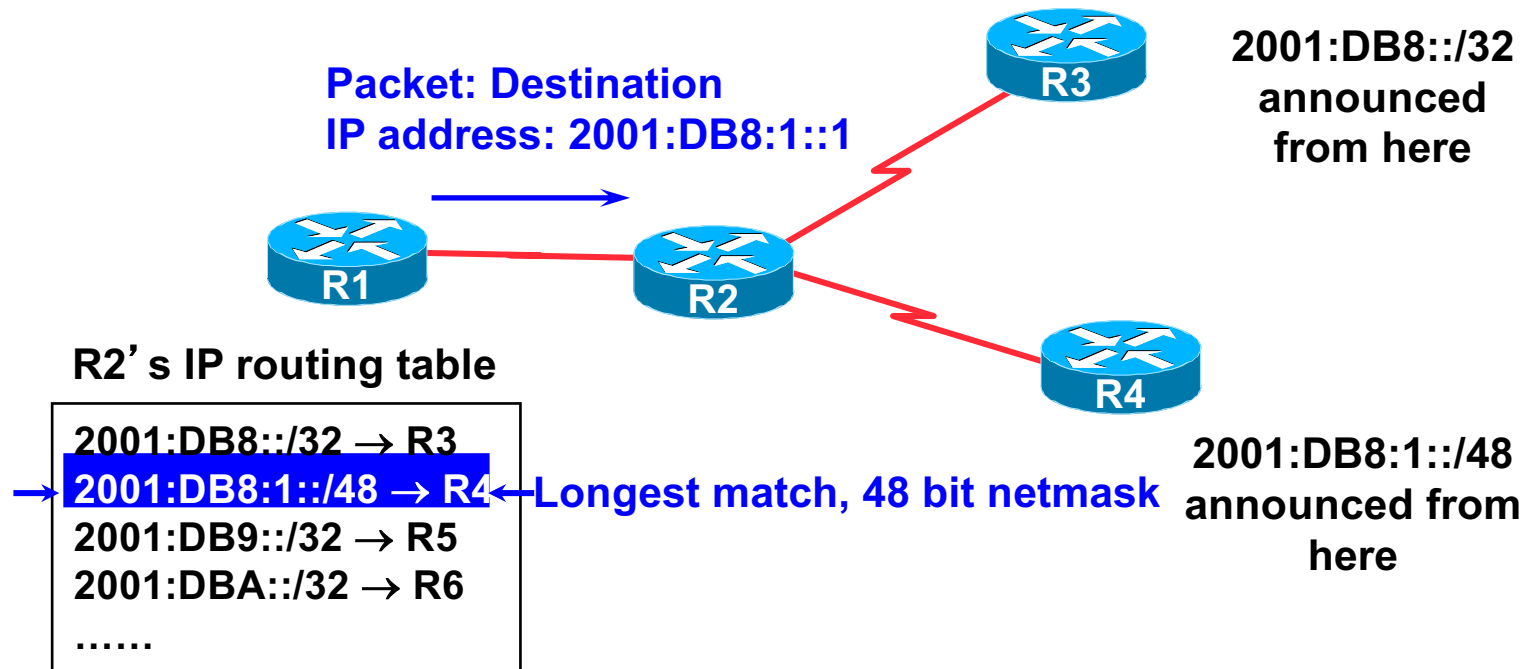
- Based on destination IP address



# IP route lookup: Longest match routing

---

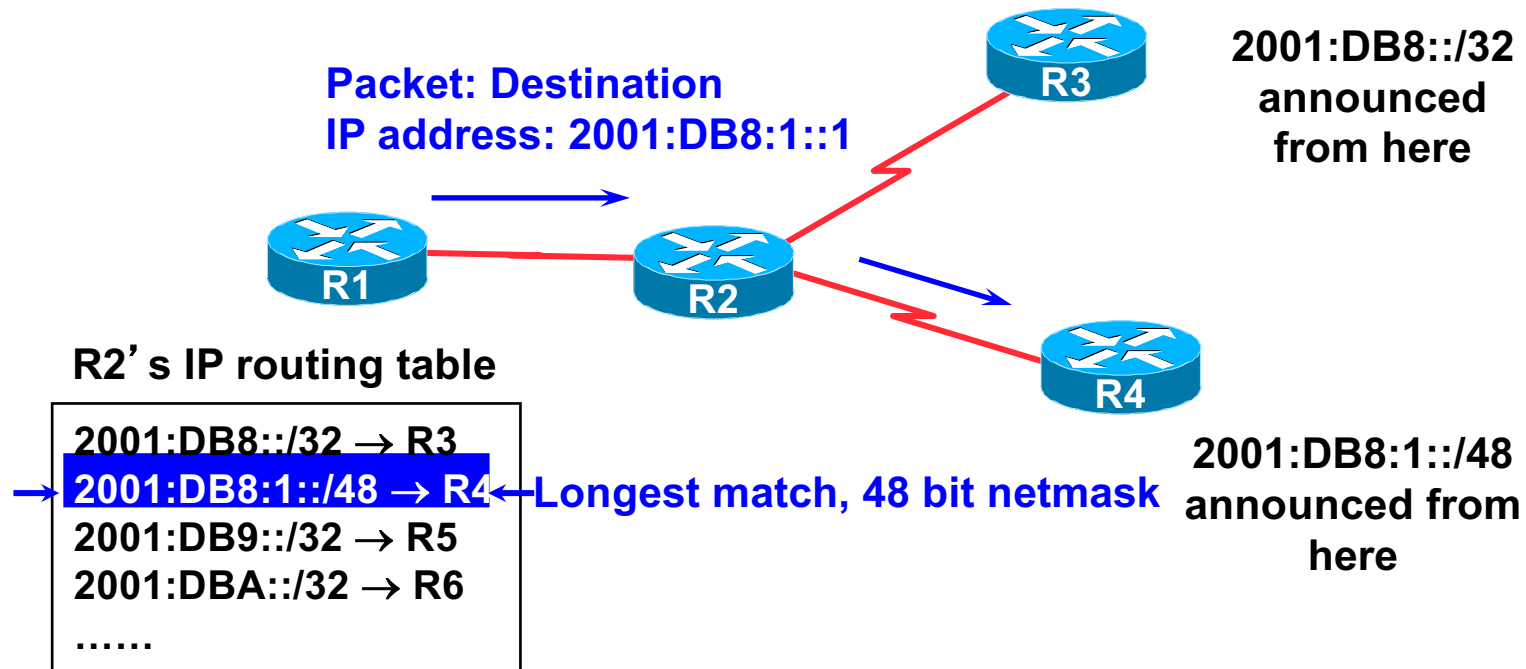
- Based on destination IP address



# IP route lookup: Longest match routing

---

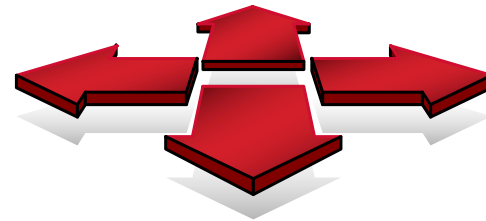
- Based on destination IP address



# Routing versus Forwarding

---

- Routing = building maps and giving directions
- Forwarding = moving packets between interfaces according to the “directions”



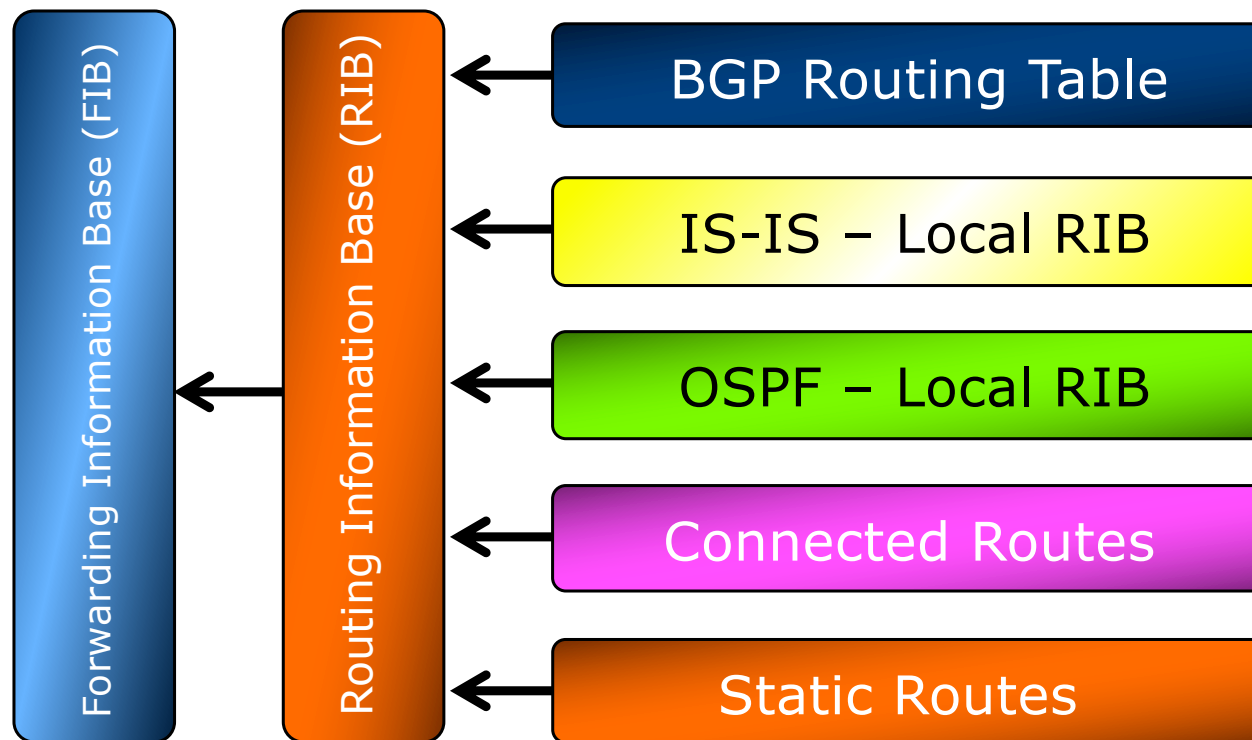
# IP Forwarding

---

- 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, the interfaces and the next-hops to get to those destinations
  - It is built from the router's Global RIB
  - Used by the router to figure out where to send the packet
  - Cisco IOS: "show ip cef"

# The Global RIB

---

- The Global RIB is the Routing Table
  - Built from the routing tables/RIBs of the routing protocols and static routes on the router
    - Routing protocol priority varies per vendor – see addendum
  - It contains all the known destinations and the next-hops used to get to those destinations
  - One destination can have lots of possible next-hops – only the best next-hop goes into the Global RIB
  - The Global RIB is used to build 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

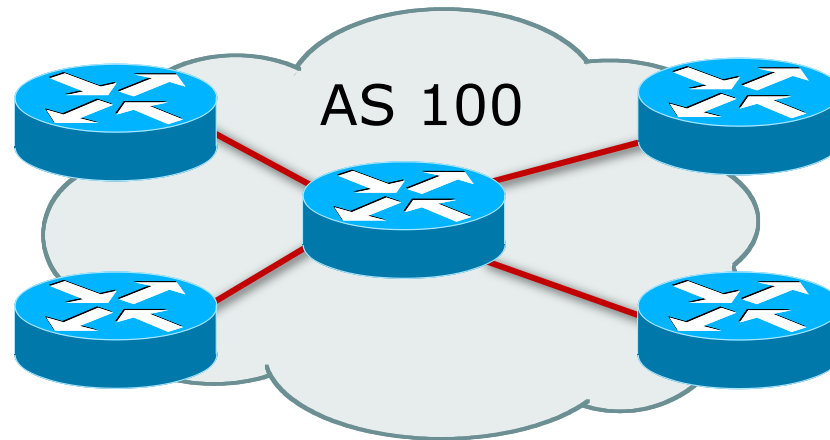
# Ingress Traffic

---

- 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

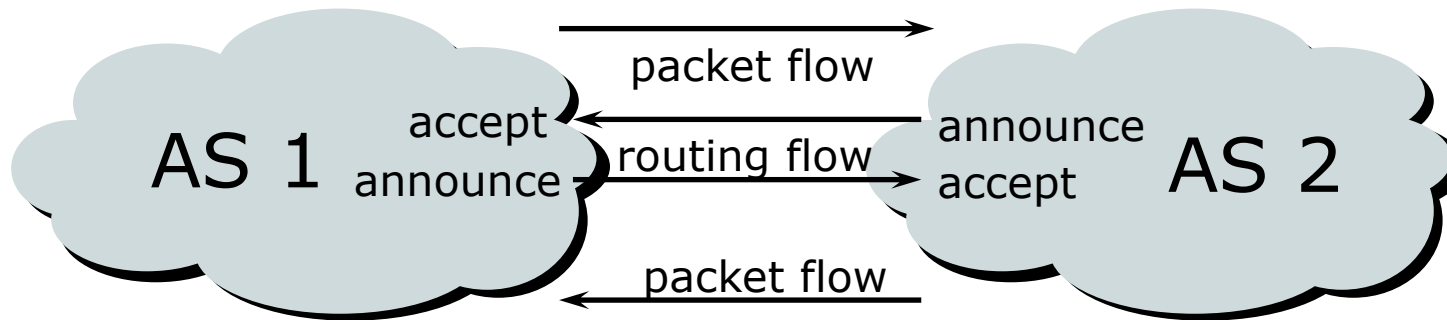
# Definition of terms

---

- **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

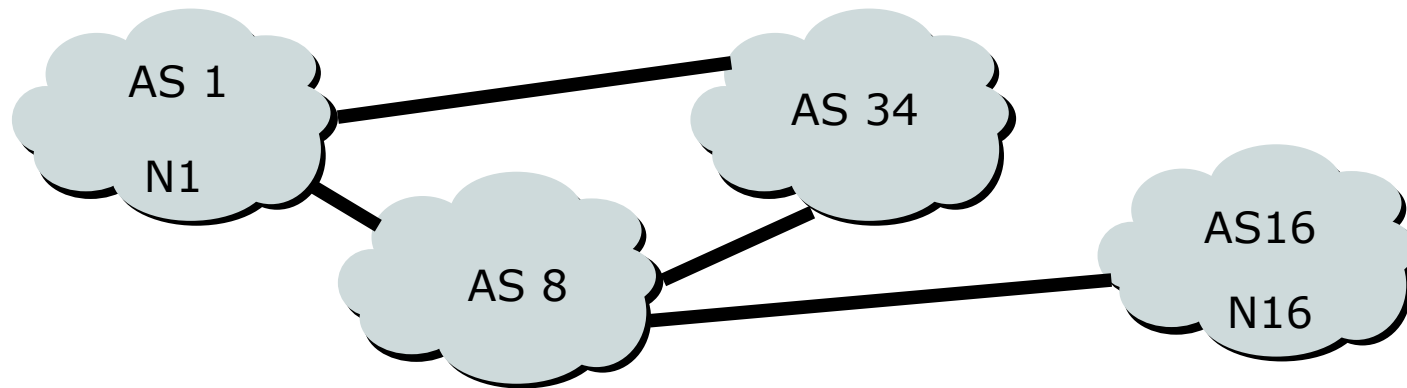
# Routing flow and Traffic flow

---

- 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

---

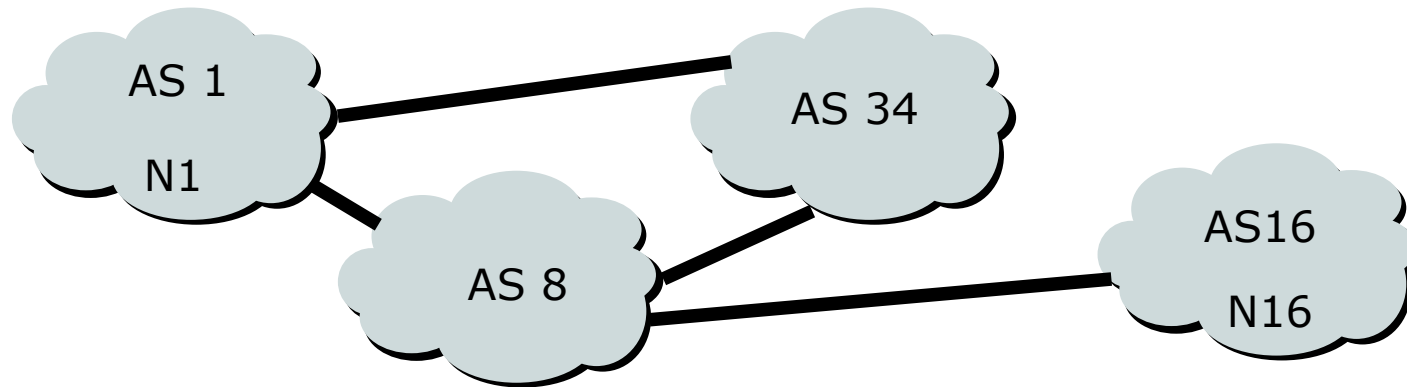


- For net N1 in AS1 to send traffic to net N16 in AS16:
  - AS16 must originate and announce N16 to AS8.
  - AS8 must accept N16 from AS16.
  - AS8 must announce N16 to AS1 or AS34.
  - AS1 must accept N16 from AS8 or AS34.
- For two-way packet flow, similar policies must exist for N1



# Routing Flow/Packet Flow: With multiple ASes

---



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

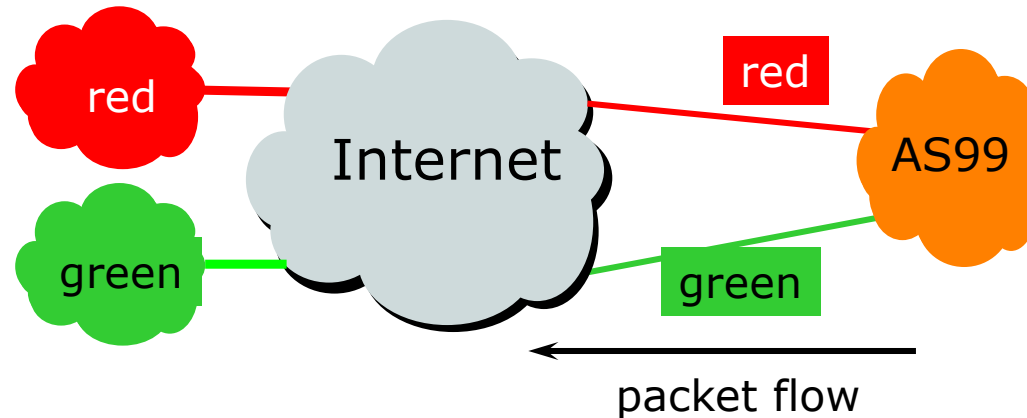
# Routing Policy

---

- 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

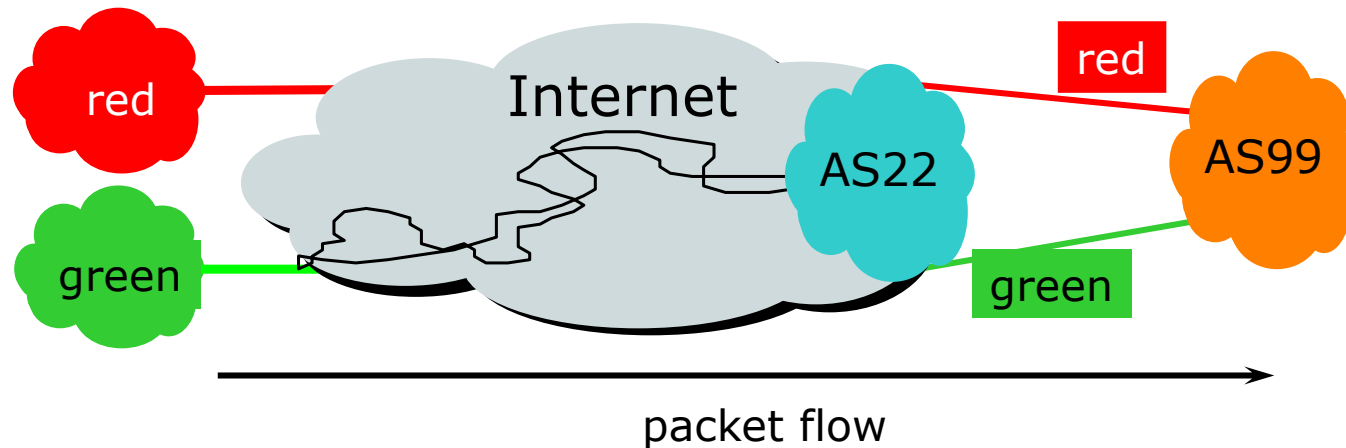
---



- ❑ 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

---

- December 2018:
  - 58000 IPv6 prefixes & 728000 IPv4 prefixes
    - Not realistic to set policy on all of them individually
  - 62600 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 its neighbouring ISPs the names of the customers
  - (network equipment does not understand names)
- Instead, it has received an IP address block as a member of the Regional Internet Registry serving Kenya
  - Its customers have received address space from this address block as part of their "Internet service"
  - And it announces this address block to its 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?

---

- Interior Gateway Protocol
- 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?

---

- ❑ Exterior Gateway Protocol
- ❑ 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

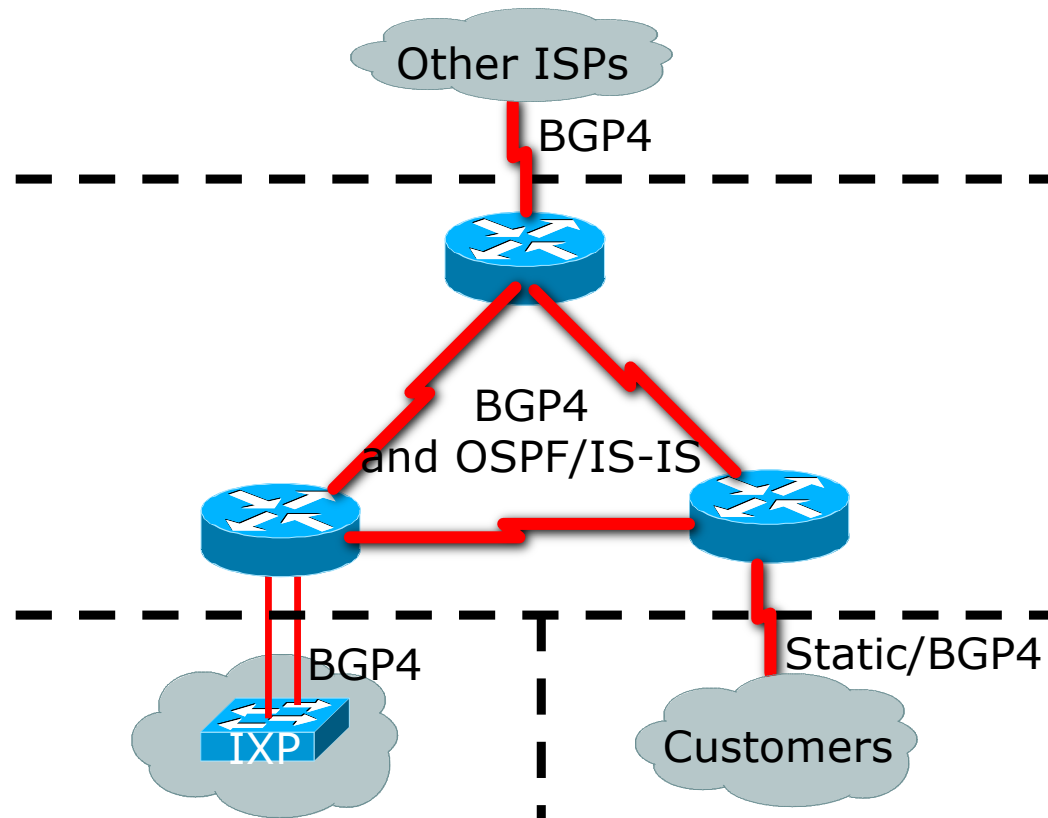
- Carries ISP infrastructure addresses only
- ISPs aim to keep the IGP small for efficiency and scalability

## □ 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	Nokia/ALU	Mikrotik
<b>Connected Interface</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Static Route</b>	<b>1</b>	<b>5</b>	<b>60</b>	<b>1</b>	<b>1</b>	<b>1</b>
EIGRP Summary Route	5	N/A	?	N/A	N/A	N/A
<b>External BGP</b>	<b>20</b>	<b>170</b>	<b>255</b>	<b>20</b>	<b>170</b>	<b>20</b>
Internal EIGRP Route	90	N/A	?	N/A	N/A	N/A
IGRP	100	N/A	?	N/A	N/A	N/A
<b>OSPF</b>	<b>110</b>	<b>10</b>	<b>10</b>	<b>110</b>	<b>10</b>	<b>110</b>
<b>IS-IS</b>	<b>115</b>	<b>18</b>	<b>15</b>	<b>115</b>	<b>18</b>	N/A
RIP	120	100	100	120	100	120
EGP	140	N/A	N/A	N/A	N/A	N/A
External EIGRP	170	N/A	?	N/A	N/A	N/A
<b>Internal BGP</b>	<b>200</b>	<b>170</b>	<b>255</b>	<b>200</b>	<b>130</b>	<b>200</b>
Unknown	255	255	?	255	?	

# Routing Basics



ISP Workshops