

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 6th April 2019

Acknowledgements

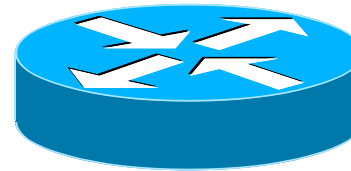
- This material originated from the Cisco ISP/IXP Workshop Programme developed by Philip Smith & Barry Greene
- Use of these materials is encouraged as long as the source is fully acknowledged and this notice remains in place
- Bug fixes and improvements are welcomed
 - Please email *workshop (at) bgp4all.com*

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

Destination	Next-Hop	Interface
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

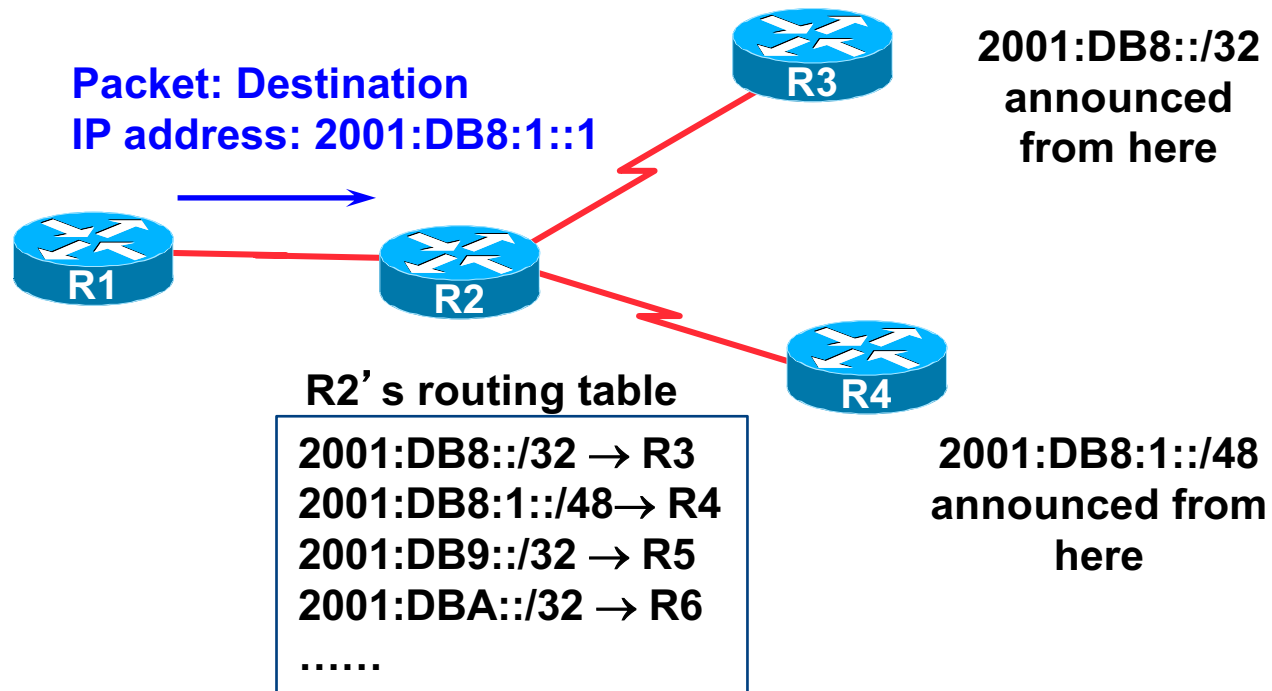
- ❑ Routing table entry (the path) is created by the administrator (static) or received from a routing protocol (dynamic)
- ❑ More than one routing protocol may run on a router
 - Each routing protocol builds its own routing table (Local RIB)
- ❑ Several alternative paths may exist
 - Best path selected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

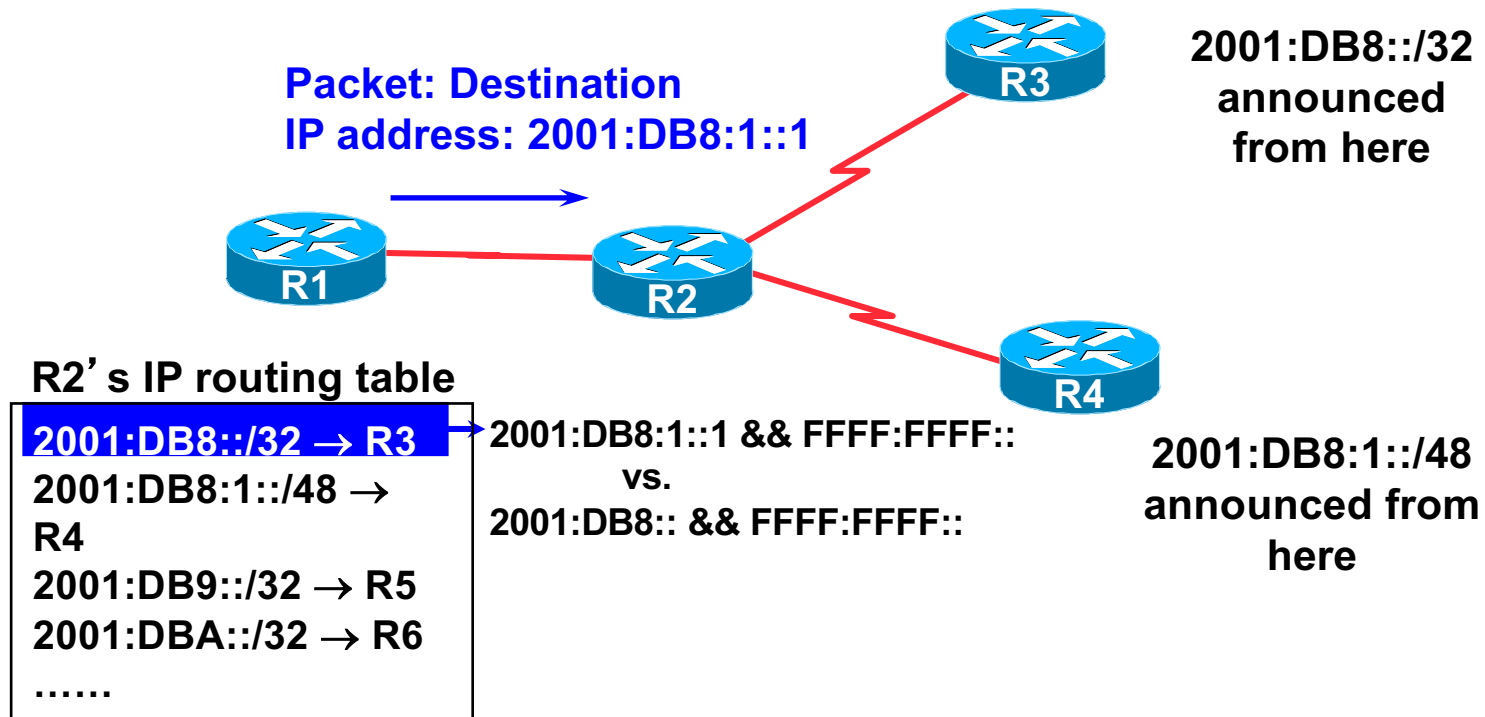
IP route lookup

- Based on destination IP address



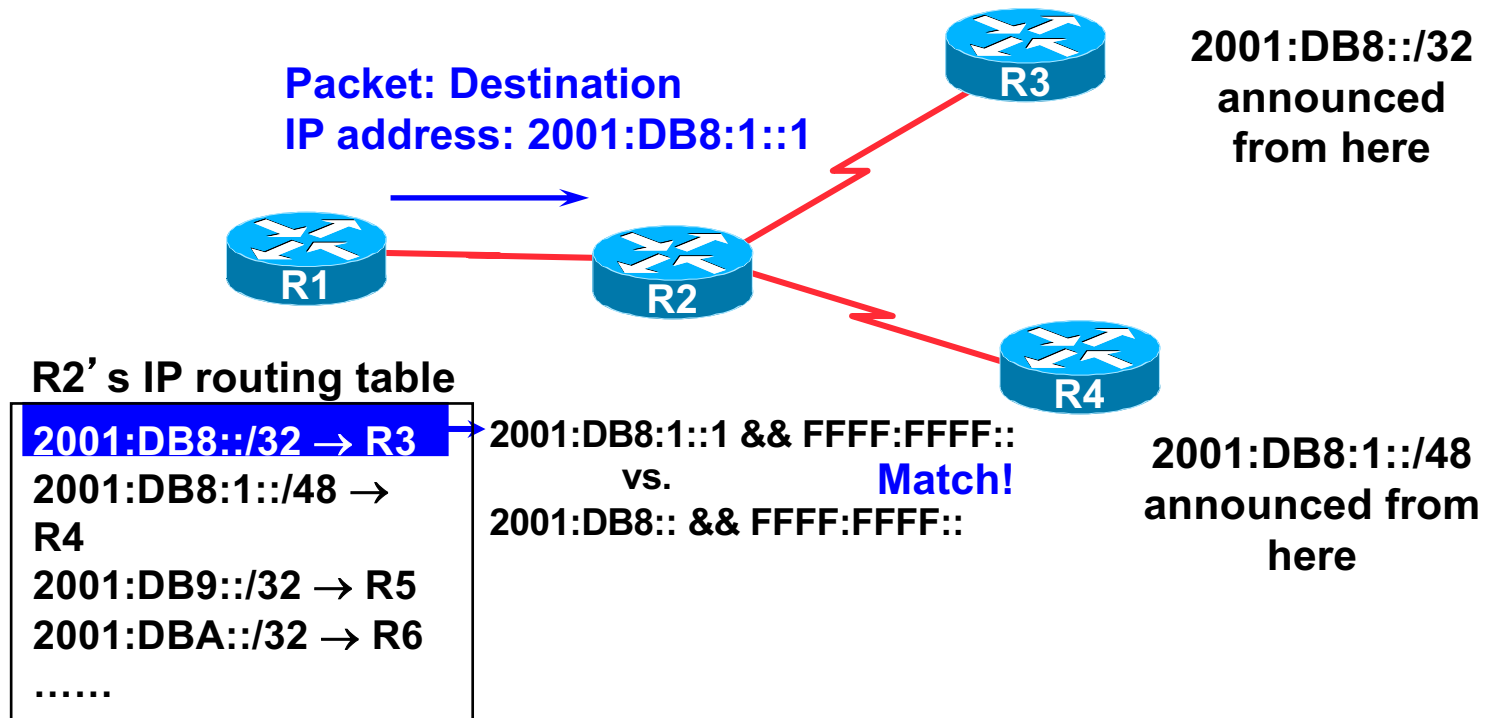
IP route lookup: Longest match routing

- Based on destination IP address



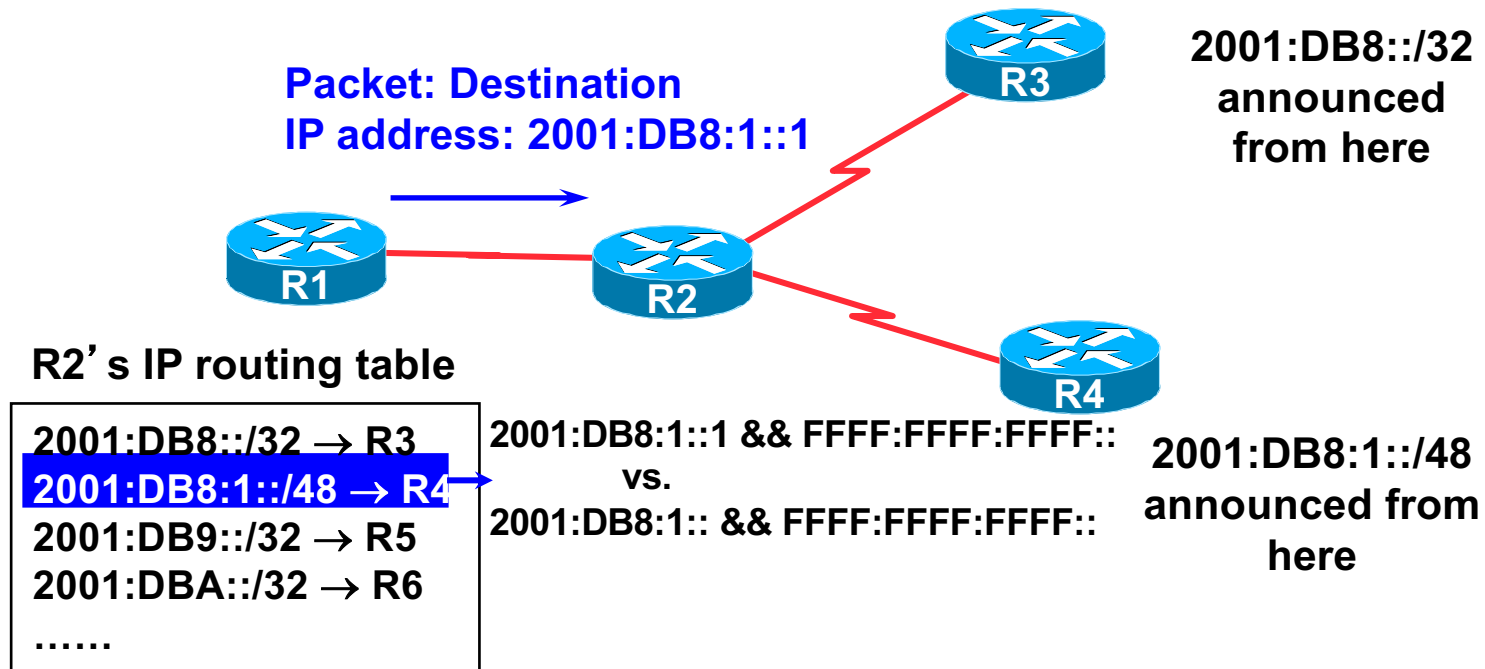
IP route lookup: Longest match routing

- Based on destination IP address



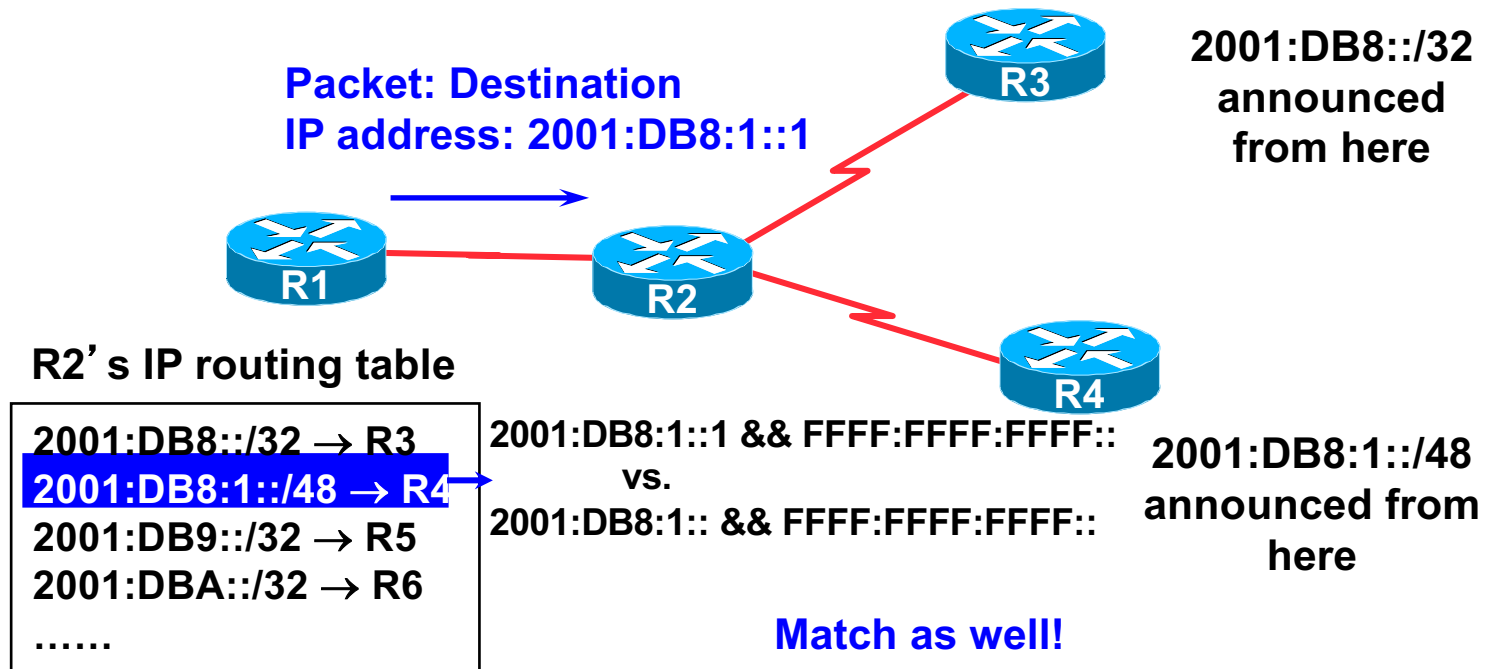
IP route lookup: Longest match routing

- Based on destination IP address



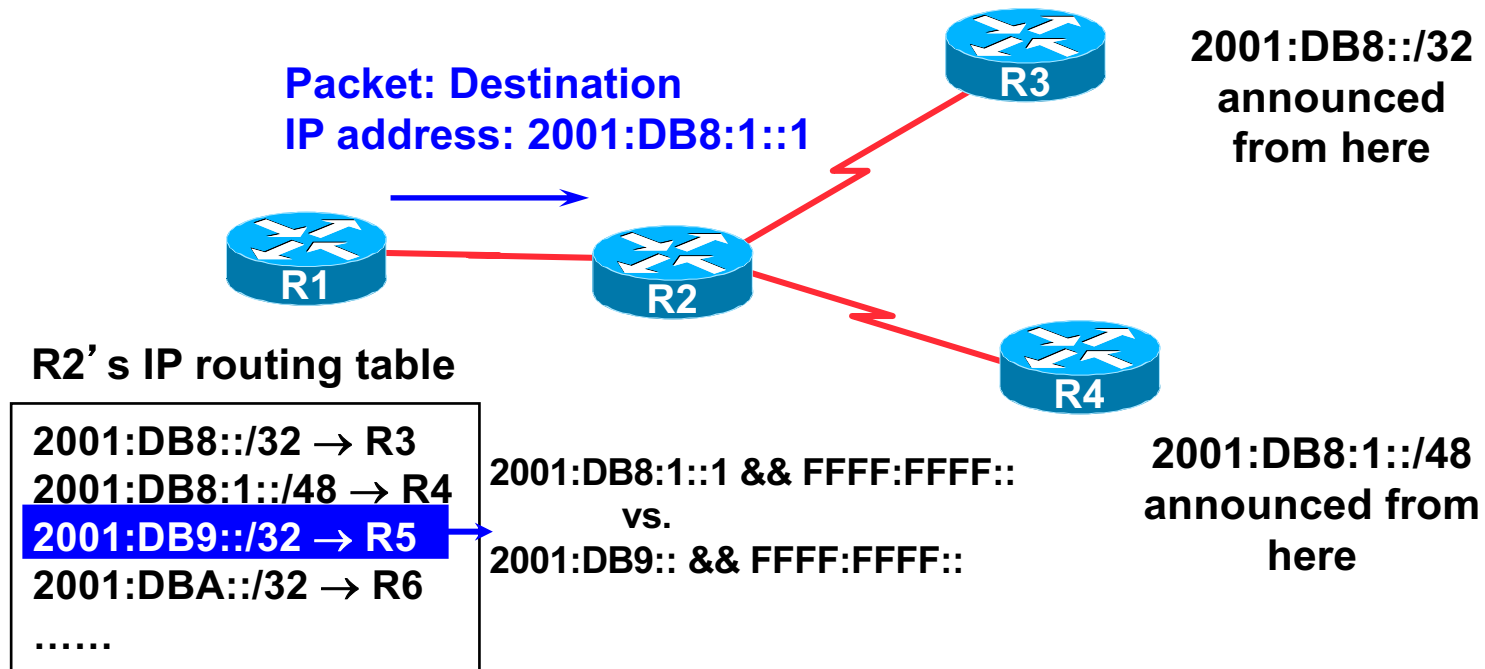
IP route lookup: Longest match routing

- Based on destination IP address



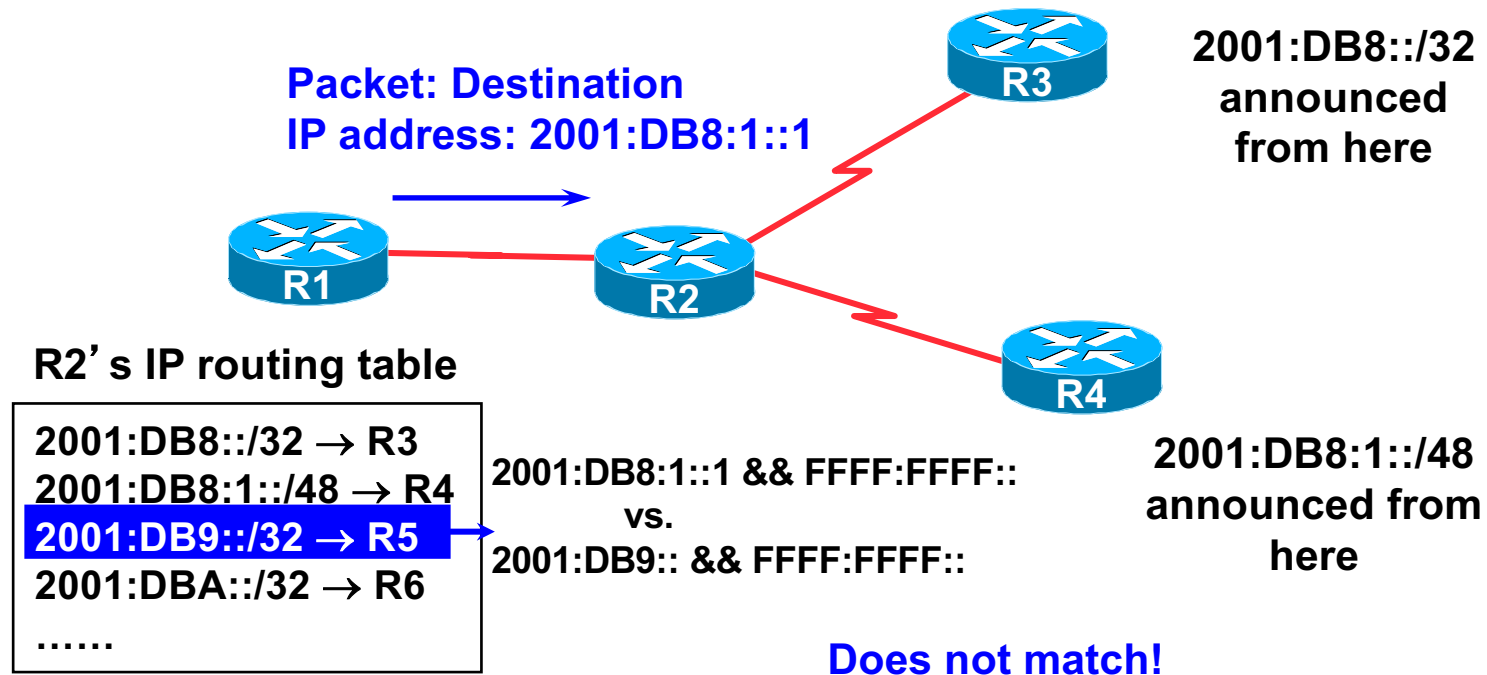
IP route lookup: Longest match routing

- Based on destination IP address



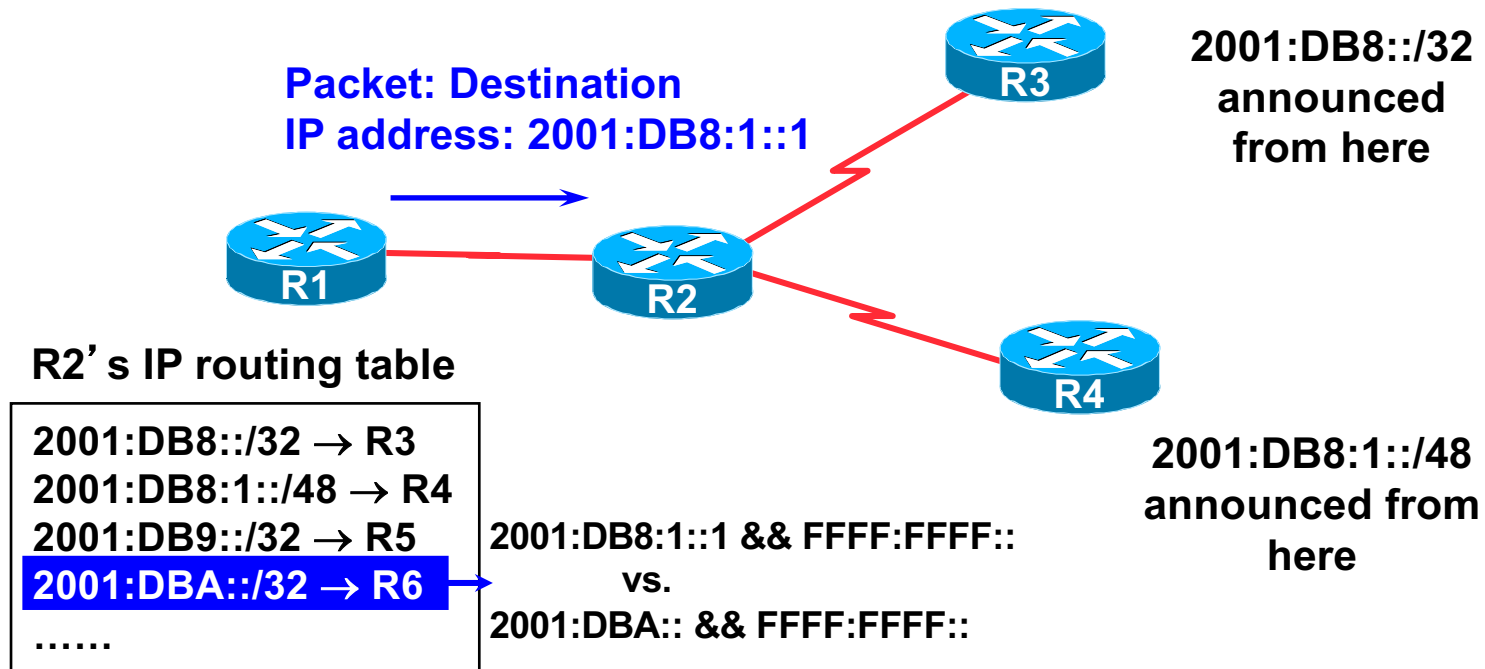
IP route lookup: Longest match routing

- Based on destination IP address



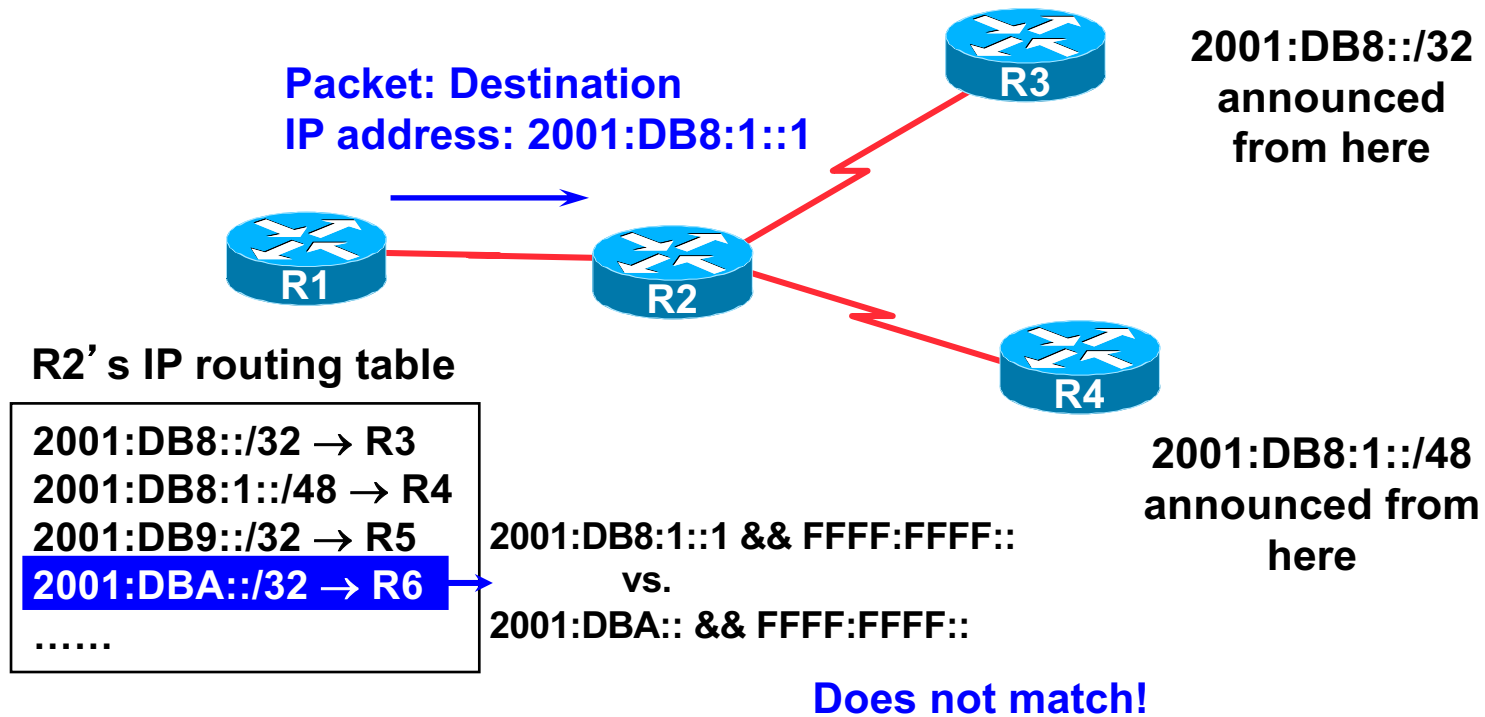
IP route lookup: Longest match routing

- Based on destination IP address



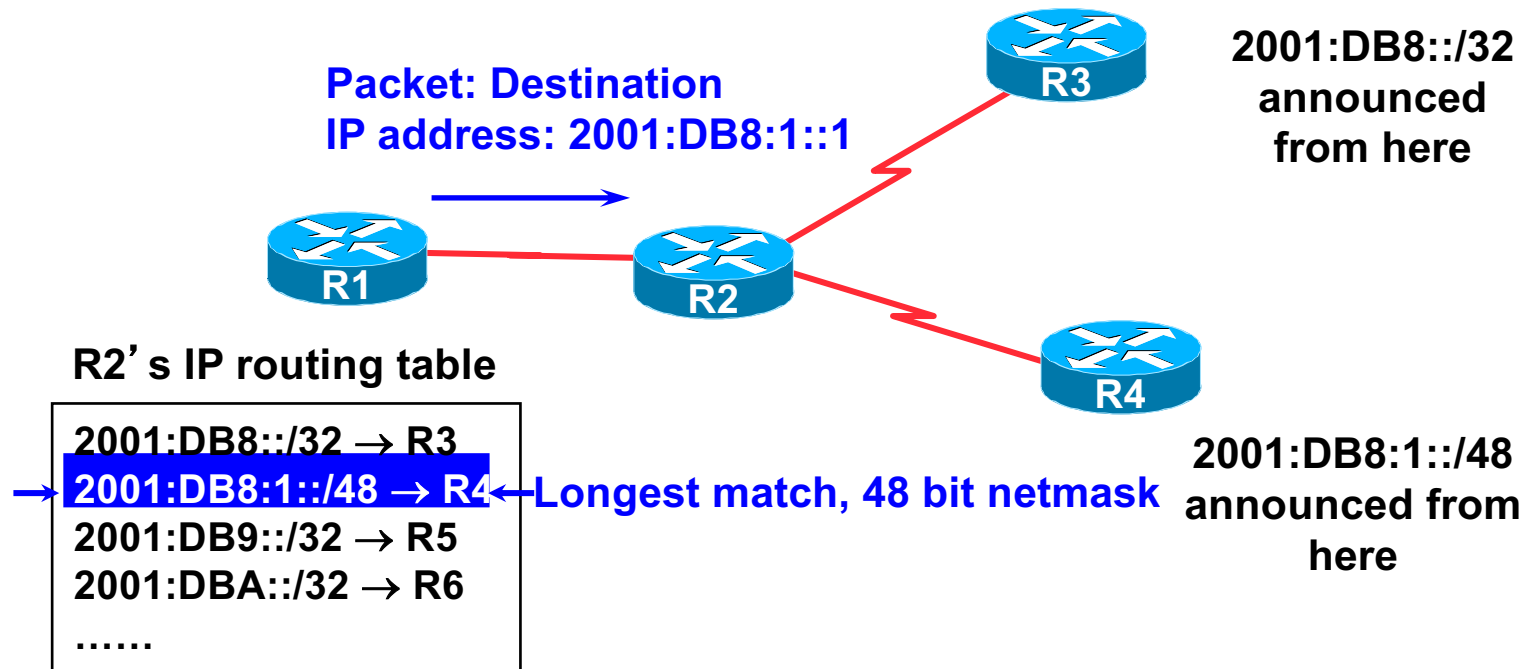
IP route lookup: Longest match routing

- Based on destination IP address



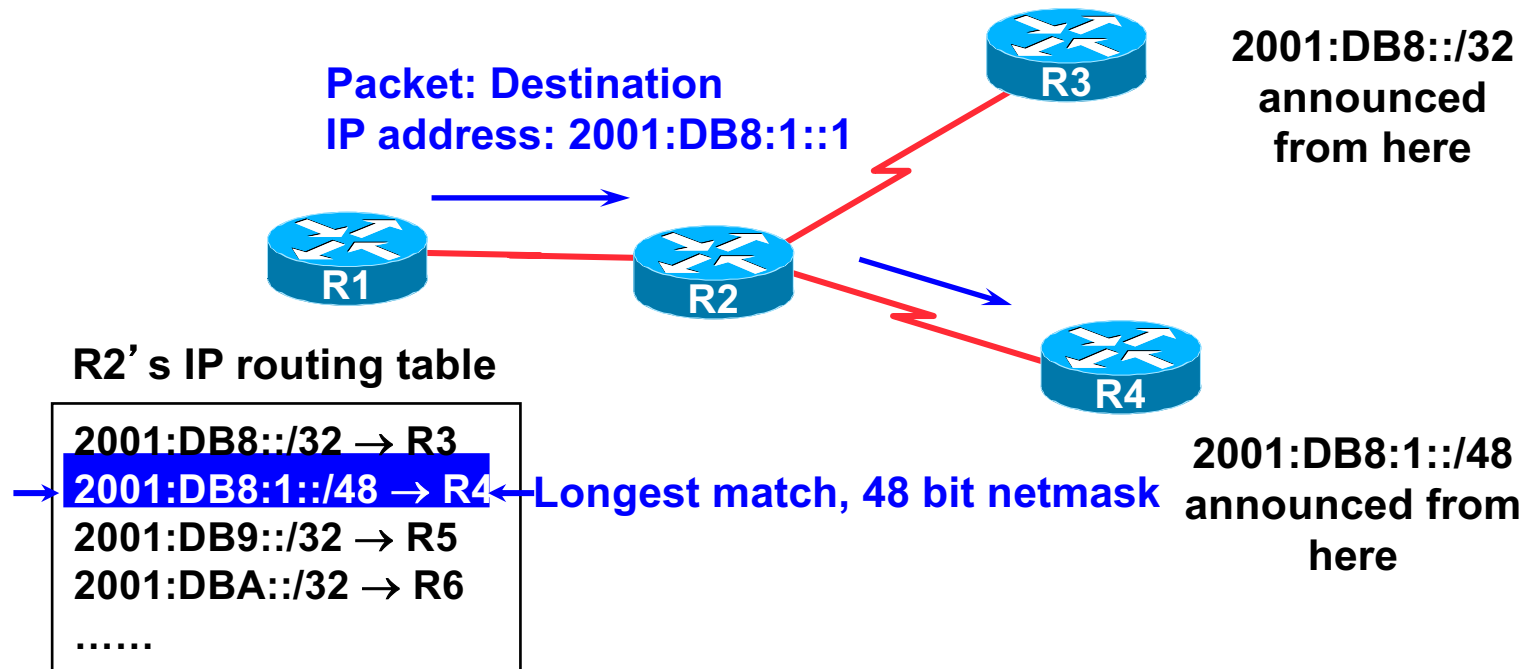
IP route lookup: Longest match routing

- Based on destination IP address



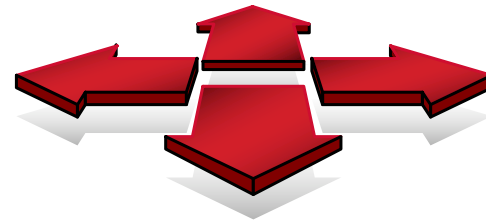
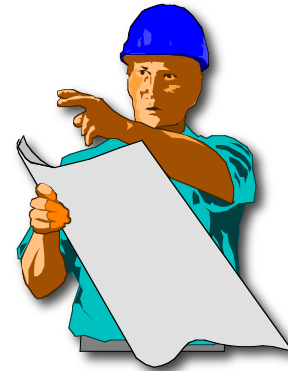
IP route lookup: Longest match routing

- Based on destination IP address



Routing versus Forwarding

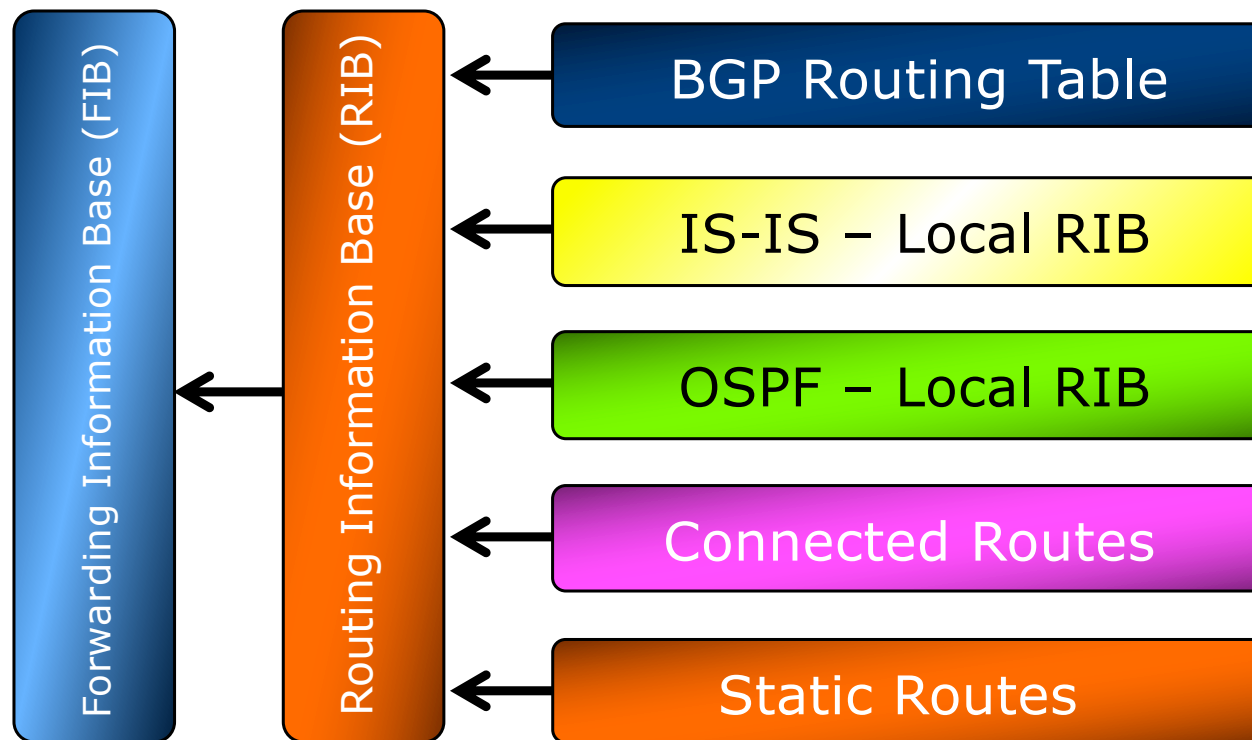
- Routing = building maps and giving directions
- Forwarding = moving packets between interfaces according to the “directions”



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

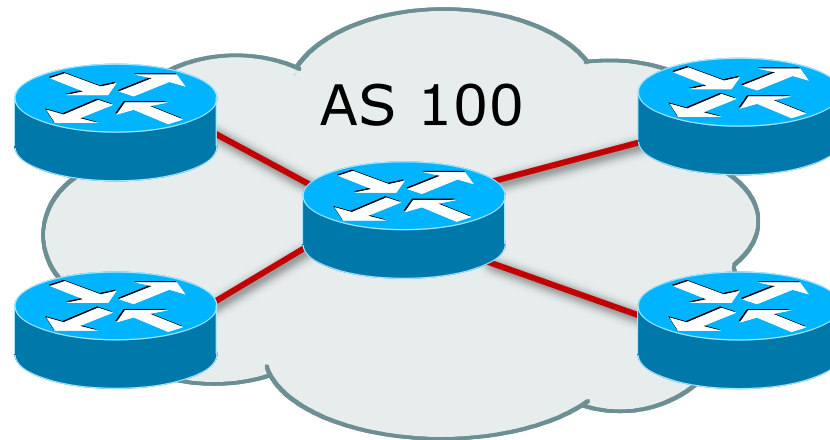
Egress Traffic

- 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)

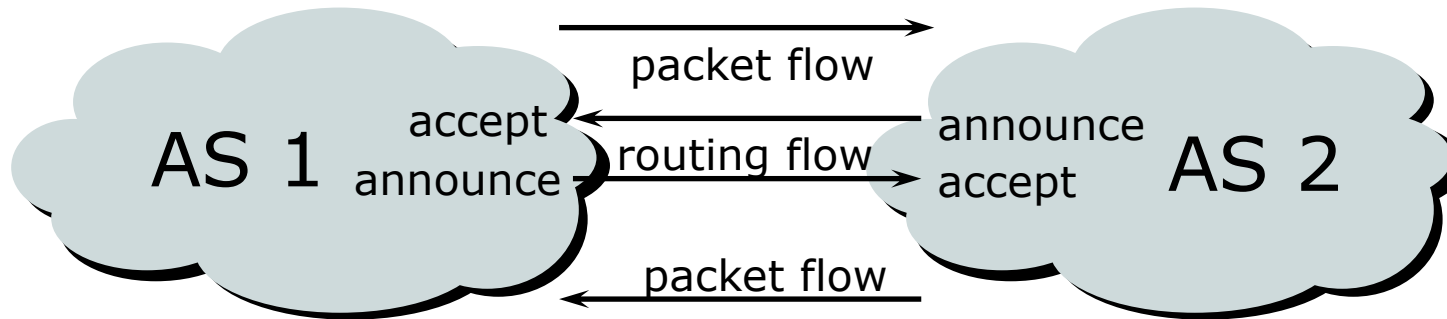


- ❑ Collection of networks with same routing policy
- ❑ Single routing protocol
- ❑ Usually under single ownership, trust and administrative control

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



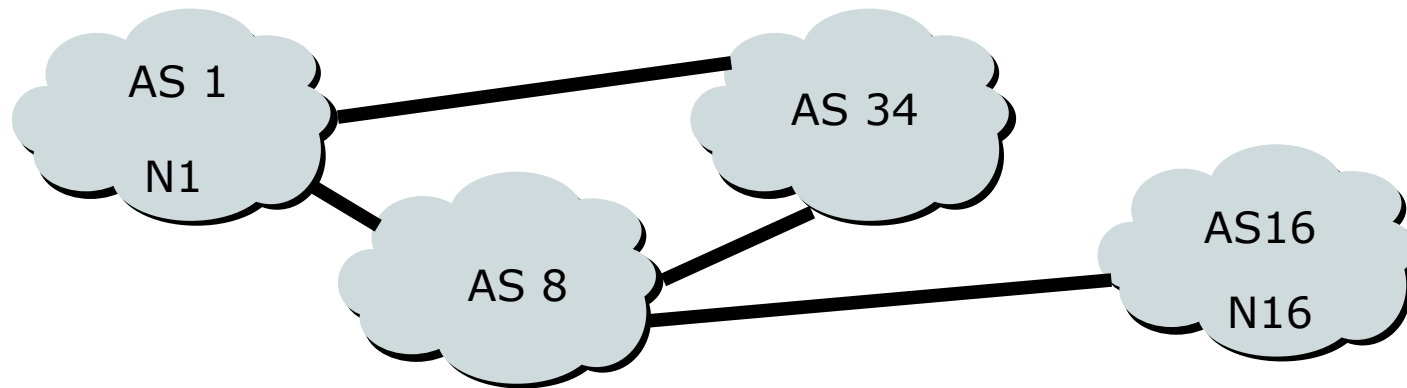
For networks in AS1 and AS2 to communicate:

- 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

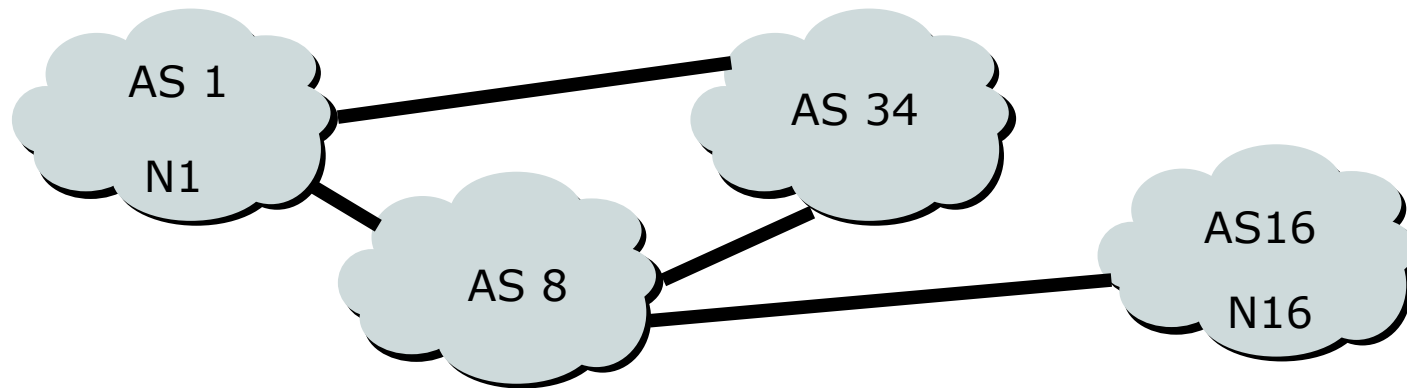
- Traffic flow is always in the opposite direction of the flow of Routing information
 - Filtering outgoing routing information inhibits traffic flow inbound
 - Filtering inbound routing information inhibits traffic flow outbound

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

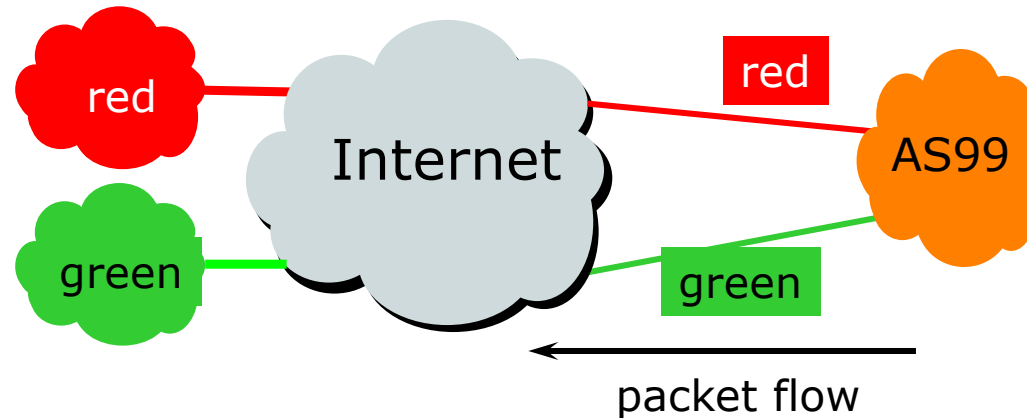


- As more and more paths are implemented between sites it is easy to see how policies can become quite complex.

Routing Policy

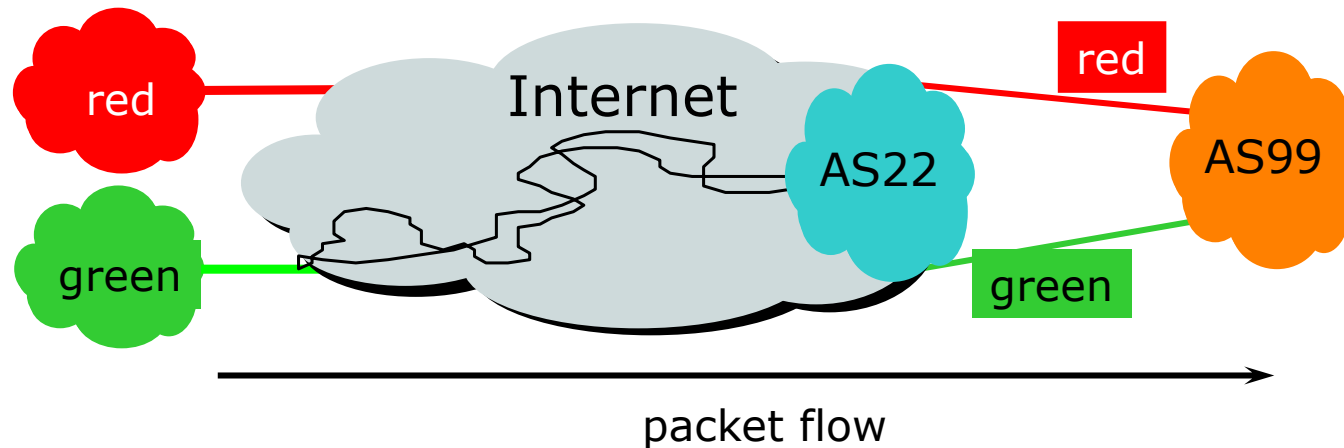
- Used to control traffic flow in and out of a network
- The network operator makes decisions on what routing information to accept and discard from its neighbours
 - Individual routes
 - Routes originated by specific ASes
 - Routes traversing specific ASes
 - Routes belonging to other groupings
 - Groupings 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

- April 2019:
 - 67000 IPv6 prefixes & 744000 IPv4 prefixes
 - Not realistic to set policy on all of them individually
 - 63800 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 Network Operators who connect to each other's networks
- How does an operator in Kenya tell an operator in Japan what end-site customers they have?
- And how does that operator send data packets to the customers of the Japanese operator, 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?

- The operator in Kenya could buy a direct connection to the operator in Japan
 - But this doesn't scale – there are thousands of distinct networks, would need thousands of connections, and cost would be astronomical
- Instead, the operator in Kenya tells his neighbouring operators what end-sites they have
 - And the neighbouring operators pass this information on to their neighbours, and so on
 - This process repeats until the information reaches the operator 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 network operators can provide connectivity to each other
 - We have the Internet we see today

4: How Does Routing Work?

- The Network Operator in Kenya doesn't actually tell its neighbouring operators the names of the end-sites
 - (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 operators – 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?

- Network Operator backbone scaling
 - Hierarchy
 - Limiting scope of failure
 - Only used for operator'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

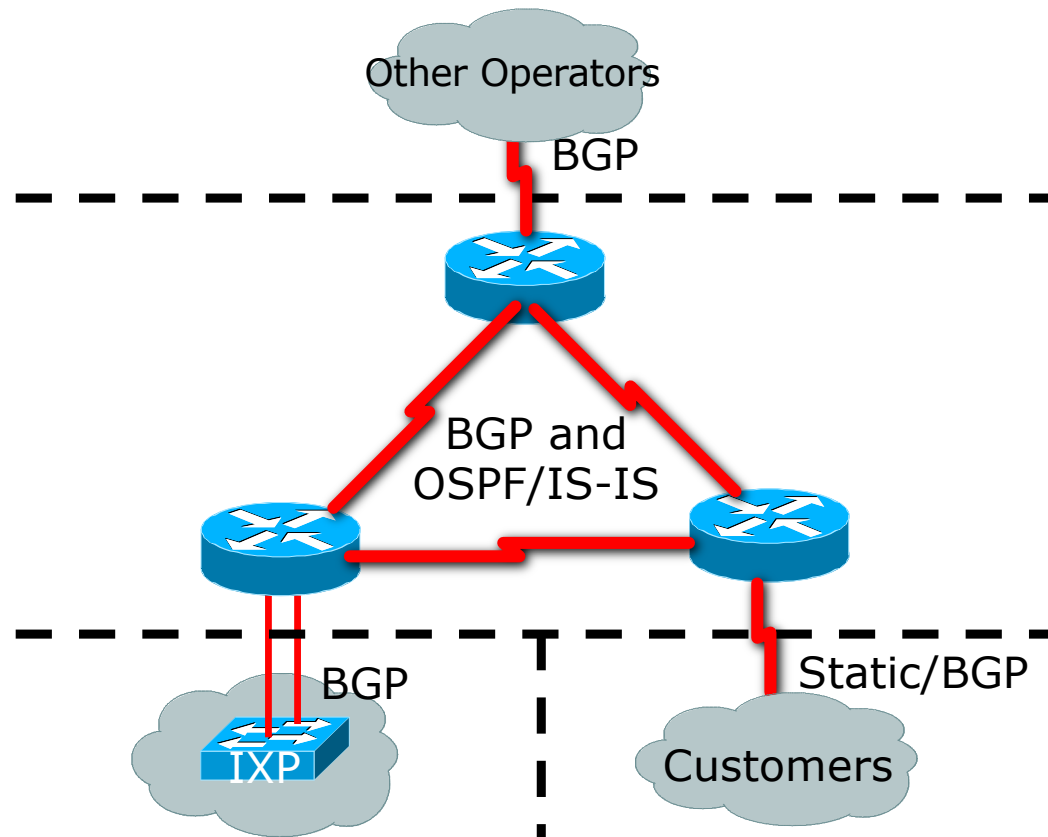
□ Interior

- Carries network infrastructure addresses only
- Network operators aim to keep the IGP small for efficiency and scalability

□ Exterior

- Carries customer prefixes
- Carries Internet prefixes
- EGPs are independent of the operator's network topology

Hierarchy of Routing Protocols



FYI: Default Administrative Distances

Route Source	Cisco	Juniper	Huawei	Brocade	Nokia/ALU	Mikrotik
Connected Interface	0	0	0	0	0	0
Static Route	1	5	60	1	1	1
EIGRP Summary Route	5	N/A	?	N/A	N/A	N/A
External BGP	20	170	255	20	170	20
Internal EIGRP Route	90	N/A	?	N/A	N/A	N/A
IGRP	100	N/A	?	N/A	N/A	N/A
OSPF	110	10	10	110	10	110
IS-IS	115	18	15	115	18	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
Internal BGP	200	170	255	200	130	200
Unknown	255	255	?	255	?	

Routing Basics



ISP Workshops