

Routing Basics



ISP Workshops



Routing Concepts

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

IPv4

- Internet historically has used IPv4
 - (now considered a legacy protocol)
 - Addresses are 32 bits long
 - Addresses are written in decimal with each 8-bit range separated by a “.”
 - Internet addresses range from 1.0.0.0 to 223.255.255.255
 - The remaining IPv4 range is either reserved or has special uses

IPv6

- Internet is using IPv6
 - (majority of popular content is now accessible via IPv6)
 - Addresses are 128 bits long
 - Addresses are written in hexadecimal with each 16-bit range separated by ":"
 - Internet addresses range from 2000::/16 to 3FFF::/16
 - The remaining IPv6 range is either reserved or has special uses

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:A:2::1/64
 - **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:A:2::1/64
 - 128 bits in an IPv6 address
 - 64 bits for the network portion
 - Leaves 64 bits for the host portion
 - 64 bits means there are 2^{64} possible hosts on this subnet

IP subnets

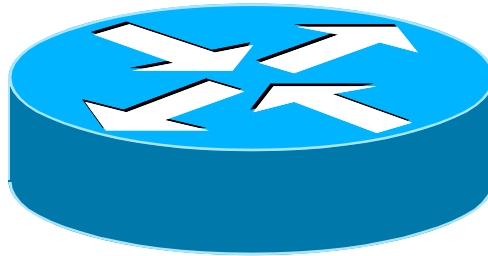
□ IPv4

- Smallest subnet is /30 – used for point-to-point links
 - /32 for loopbacks
 - Some implementations support /31 for point-to-point links

□ IPv6

- Smallest subnet is /64 – used on LANs and point-to-point links
 - /128 for loopbacks
 - Point-to-point links numbered as /127

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

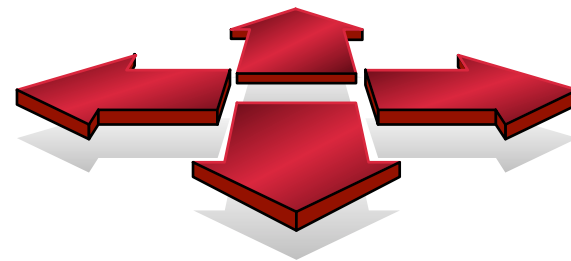
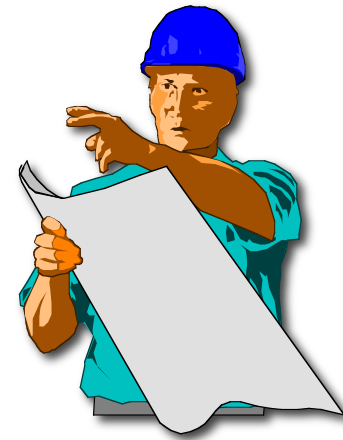
forward packet, forward packet, forward packet, forward packet...

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

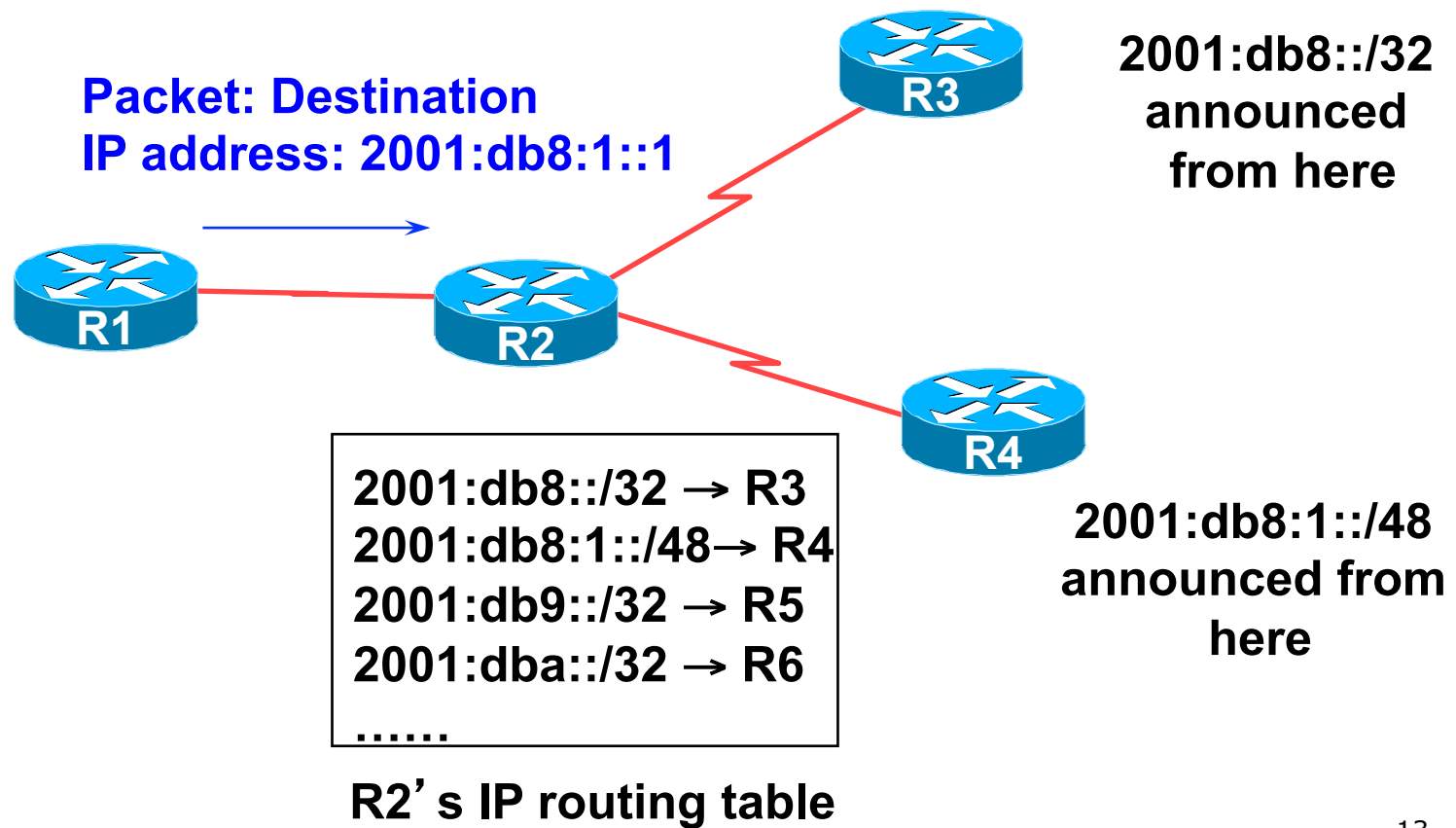
- ❑ Path derived from information received from a routing protocol
- ❑ Several alternative paths may exist
 - Best path stored in **forwarding** table
- ❑ Decisions are updated periodically or as topology changes (event driven)
- ❑ Decisions are based on:
 - Topology, policies and metrics (hop count,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

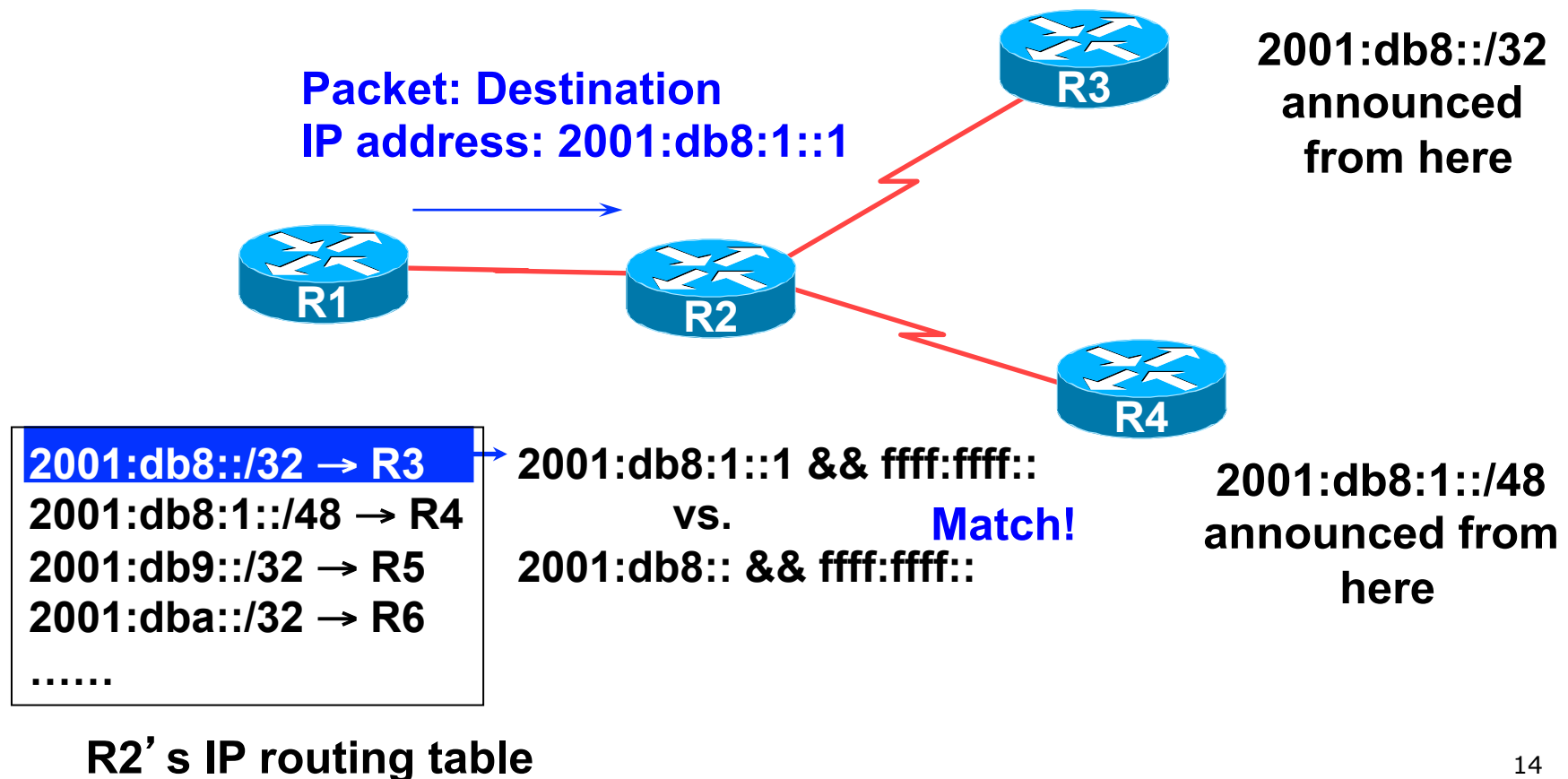
IP route lookup

- Based on destination IP address



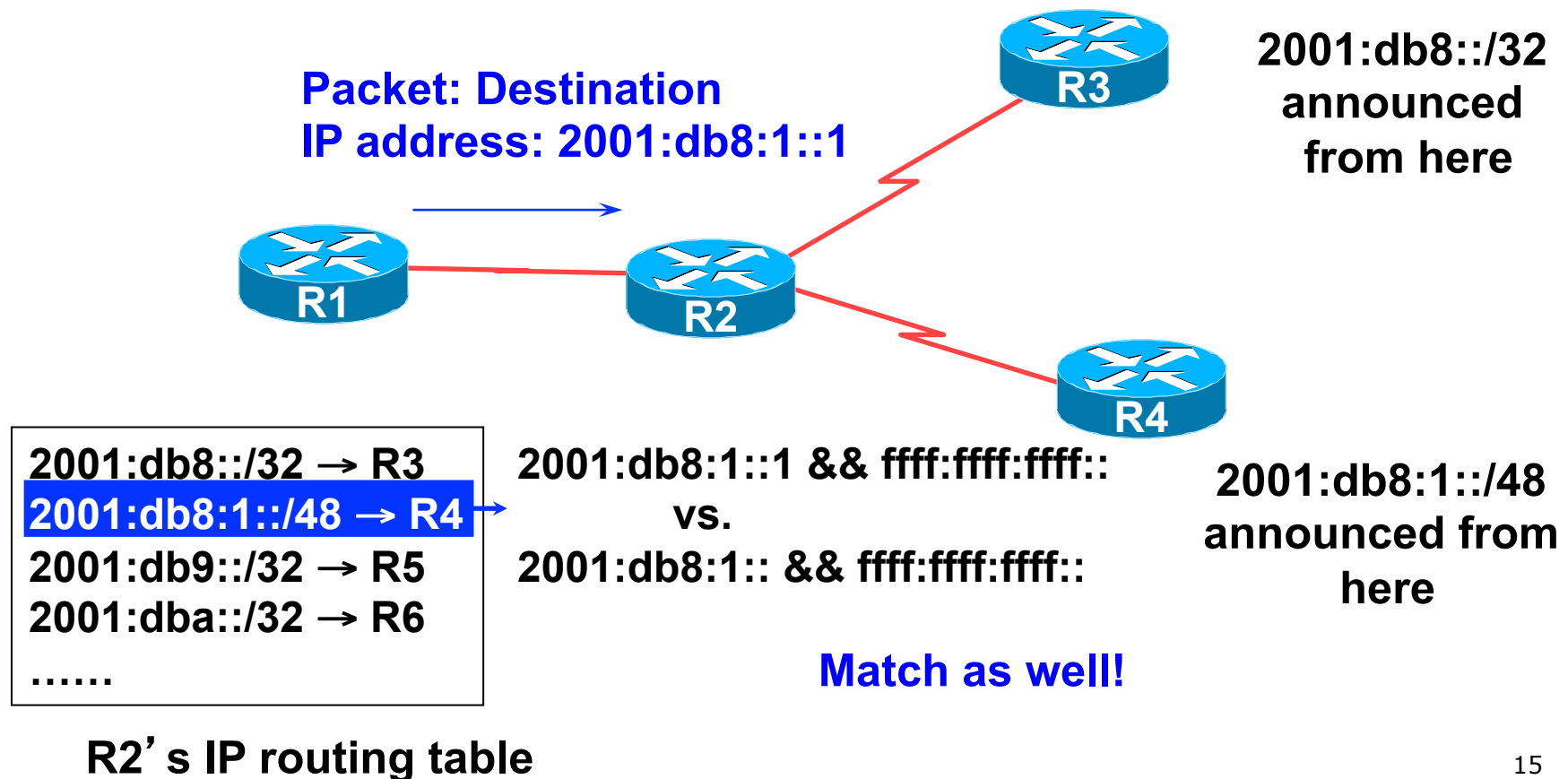
IP route lookup: Longest match routing

- Based on destination IP address



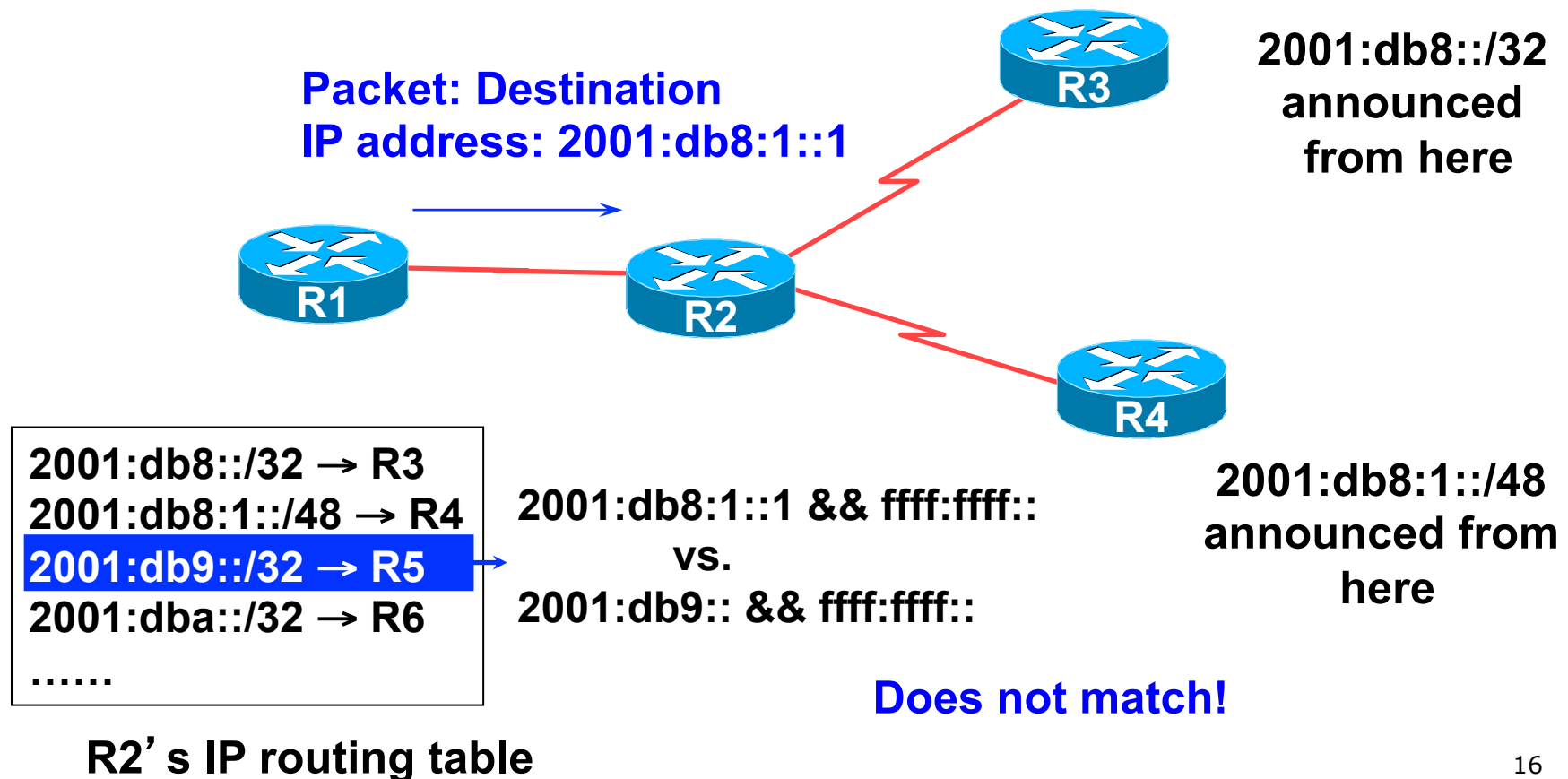
IP route lookup: Longest match routing

- Based on destination IP address



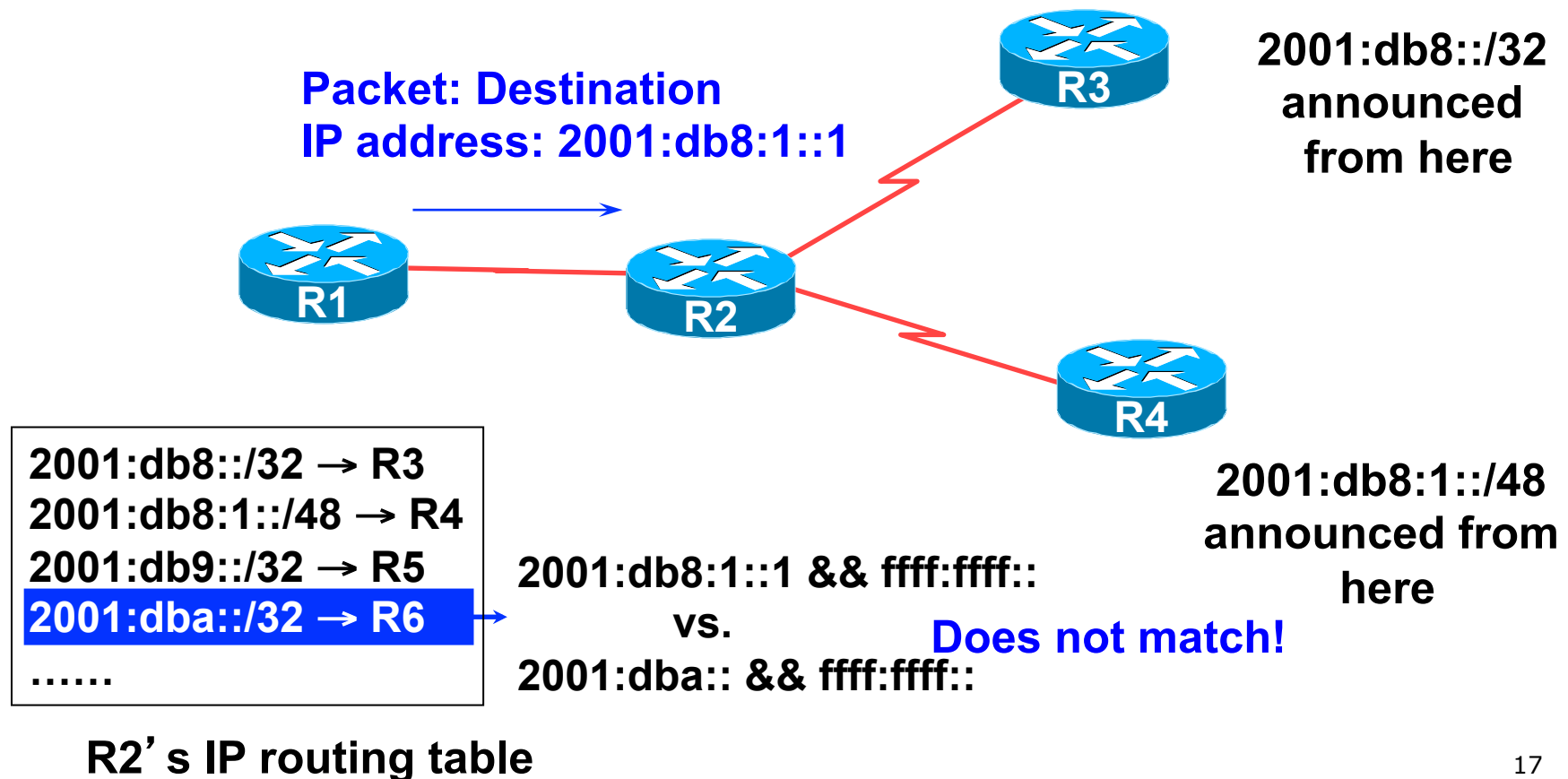
IP route lookup: Longest match routing

- Based on destination IP address



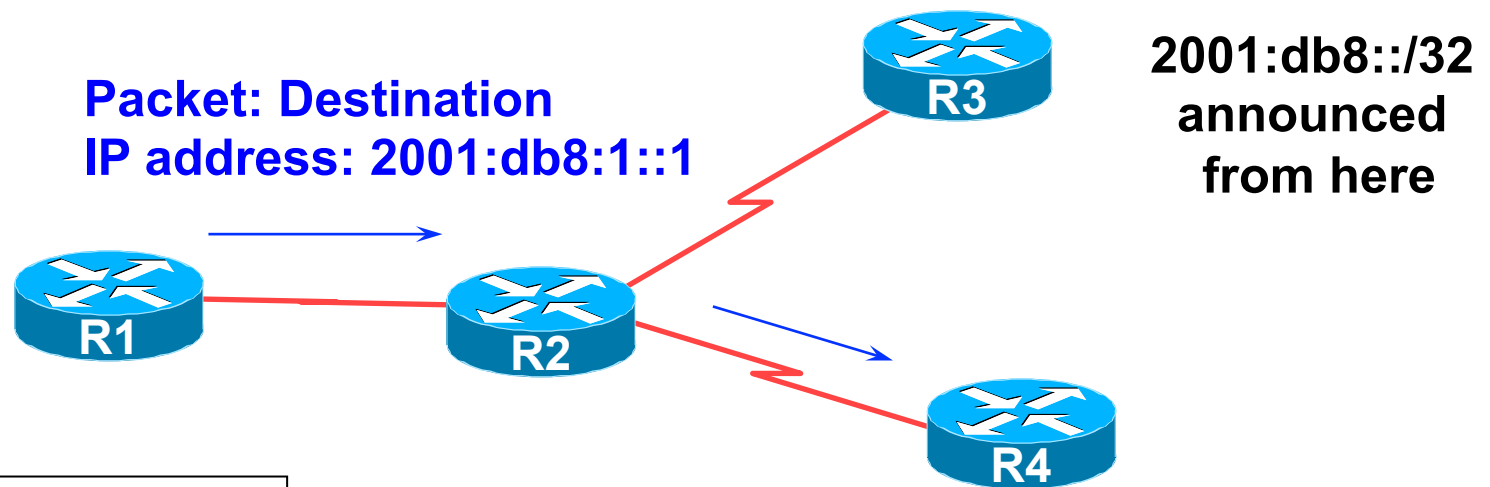
IP route lookup: Longest match routing

- Based on destination IP address



IP route lookup: Longest match routing

- Based on destination IP address



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

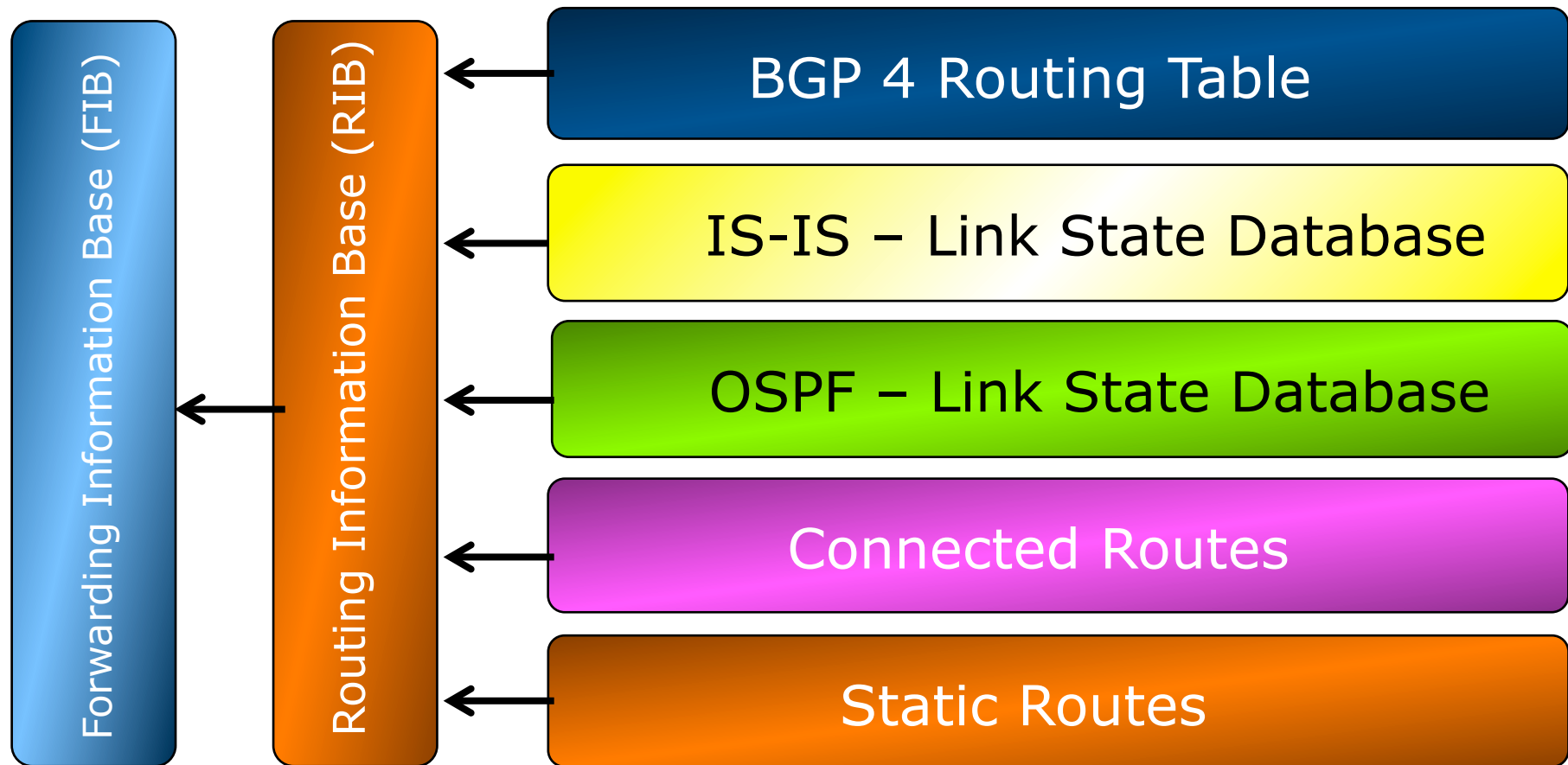
← Longest match, 48 bit netmask

R2's IP routing table

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



RIBs and FIBs

□ 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"

□ 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

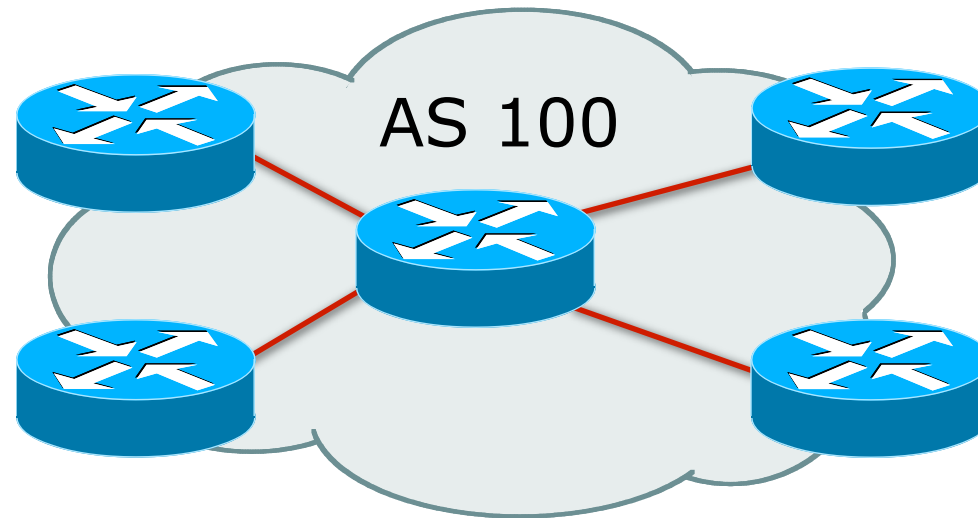
Egress Traffic

- ❑ 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)

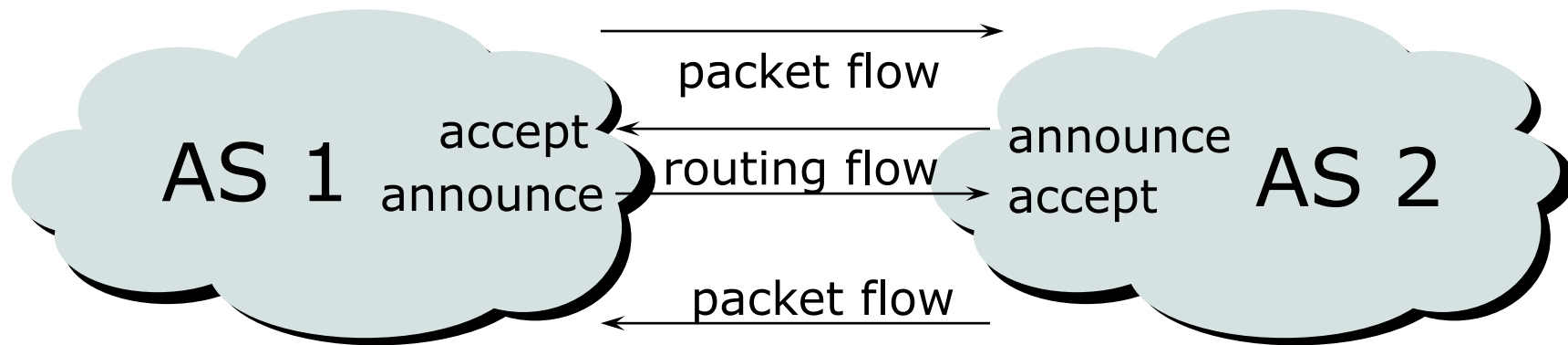


- ❑ Collection of networks with same routing policy
- ❑ Single routing protocol
- ❑ Usually under single ownership, trust and administrative control

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



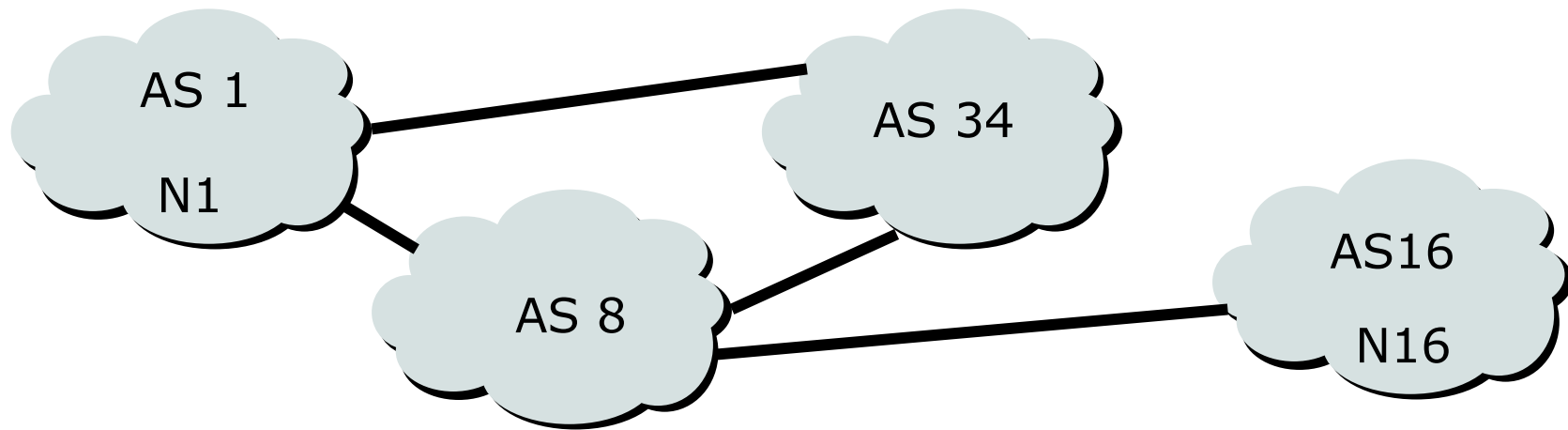
For networks in AS1 and AS2 to communicate:

- 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

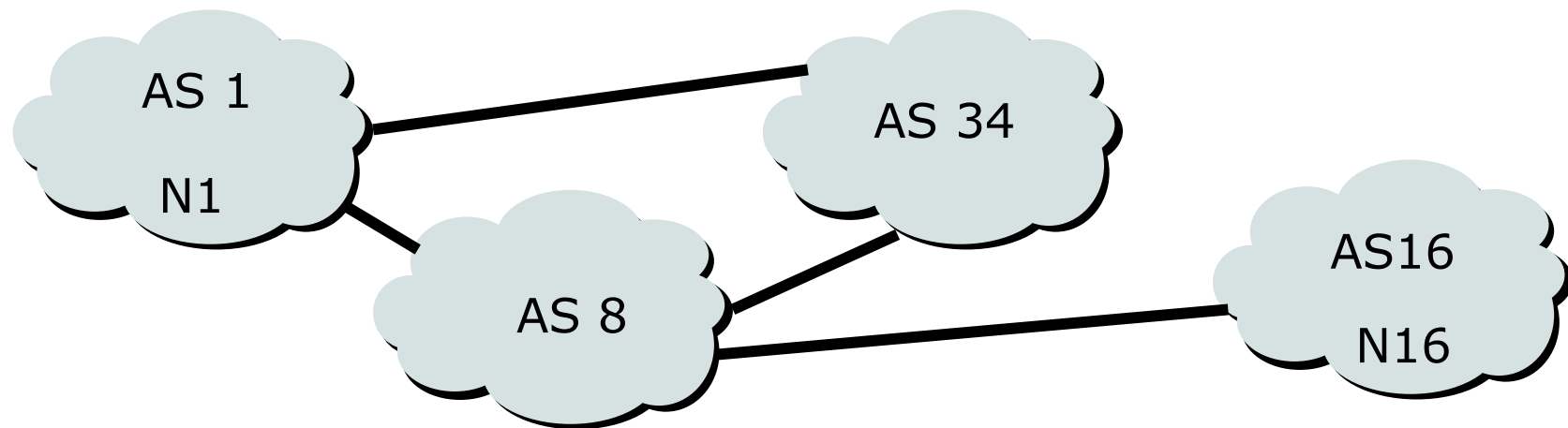
- Traffic flow is always in the opposite direction of the flow of Routing information
 - Filtering outgoing routing information inhibits traffic flow inbound
 - Filtering inbound routing information inhibits traffic flow outbound

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

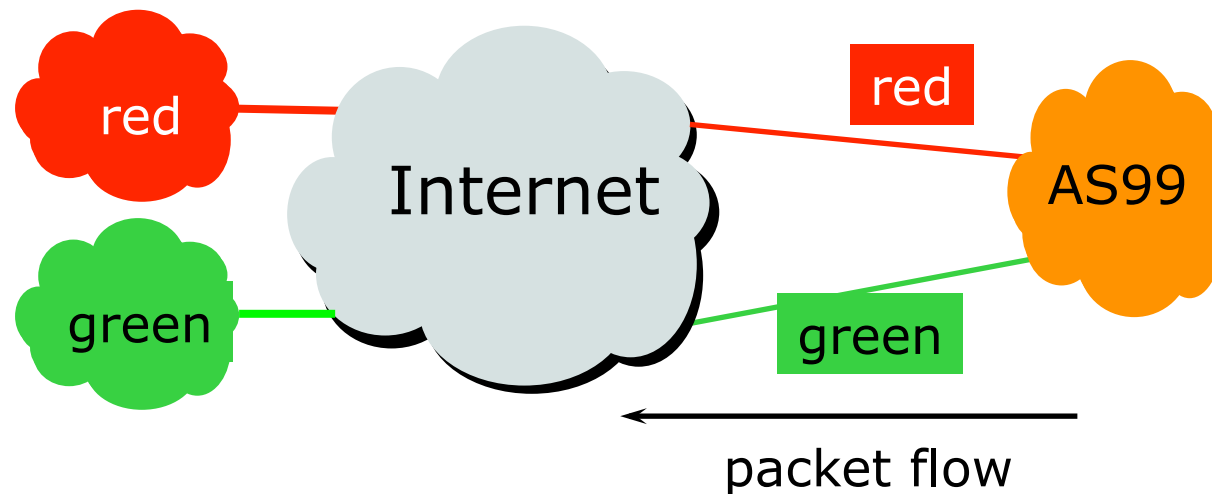


- As more and more paths are implemented between sites it is easy to see how policies can become quite complex.

Routing Policy

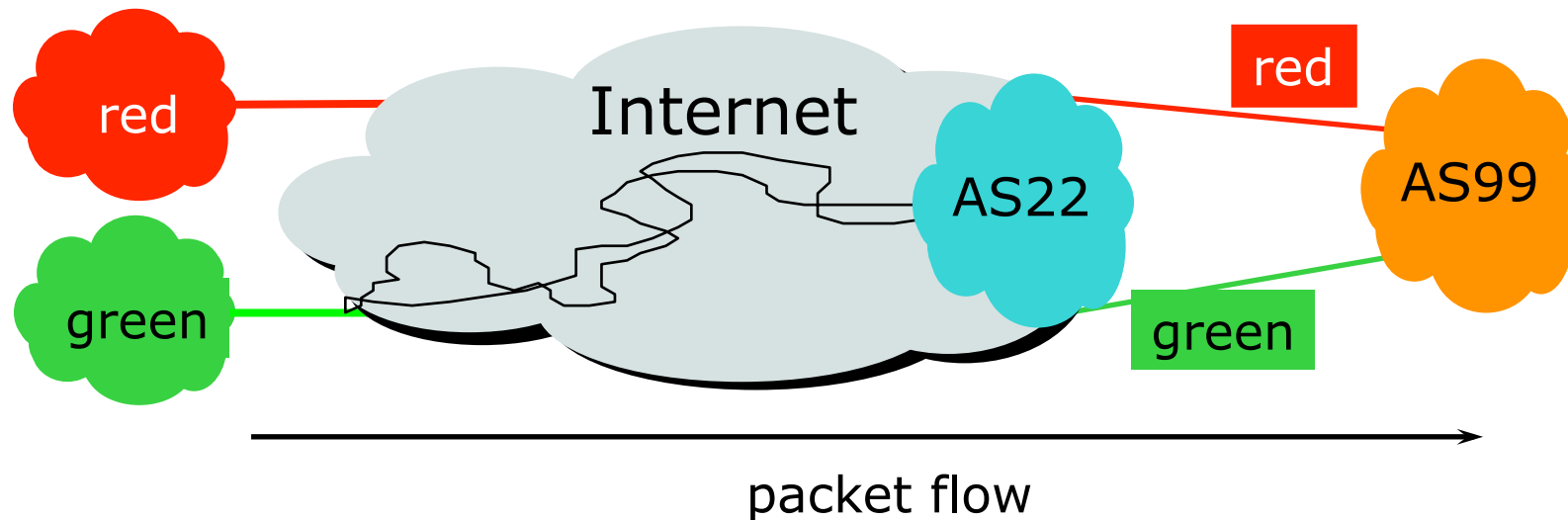
- ❑ Used to control traffic flow in and out of an ISP network
- ❑ ISP makes decisions on what routing information to accept and discard from its neighbours
 - Individual routes
 - Routes originated by specific ASes
 - Routes traversing specific ASes
 - Routes belonging to other groupings
 - ❑ Groupings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

- November 2016:
 - 34100 IPv6 prefixes & 624000 IPv4 prefixes
 - Not realistic to set policy on all of them individually
 - 55300 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?

- ❑ 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

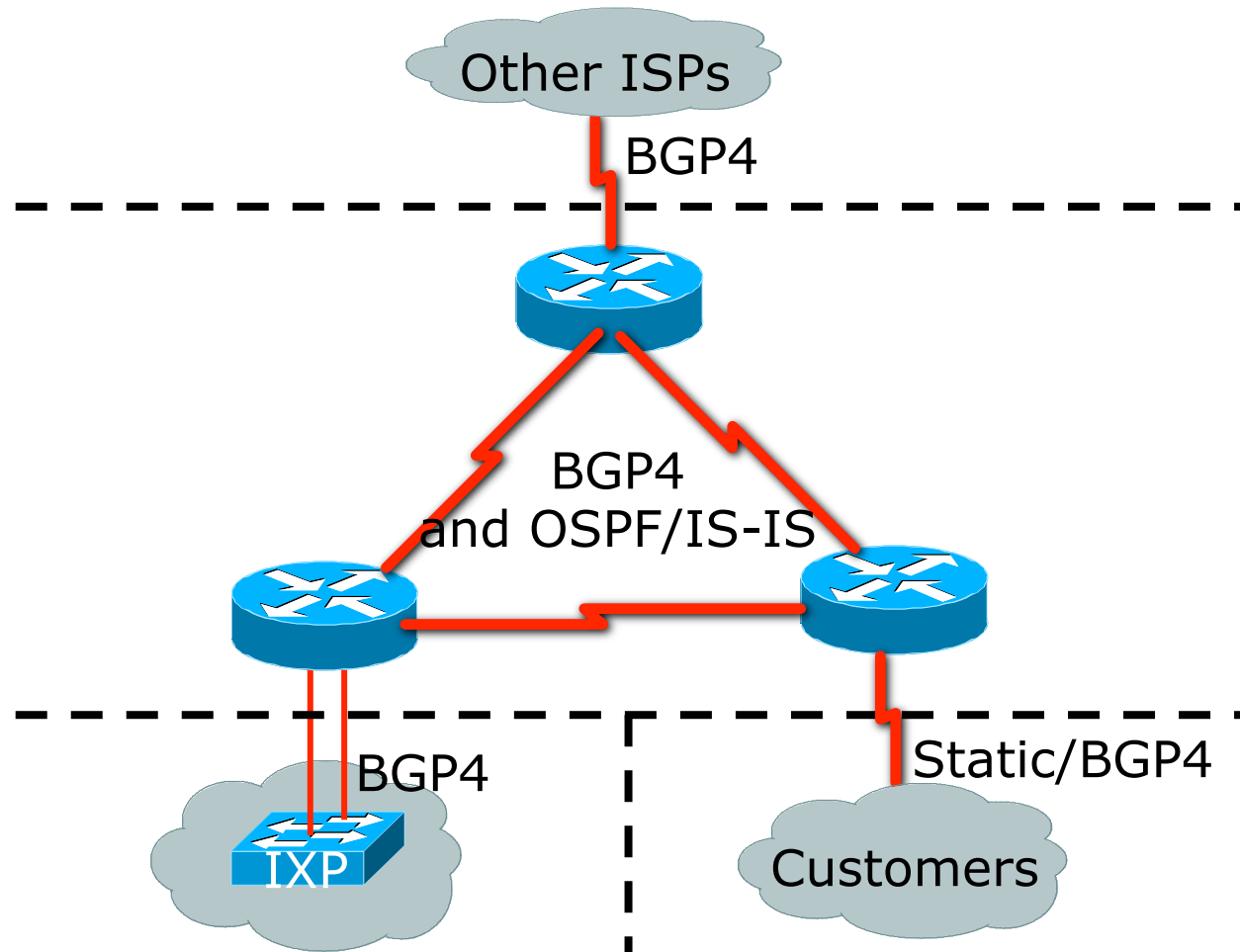
□ Interior

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

Routing Basics



ISP Workshops