Promoting Routability

Routing for the Internet

APRICOT'99 Tutorial - Singapore

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CISCO SYSTEMS

Introduction

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- **Please ask questions**

Agenda

- Routing Terms and Concepts
- Introduction to IGPs
- BGP for ISPs
- Routing Design for ISPs
- Routing Etiquette and the IRR

Goals

- **Promoting a healthy Internet**
- **Efficient and Effective Routing Configuration**
- **Internet Routing Registry**

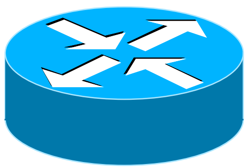
  awareness

  understanding

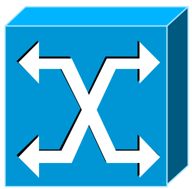
  participation

Routing Terms and Concepts

Some Icons



Router
(layer 3, IP datagram forwarding)



ATM or Frame Relay switch
(layer 2, frame or cell forwarding)

Network Cloud

Definitions

- **PoP - Point of Presence**

  physical location of ISP's equipment

- **vPoP - virtual PoP**

  apparent ISP location

  in reality a back hauled access point

  used mainly for dial access networks

- **Hub - large central PoP**

Network Topologies

Routed backbone

- HDLC or PPP links between routers
- Easier routing configuration and debugging

Switched backbone

- Frame Relay/ATM switches in core
- Surrounded by routers
- Complex routing & debugging
- Traffic Engineering

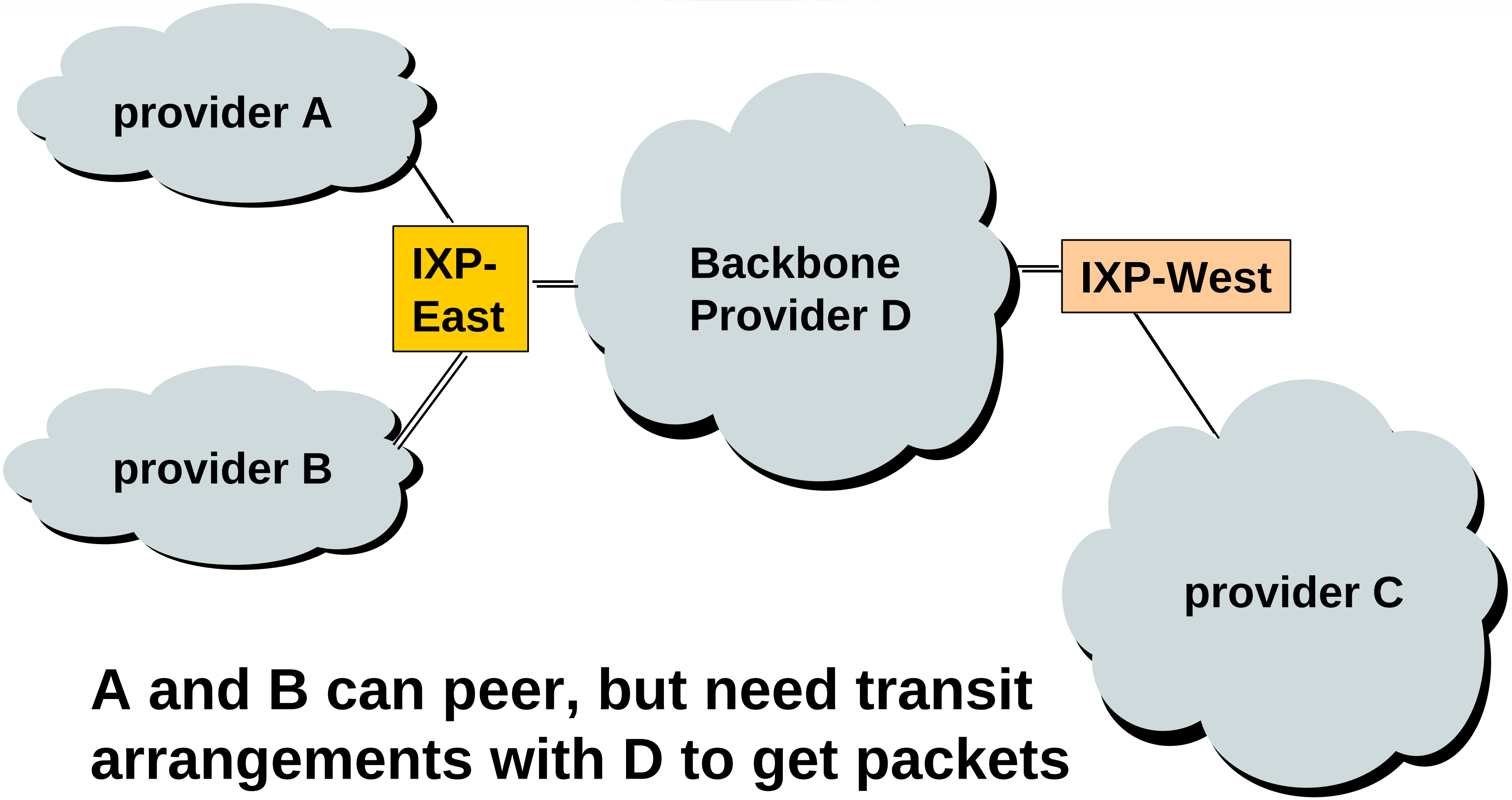
PoP Topologies

- Core routers - high speed trunk connections
- Distribution routers and Access routers - high port density
- Border routers - connections to other AS's
- Service routers - hosting and servers
- Some functions might be handled by a single router

Definitions

- **Transit** - carrying traffic across a network, usually for a fee
- **Peering** - exchanging routing information and traffic
- **Default** - where to send traffic when there is no explicit match is in the routing table

Peering and Transit example



A and B can peer, but need transit arrangements with D to get packets to/from C

Network Interconnections

- **Direct Interconnect**
- **Local IXP (Internet eXchange Point)**

  peering point for a group of local/regional providers

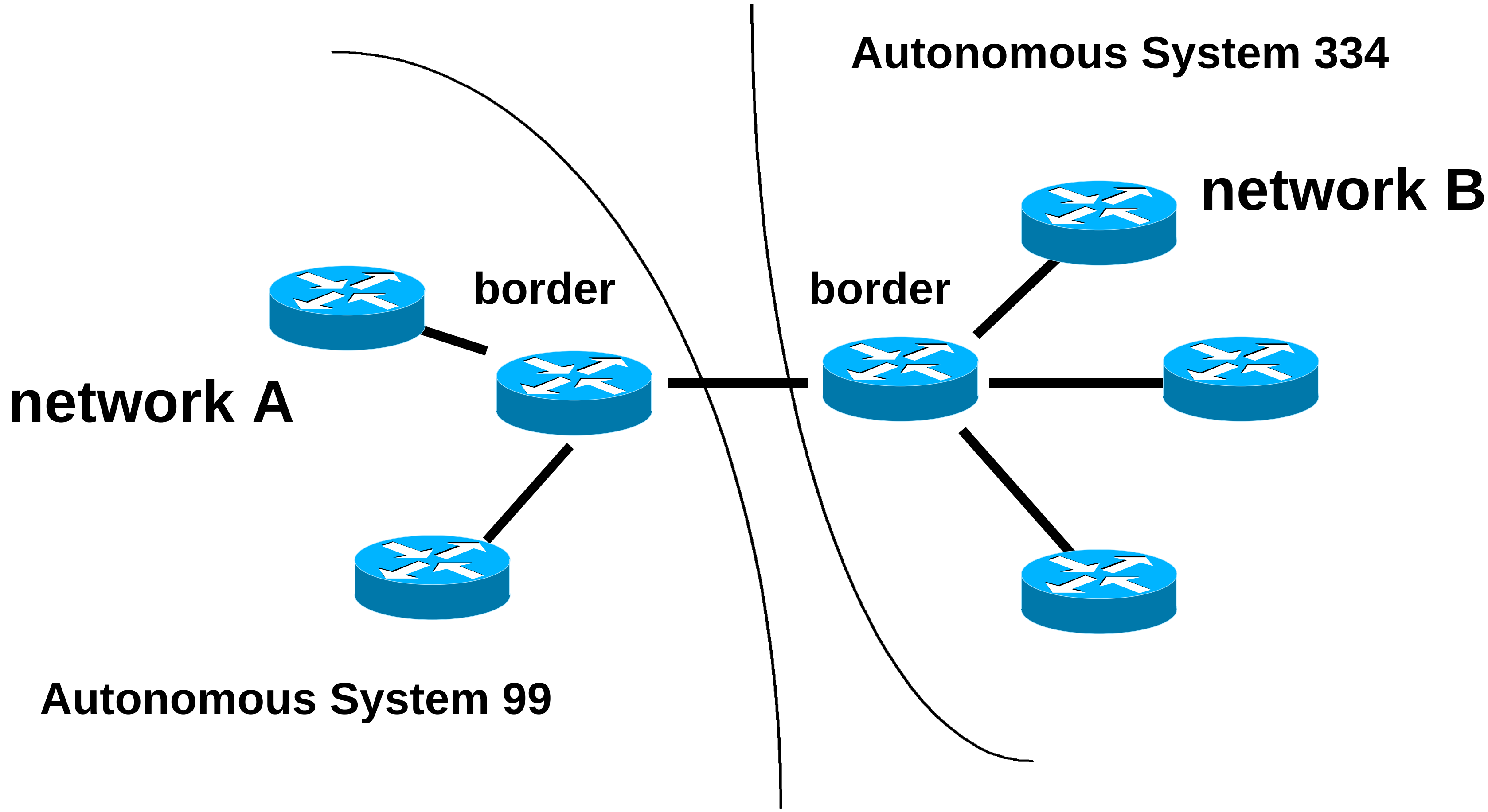
- **Transit IXP**

  connects local providers to backbone (transit) providers

- **Hybrid IXP**

  combines the function of local and transit

Direct (private) Interconnect

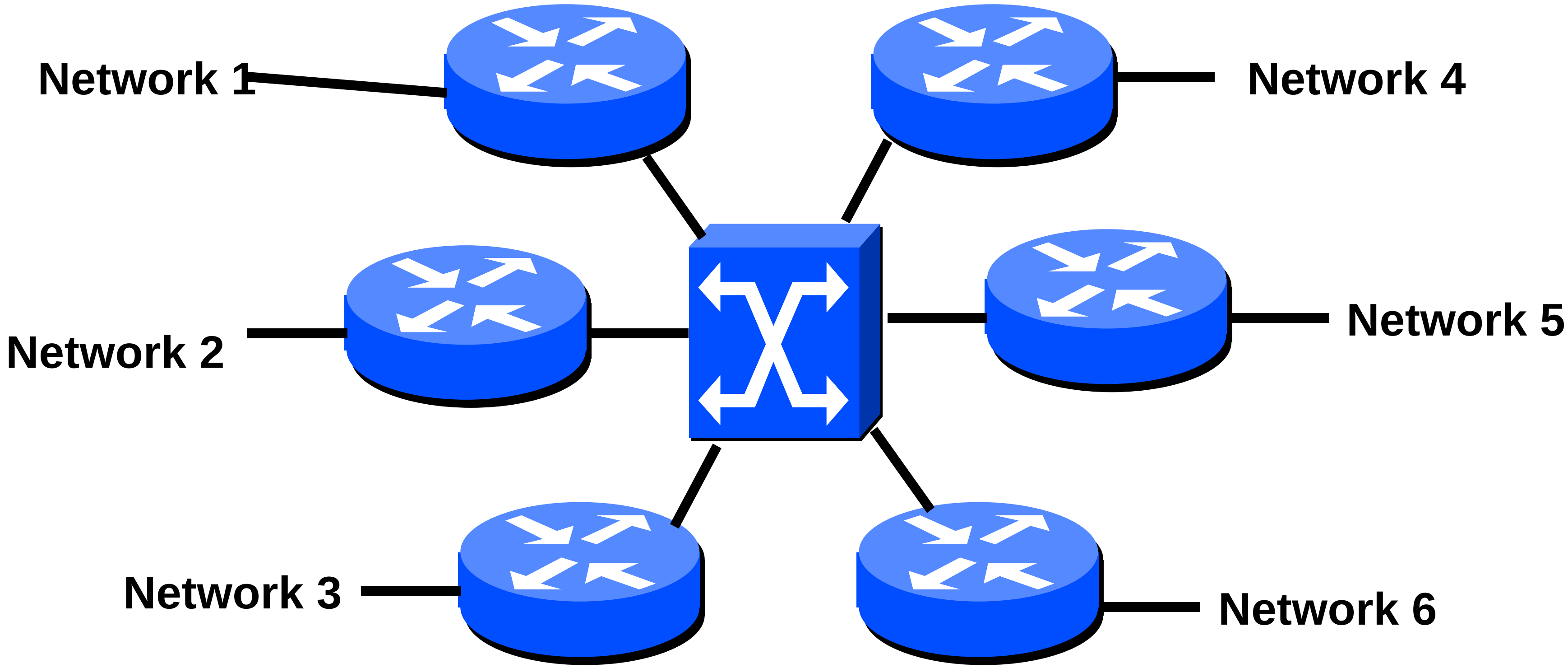


Public Interconnect Point

- **Centralised (in one facility)**
- **Distributed (connected via WAN links)**
- **Shared, switched or routed interconnect**

  Router, FDDI, Ethernet, ATM, Frame relay, SMDS, etc.

Public Interconnect Point



each of these represents a border router in a different autonomous system

Route Server

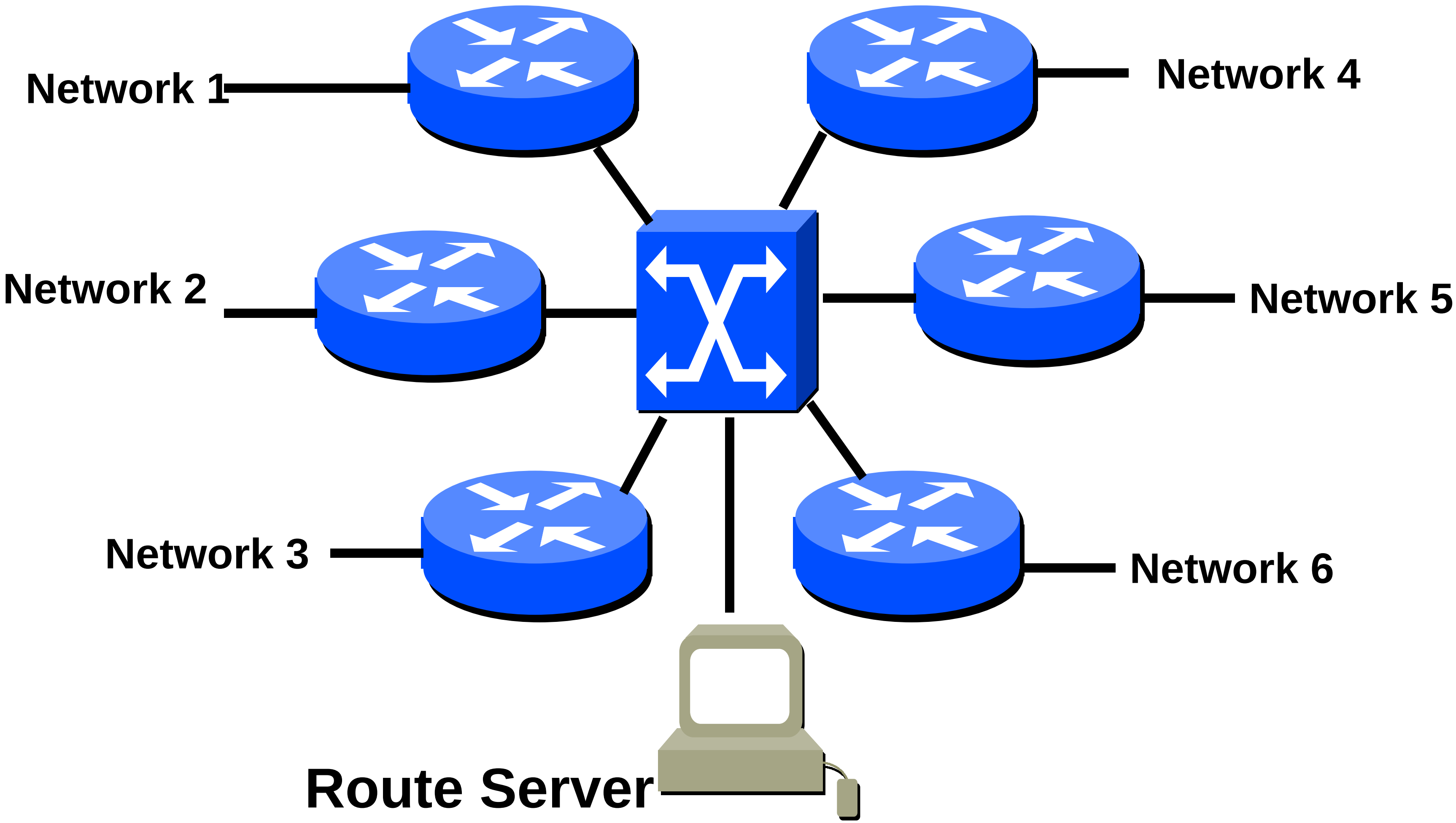
- **Device which maintains BGP routing table at IXP and forwards it to IXP participants**
- **Advantages:**

  reduces resource burden on border routers (CPU, memory, configuration complexity)

  reduces administrative burden on providers
- **Disadvantages:**

  must rely on a third party (for management, configuration, software updates, maintenance, etc)

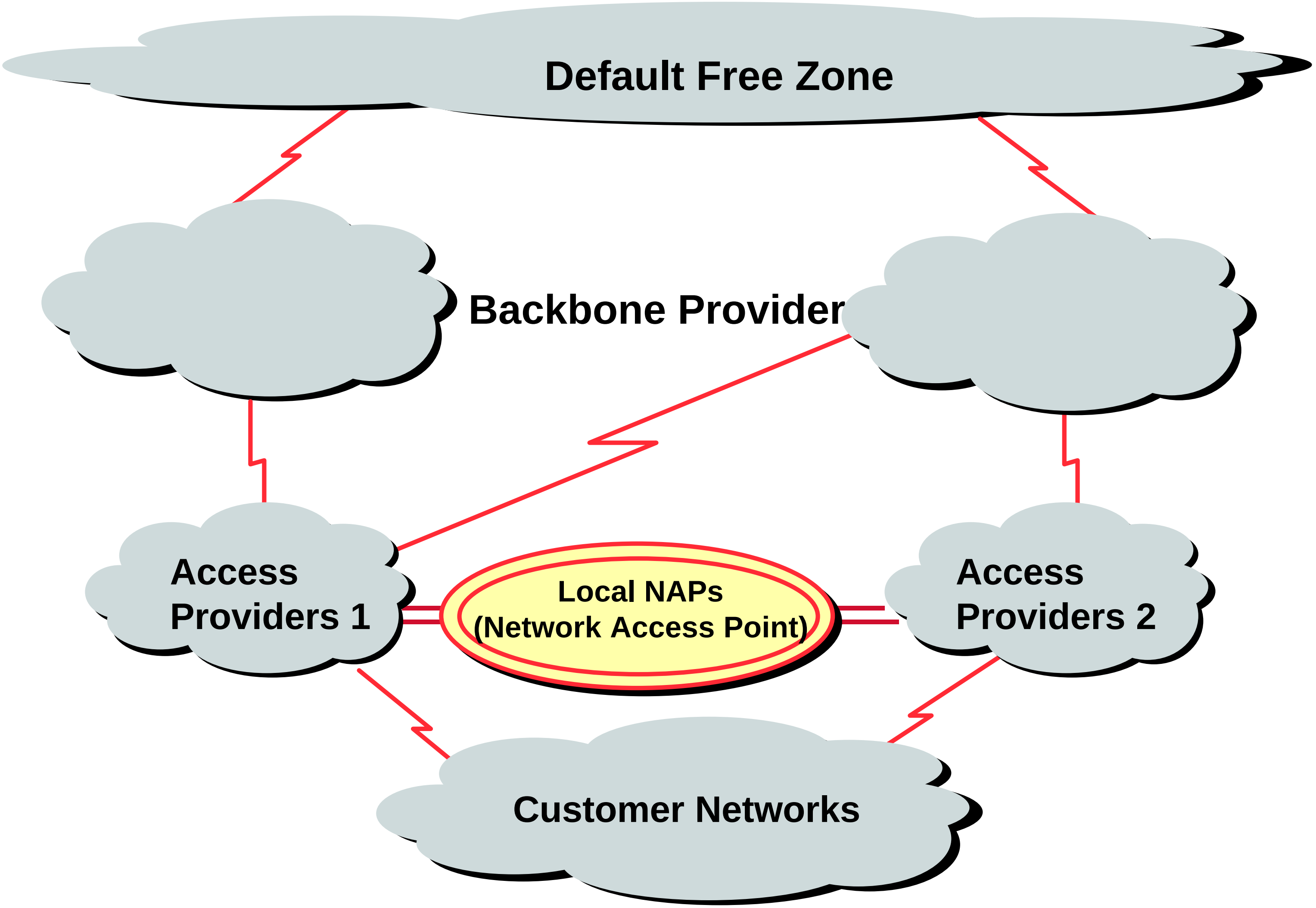
Route Server



Default Free Zone

The default free zone is made up of Internet routers which have explicit routing information about the rest of the Internet, and therefore do not need to use a default route.

High Level View of the Global Internet

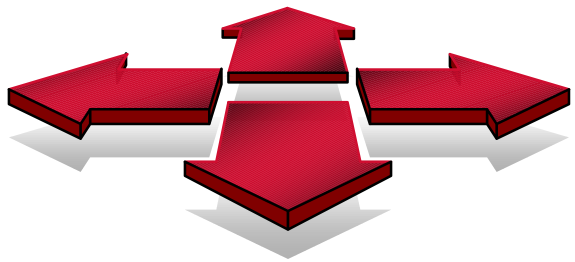


Routing Concepts

- Routing and Forwarding
- Routing definitions
- Policy options
- Addressing
- Routing Protocols

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 next hop 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 packet
- "longest match" routing

  more specific prefix preferred over less specific prefix

  example: packet with destination of 10.1.1.1/32 is sent to the router announcing 10.1/16 rather than the router announcing 10/8.

IP Forwarding

- **Router makes decision on 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)
- **Can be aided by special hardware**

Explicit versus Default routing

- **Default:**
  - **simple, cheap (cycles, memory, bandwidth)**
  - **low granularity (metric games)**
- **Explicit (default free zone)**
  - **high overhead, complex, high cost, high granularity**
- **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

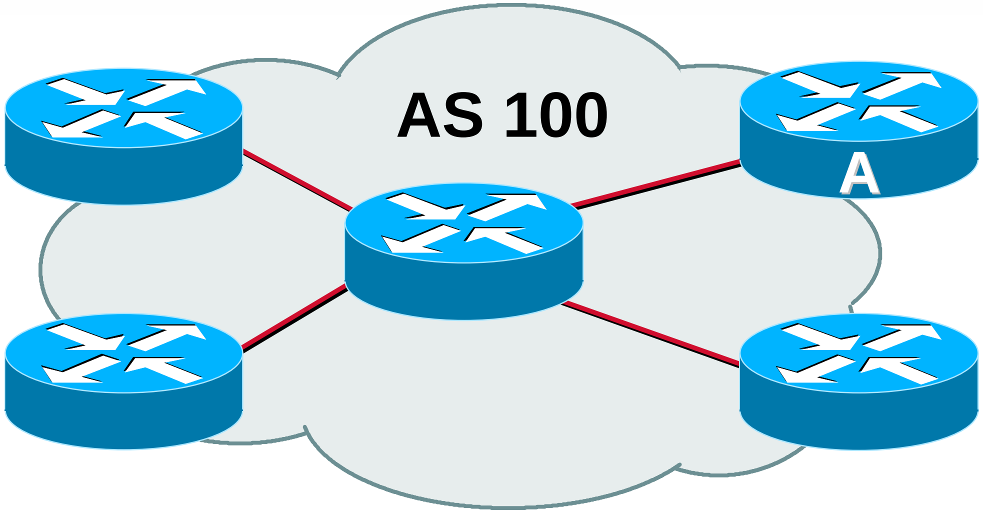
- **How packets get to your network and your customers' networks**
- **Ingress traffic depends on:**

  what information you send and to whom

  based on your addressing and AS's

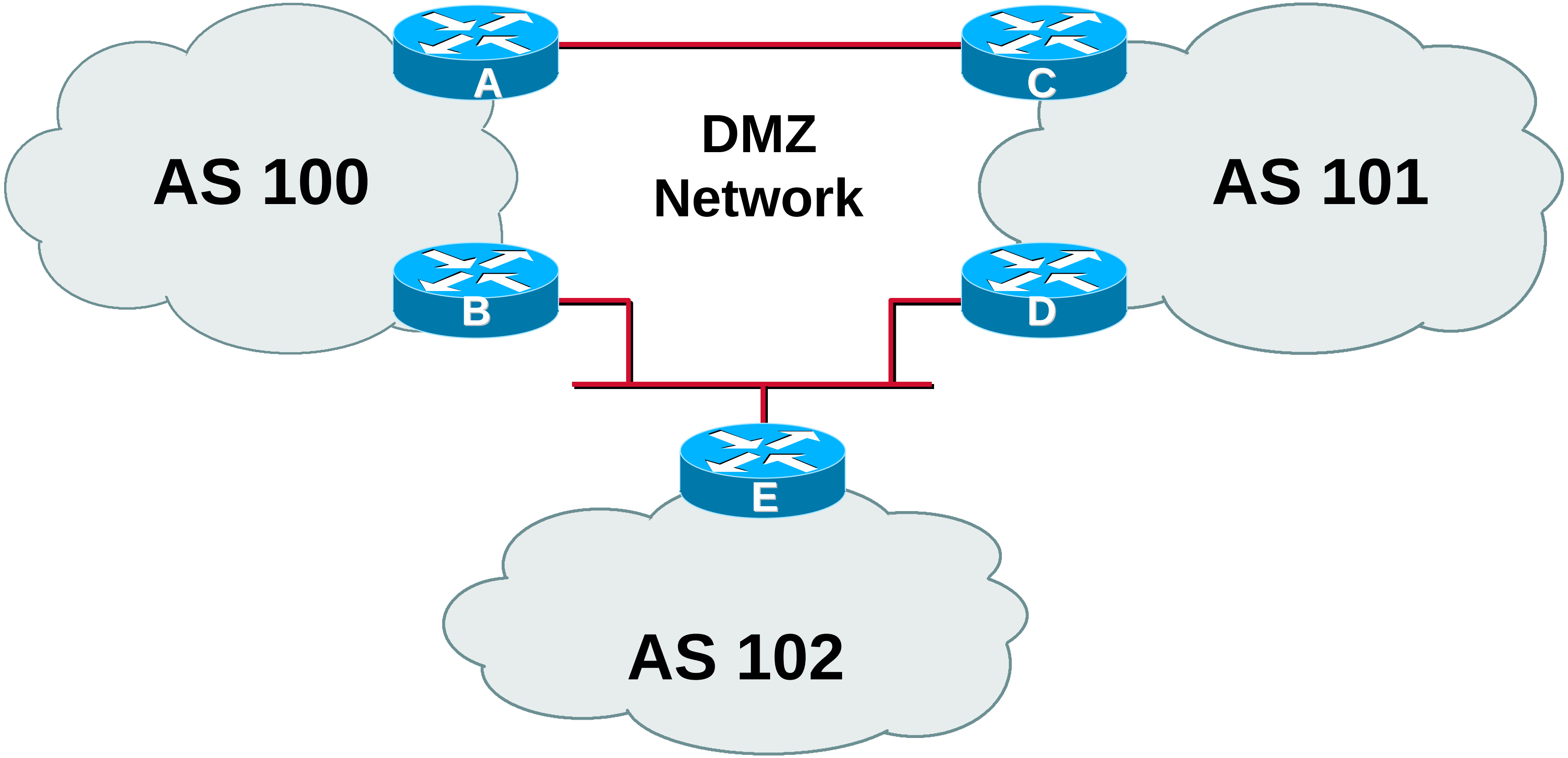
  based on others' policy (what they accept from you and what they do with it)

Autonomous System (AS)



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

Demarcation Zone (DMZ)

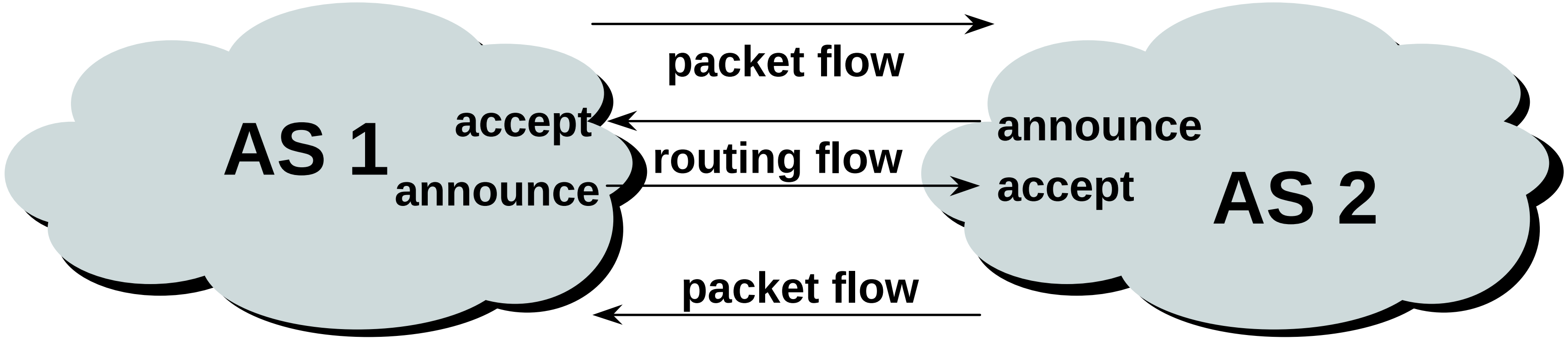


- Network shared between AS's

Definition of terms

- **Neighbours** - AS’s which directly 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

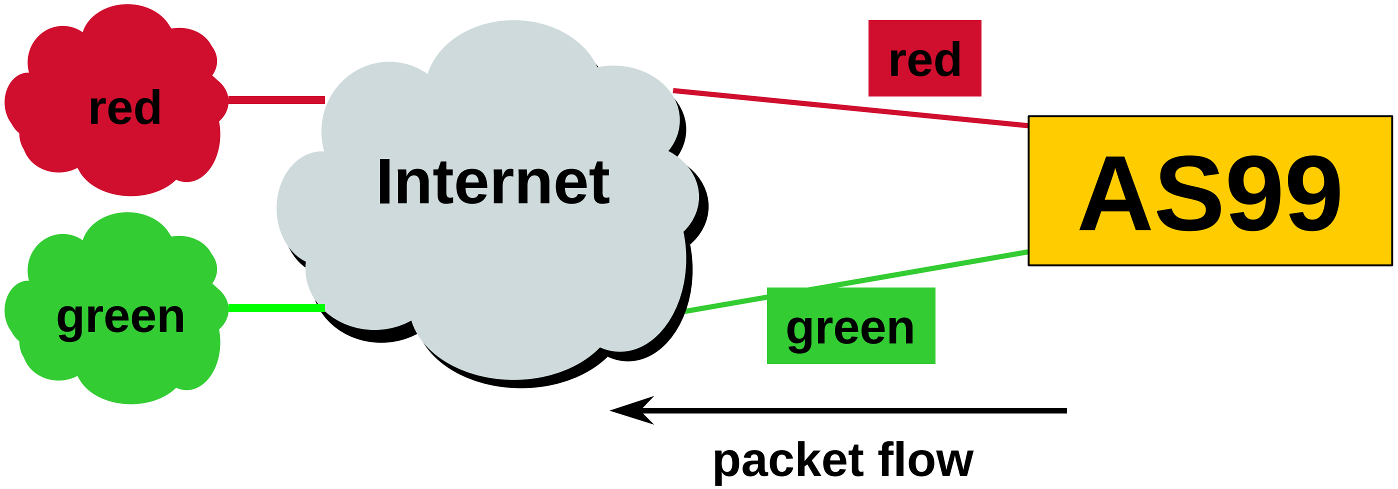
Routing flow and Traffic flow

- Traffic flow is always in the opposite direction of the flow of routing information

  filtering outgoing routing information inhibits traffic flowing in

  filtering incoming routing information inhibits traffic flowing out

Routing policy limitations

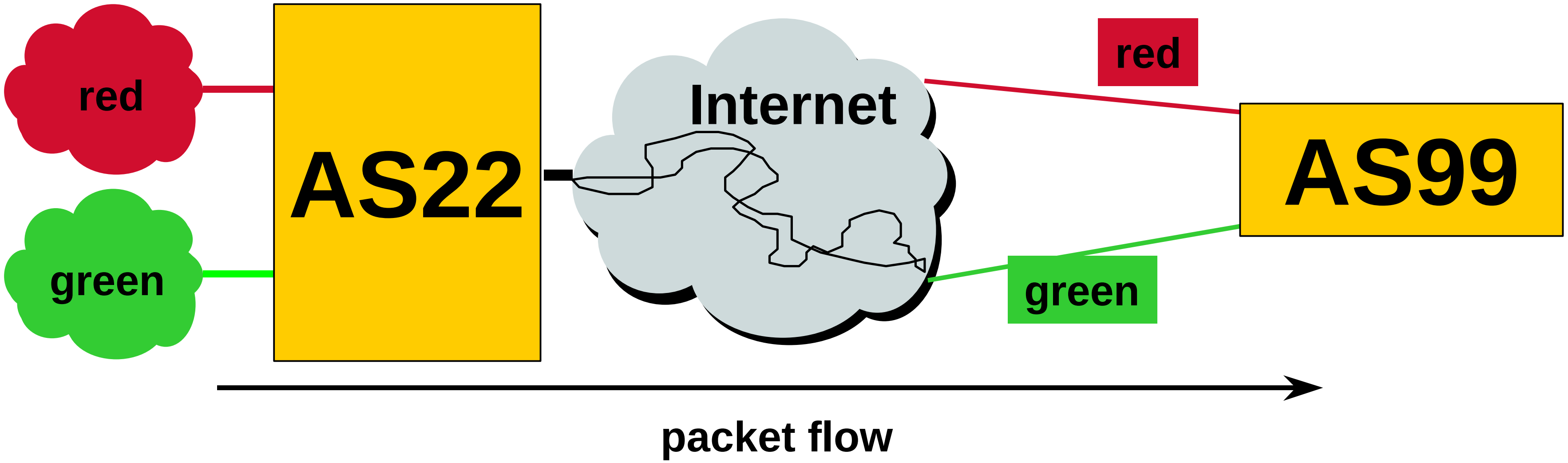


AS99 uses red link for traffic going to the red AS and green link for traffic going to the green AS

To implement this policy for AS99:

- **accept routes originating in the red AS on the red link**
- **accept all other routes on the green link**

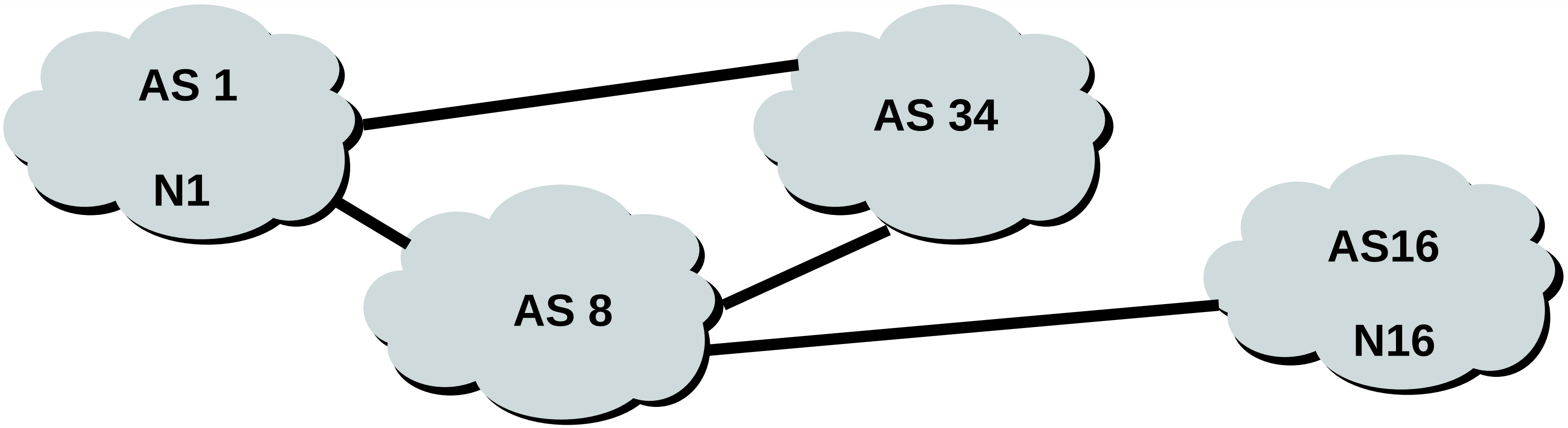
Routing policy limitations



For packets flowing *toward* AS 99:

Unless AS 22 and all other intermediate AS's co-operate in pushing green traffic to the green link then some reasonable policies can not be implemented.

Routing policy with multiple AS's



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.

Granularity of routing policy

- **What to announce/accept**
- **Preferences between multiple accepts**
  - **single route**
  - **routes originated by single AS**
  - **routes originated by a group of AS's**
  - **routes traversing specific path**
  - **routes traversing specific AS**
  - **routes belonging to other groupings (including combinations)**

Routing Policy Issues

- 55,000+ prefixes (not realistic to set policy on all of them individually)
- 4500+ AS's (too many)
- routes tied to a specific AS or path may be unstable regardless of connectivity
- groups of AS's are a natural abstraction for filtering purposes

Routing Policy Issues

- Destination based limitations
- Global topology not known (and constantly changing)
- Route groupings are not known
  - AS membership or AS groups
- Set of all routes in the Internet is not known

IP Addressing

- Internet is classless
- Concept of Class A, class B and class C is no more

  engineers talk in terms of prefix length, for example the class B 158.43 is now called 158.43/16.

- All routers must be CIDR capable

  Classless InterDomain Routing

IP Addressing

- **IP Address space is a resource shared amongst *all* Internet users**

  Regional Internet Registries delegated allocation responsibility by the IANA

  RIRs allocate address space to ISPs or Local/National Internet Registries

  Address space is assigned to end customers/users by RIRs/LIRs/ISPs

  When address space is not used, it should be returned to the free pool for reallocation

Geographical and Provider addressing

- **Geographical addressing**

  ARIN/APNIC/RIPE (the 3 RIRs)

  Nationally Assigned (country NICs)

- **Provider-based addressing**

  Addresses assigned by upstream provider

  Local Internet Registries

Geographical Addressing

Advantages

- Reduces global routing table - longer term
- provider independent
- good local routing at interconnects
- participant in RIR process

Disadvantages

- Increases global routing table - short term
- goes against RIR aims of aggregation
- maybe suboptimal routing

Provider Based Addressing

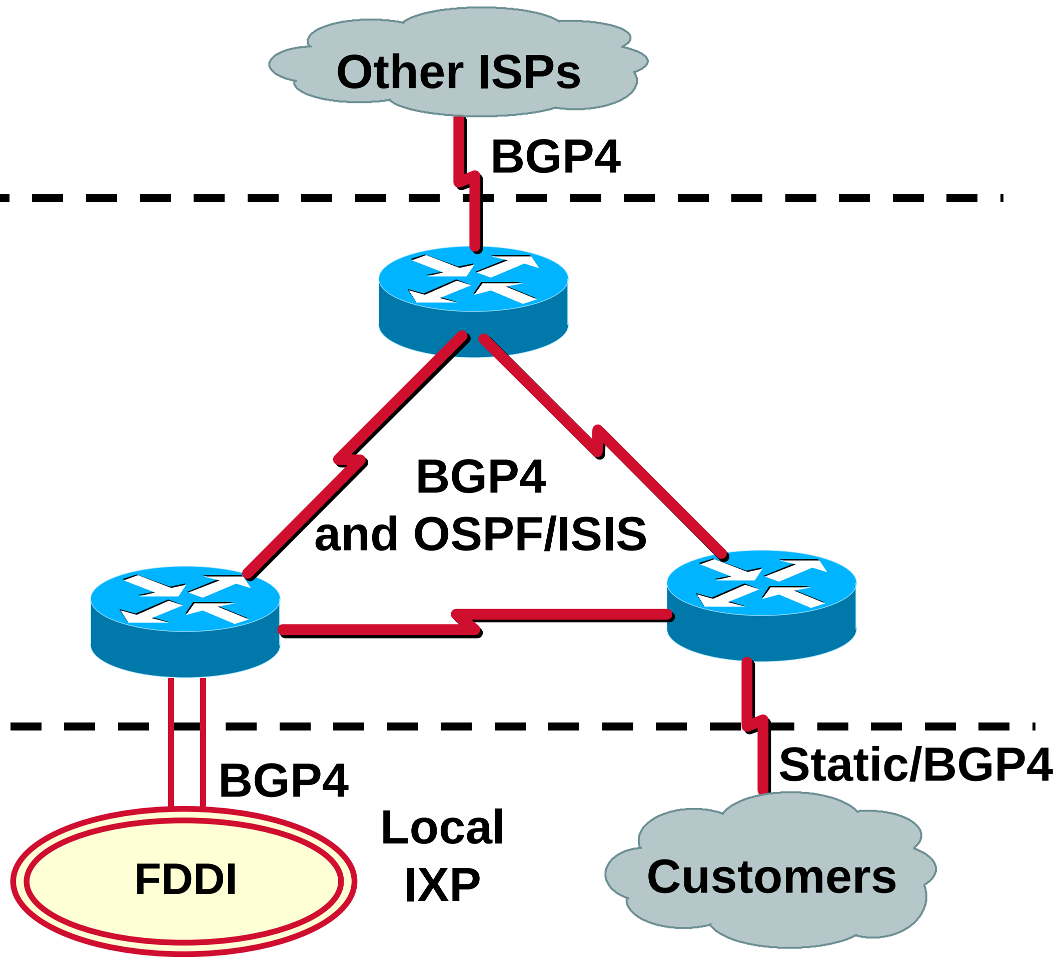
Advantages

- Easy to get started
- no increase in size of global routing table
    - part of upstream ISP's address block
- no need for an AS or BGP

Disadvantages

- Need to renumber when changing providers
- may fragment initial providers block when multihoming
- no participation in RIR process

Hierarchy of Routing Protocols



What Is an IGP?

- Interior Gateway Protocol
- Within an Autonomous System
- Carries information about internal prefixes
- Examples - OSPF, ISIS, EIGRP…

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

- Policy

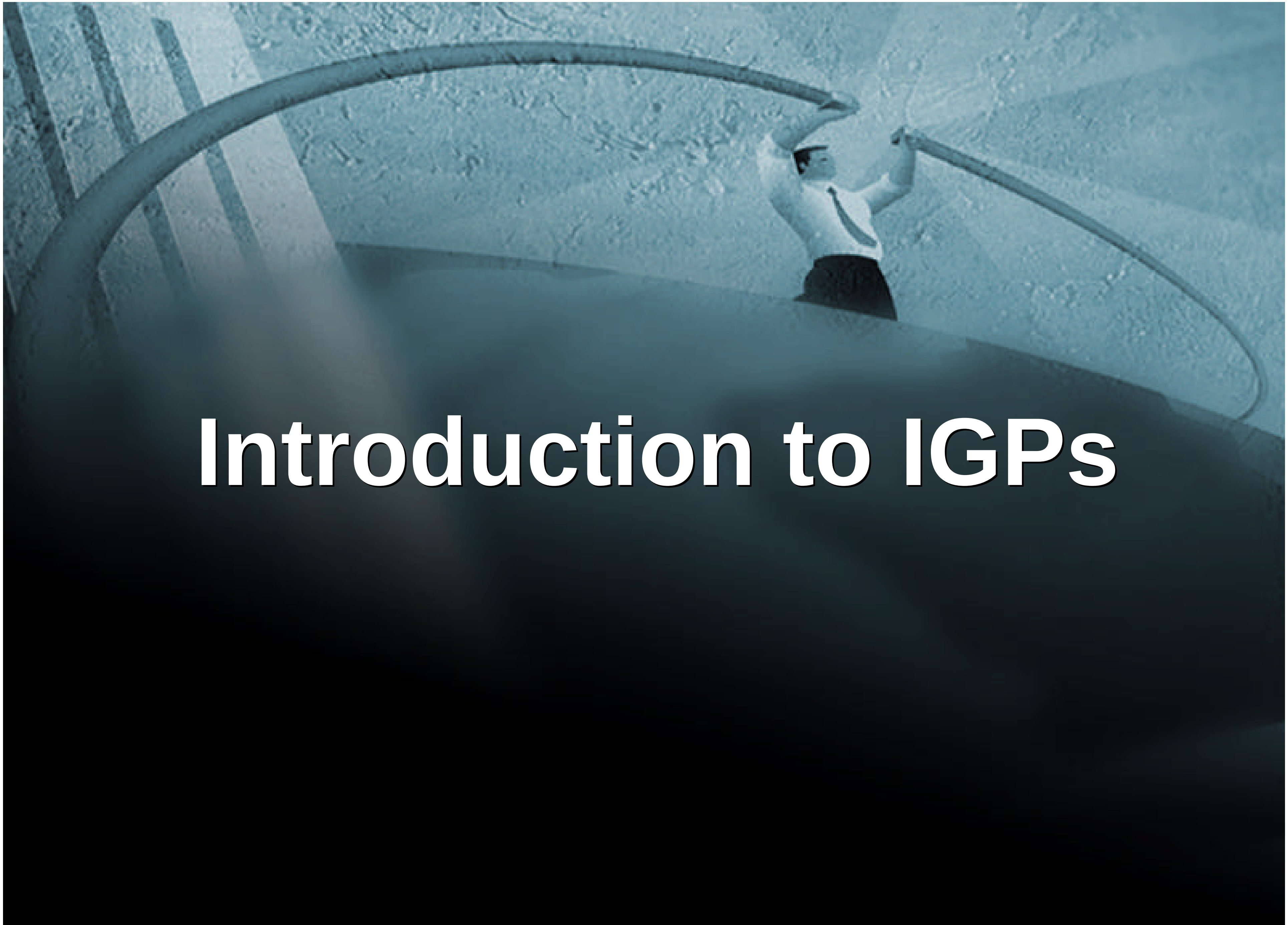
  Control reachability to prefixes

  Merge separate organizations

  Connect multiple IGPs

Interior versus Exterior Routing Protocols

- Interior
  - automatic neighbour discovery
  - generally trust your IGP routers
  - routes 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



Introduction to IGPs

ISIS - Intermediate System to Intermediate System

- Link State Routing Protocol
- OSI development now continued in IETF
- Supports VLSM
- Low bandwidth requirements
- Supports two levels

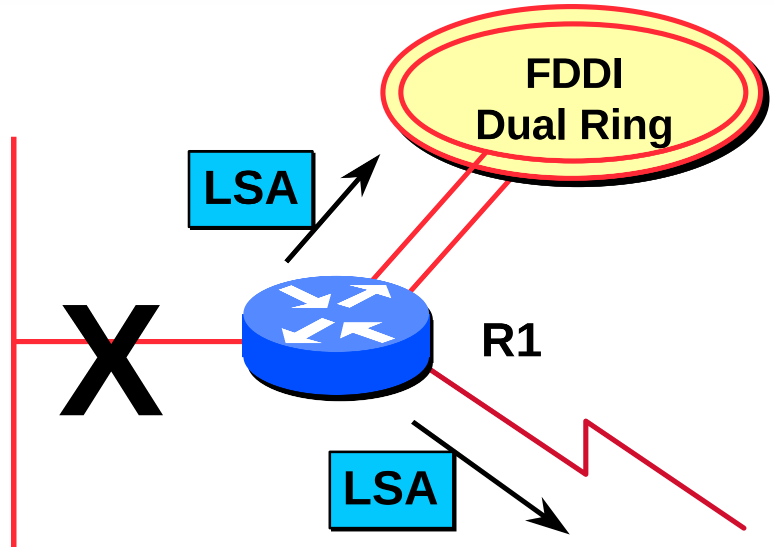
  The backbone (level 2) and areas (level 1)

- Route summarisation

OSPF - Open Shortest Path First

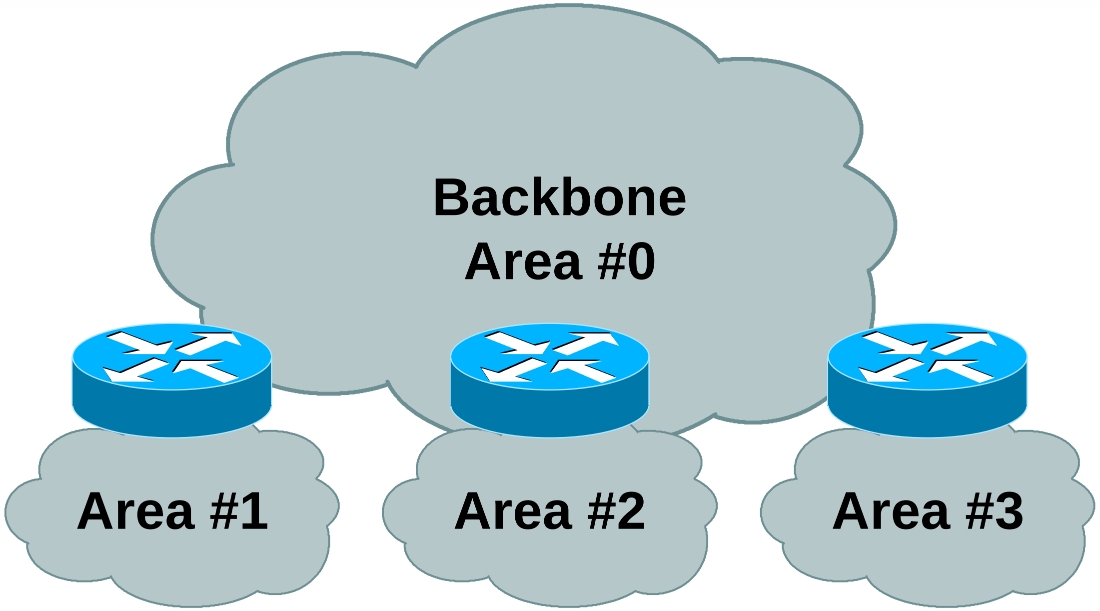
- Link State Routing Protocol
- Designed by IETF for TCP/IP - RFC2328
- Supports VLSM
- Low bandwidth requirements
- Supports different types of areas
- Route summarisation and authentication

Low Bandwidth Utilisation



- **Only changes propagated**
- **Multicast on multi-access broadcast networks**

Why Areas - OSPF Example



- **Topology of an area is invisible from outside of the area**
- **Results in marked reduction in routing traffic**

Scalable Network Design

- ISIS

  Implement level1 - level 2/level 1 hierarchy for large networks only

- OSPF

  Implement area hierarchy

- Addressing Plan
- Route Summarisation

When to Use OSPF or ISIS

- Very large, complex networks
- VLSM
- For fast convergence
- Complex network design
- Adherence to IETF standards

Internet Routing Protocols

- IP routing protocols are characterised as

Name	Type	Proprietary	Function	Updates	Metric	VLSM	Summ
RIP	DV	No	Interior	30 Sec	Hops	No	Auto
RIPV2	DV	No	Interior	30 Sec	Hops	Yes	Auto
IGRP	DV	Yes	Interior	90 Sec	Comp	No	Auto
EIGRP	Adv DV	Yes	Interior	Trig	Comp	Yes	Both
OSPF	LS	No	Interior	Trig	Cost	Yes	Man
IS-IS	LS	No	Int/Ext	Trig	Cost	Yes	Auto
BGP	DV	No	Exterior	Trig	N/A	N/A	Man

Which IGP?

- Larger older ISPs prefer ISIS
- Many newer ISPs prefer OSPF
- Some large ISP networks use EIGRP

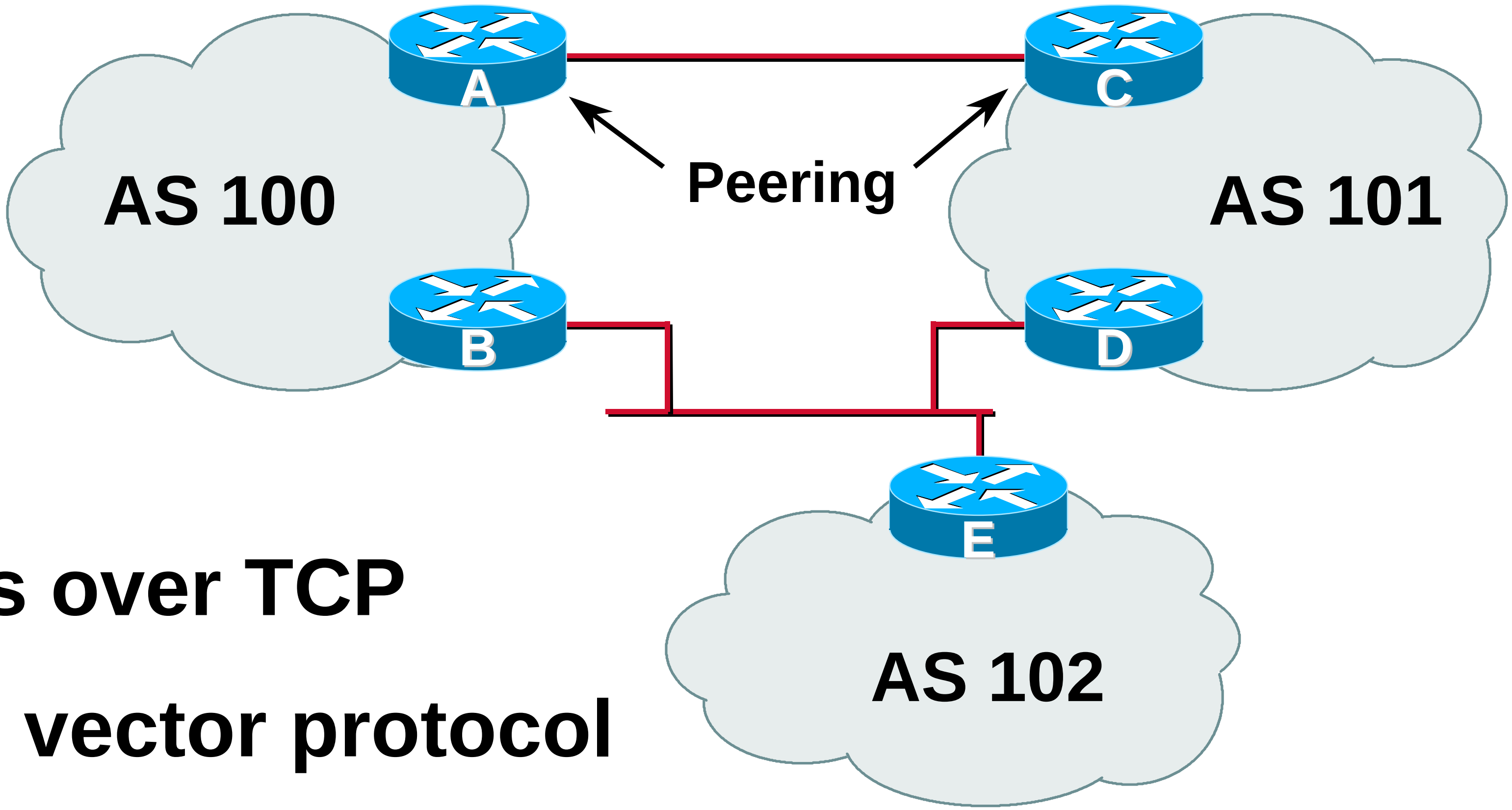
- Your choice

  all three have strengths and weaknesses

  all three are being actively developed

BGP for ISPs

BGP Basics

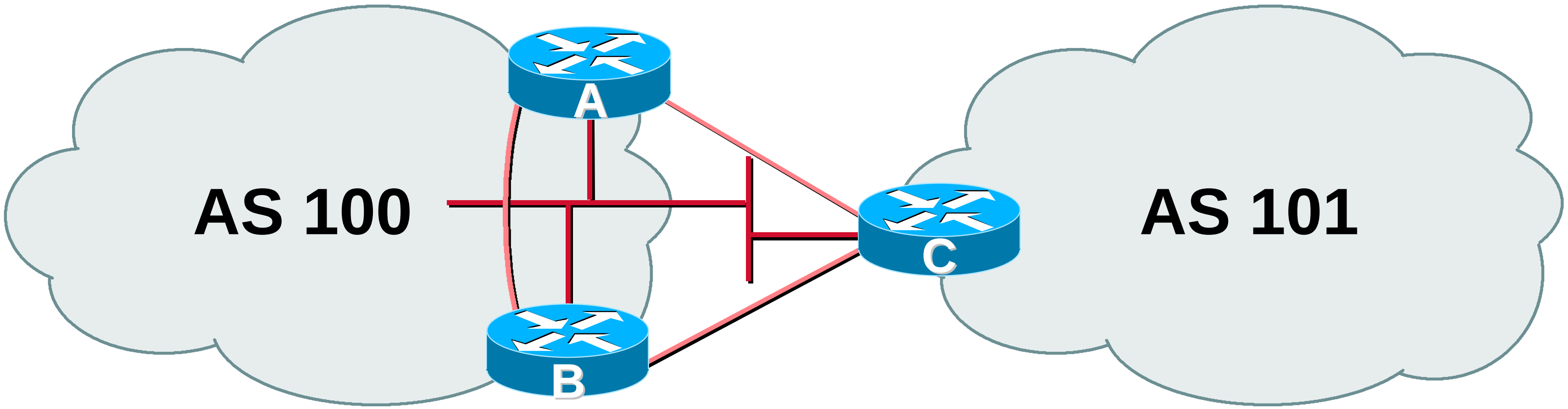


- Runs over TCP
- Path vector protocol
- Incremental update

BGP General Operation

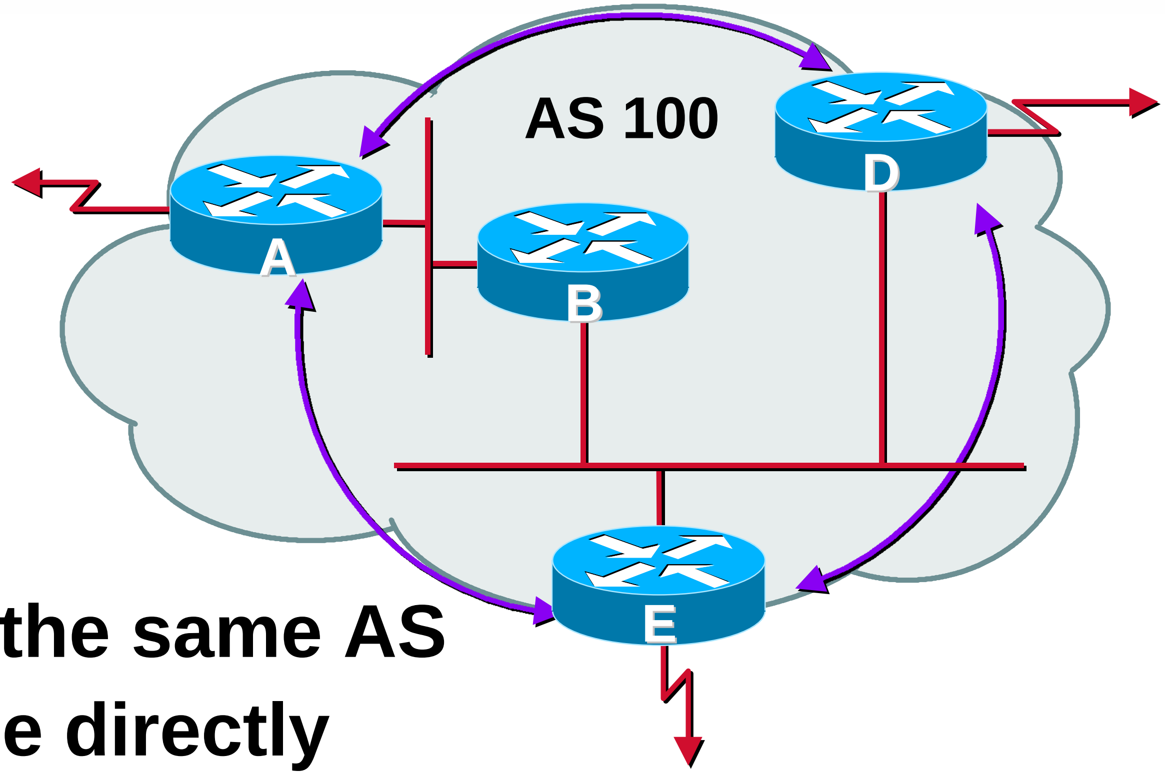
- **Learns multiple paths via internal and external BGP speakers**
- **Picks the best path and installs in the IP forwarding table**
- **Policies applied by influencing the best path selection**

External BGP Peering (eBGP)



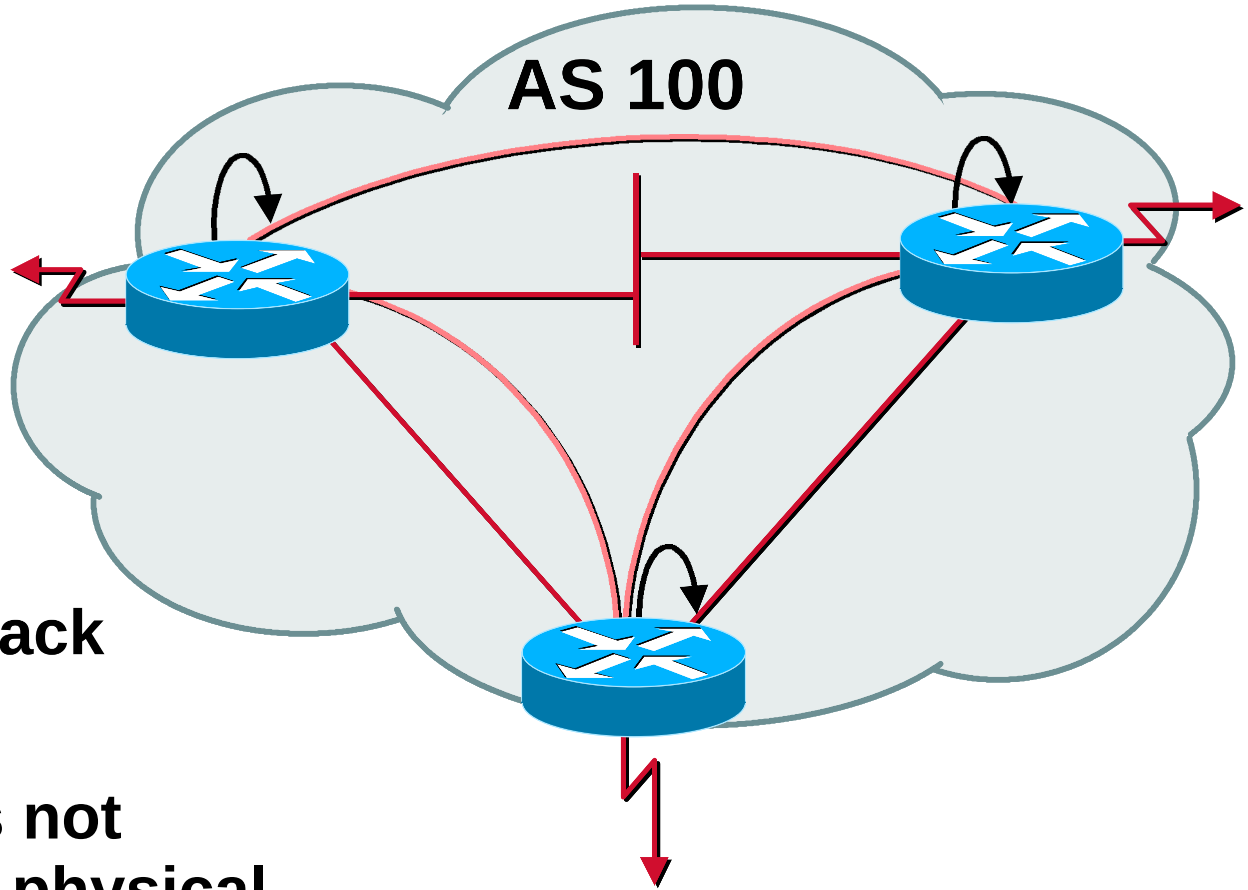
- Between BGP speakers in different AS
- Should be directly connected

Internal BGP Peering (iBGP)



- BGP peer within the same AS
- Not required to be directly connected
- iBGP neighbors should be fully meshed

Stable iBGP peering - loopback interface



- **Peer with loopback interface**
- **iBGP session is not dependent on a physical interface**

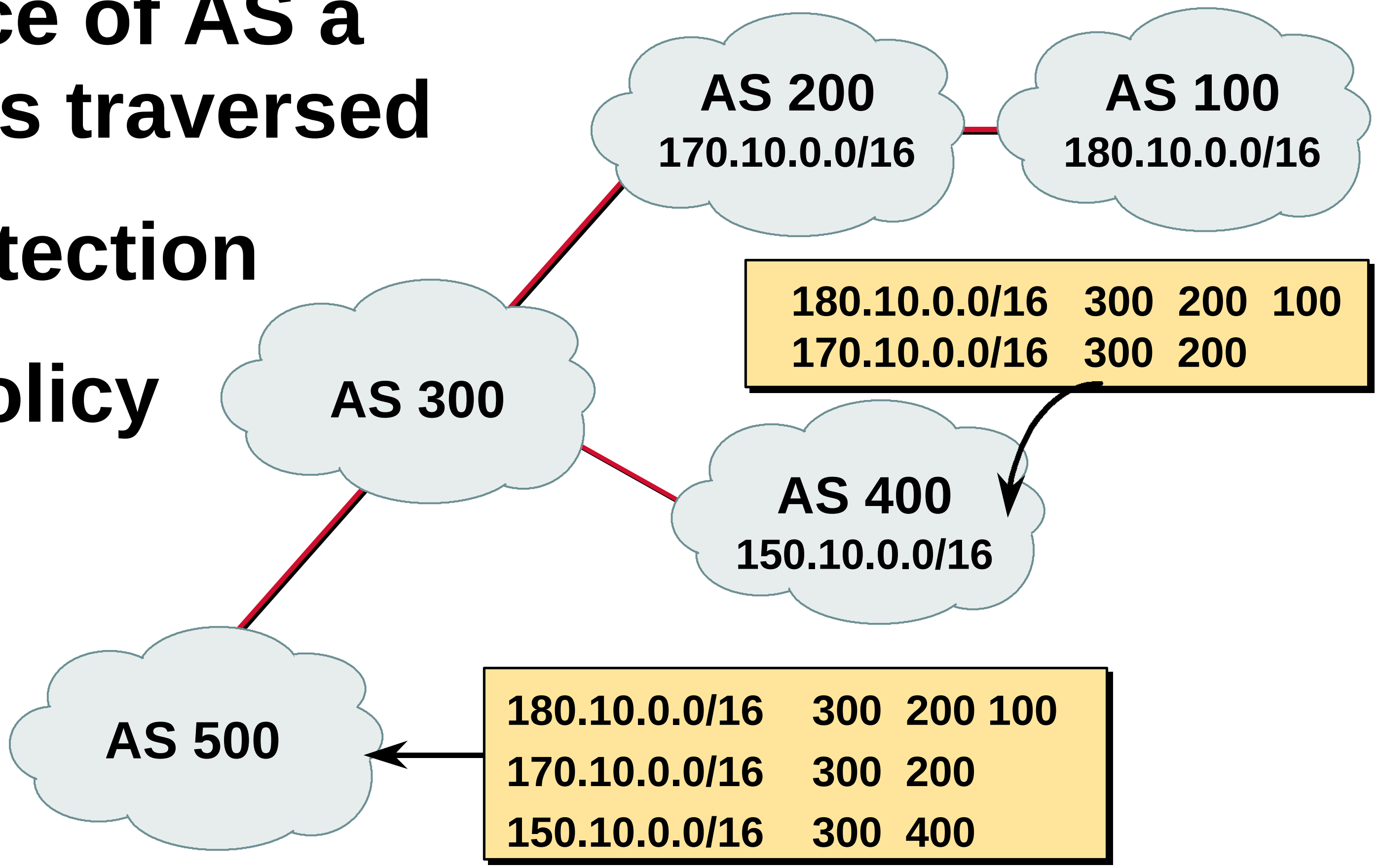
BGP Attributes

- Describes characteristics of a prefix
- Some BGP attributes:

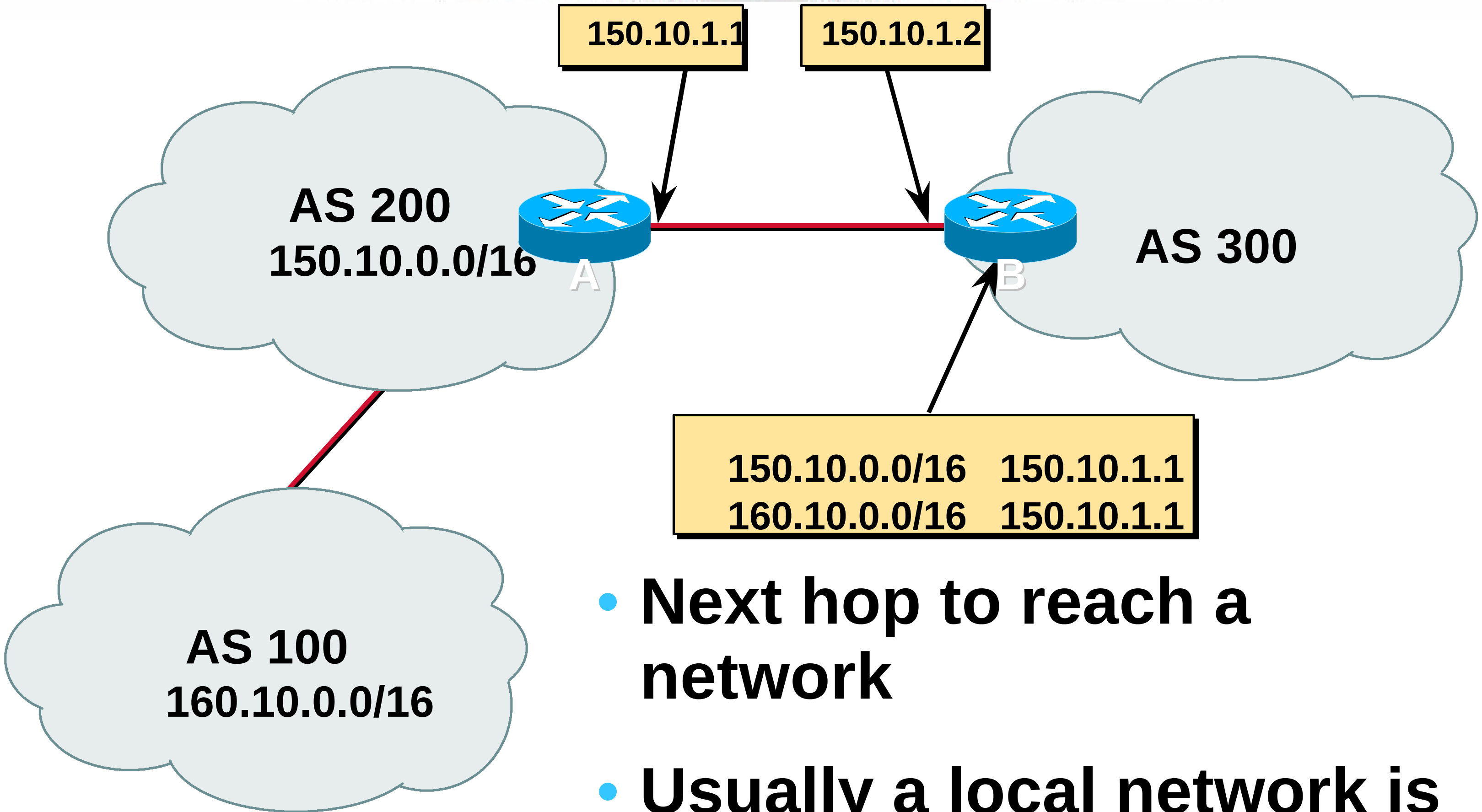
  AS path, Next hop, Local preference, Multi-Exit Discriminator (MED) and Community.
- Some are mandatory
- Some are transitive

AS-Path

- Sequence of AS a route has traversed
- Loop detection
- Apply policy

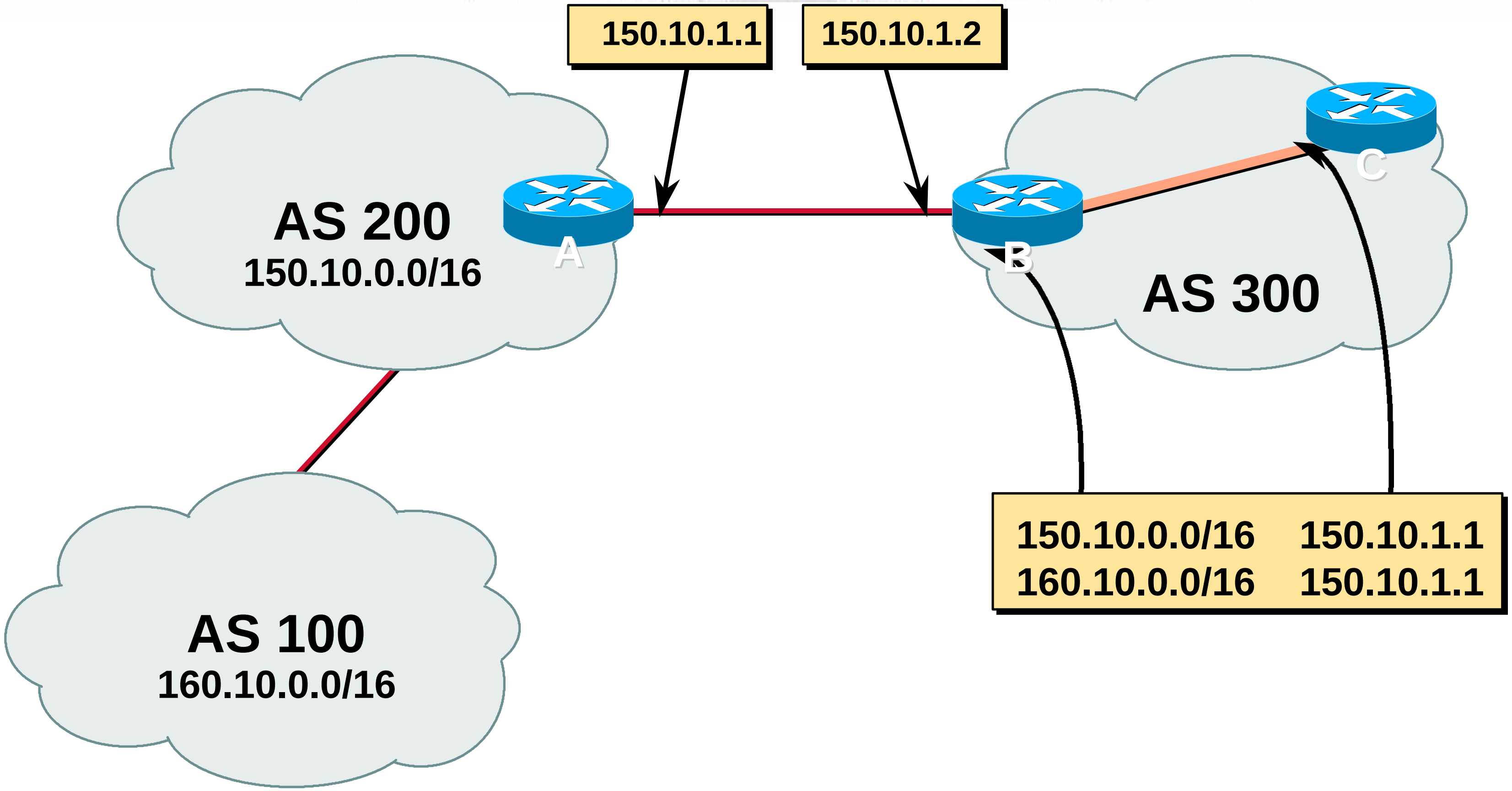


Next Hop



- Next hop to reach a network
- Usually a local network is the next hop in eBGP session

iBGP Next Hop



Next hop not changed

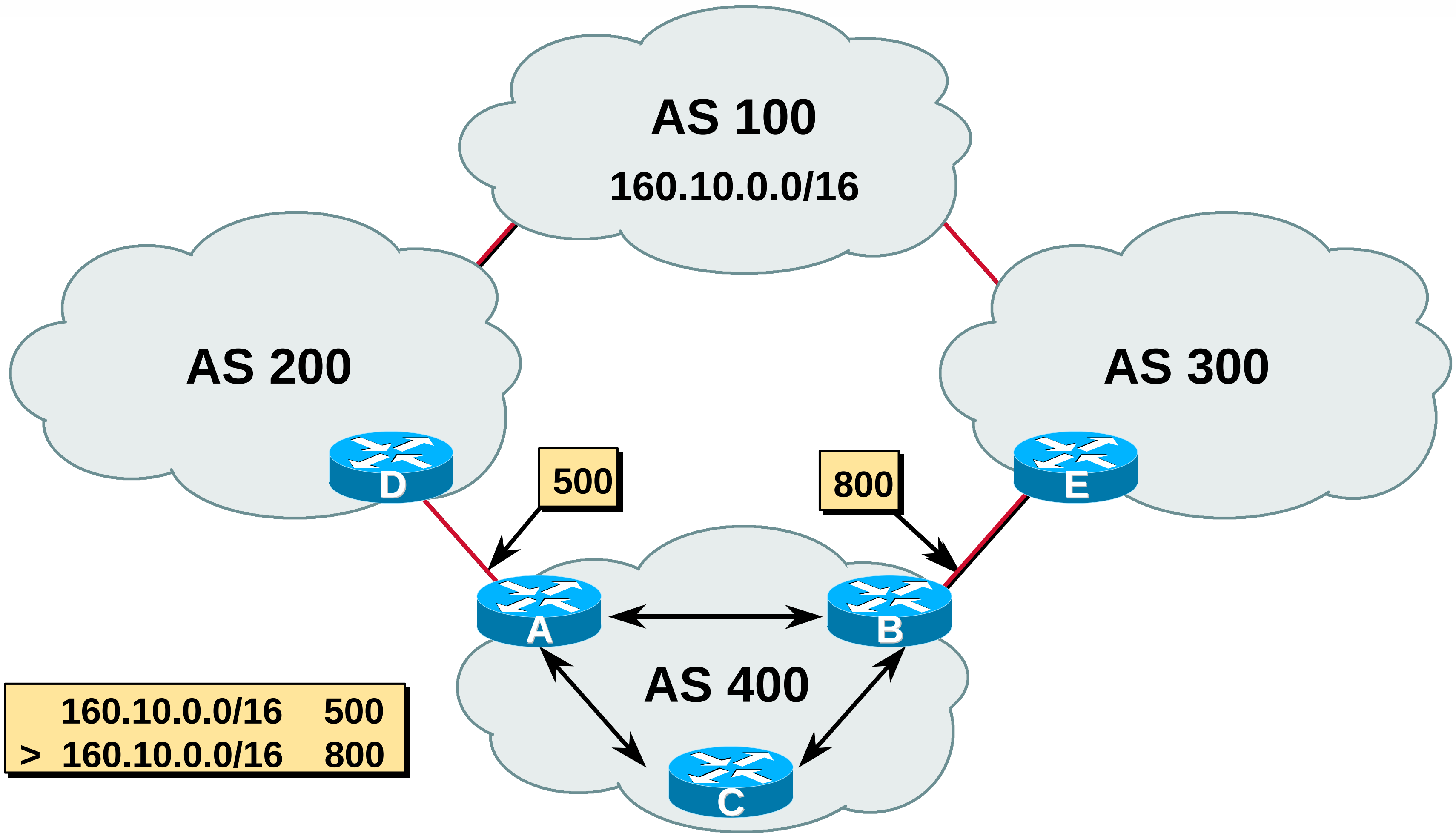
Next Hop (more)

- IGP should carry route to next hops
- Recursive route look-up
- Unlinks BGP from actual physical topology
- Allows IGP to make intelligent forwarding decision

Local Preference

- Local to an AS
- Used to influence BGP path selection
- Path with highest local preference wins

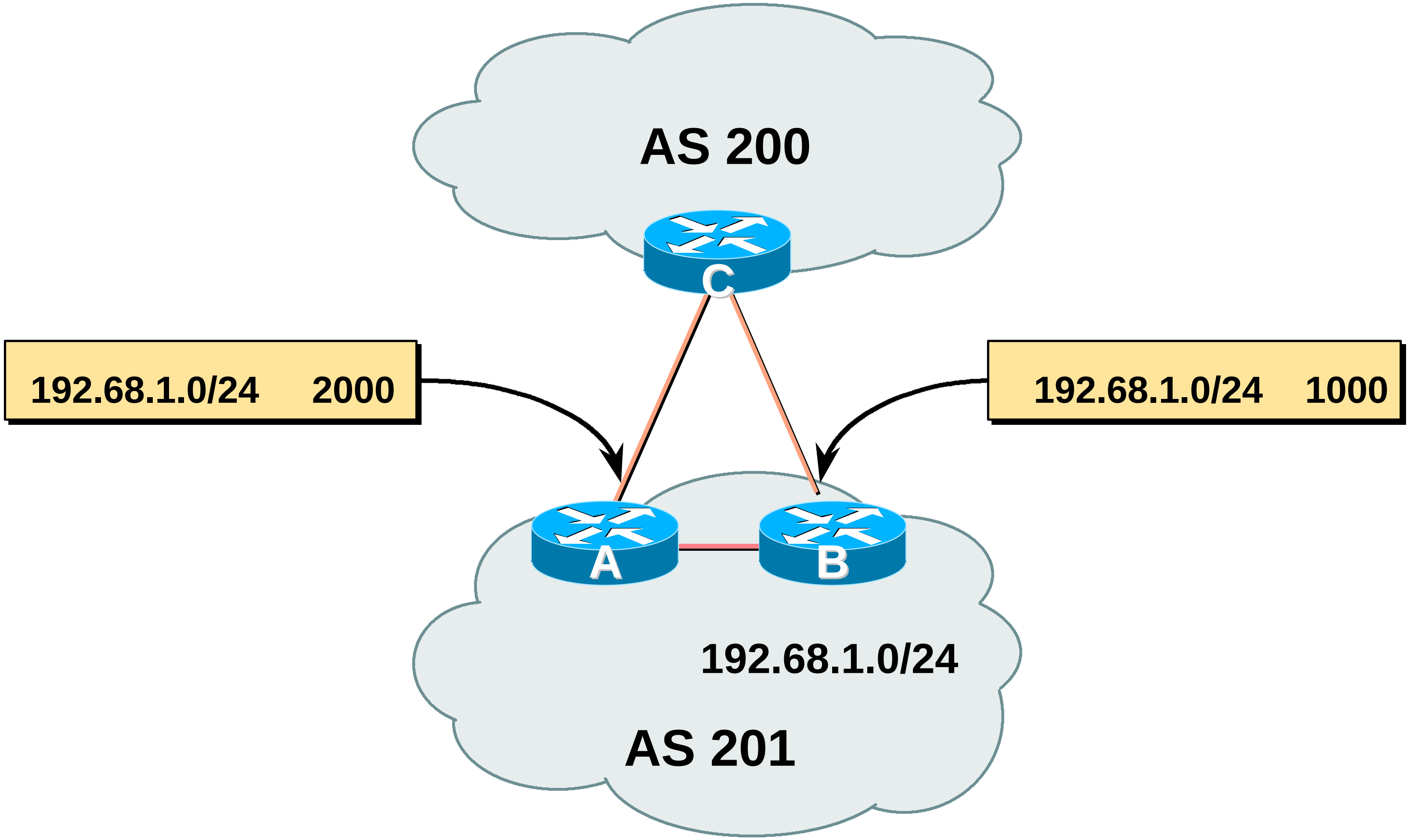
Local Preference



Multi-Exit Discriminator

- Non-transitive
- Used to convey the relative preference of entry points
- Influences best path selection
- Comparable if paths are from same AS
- IGP metric can be conveyed as MED

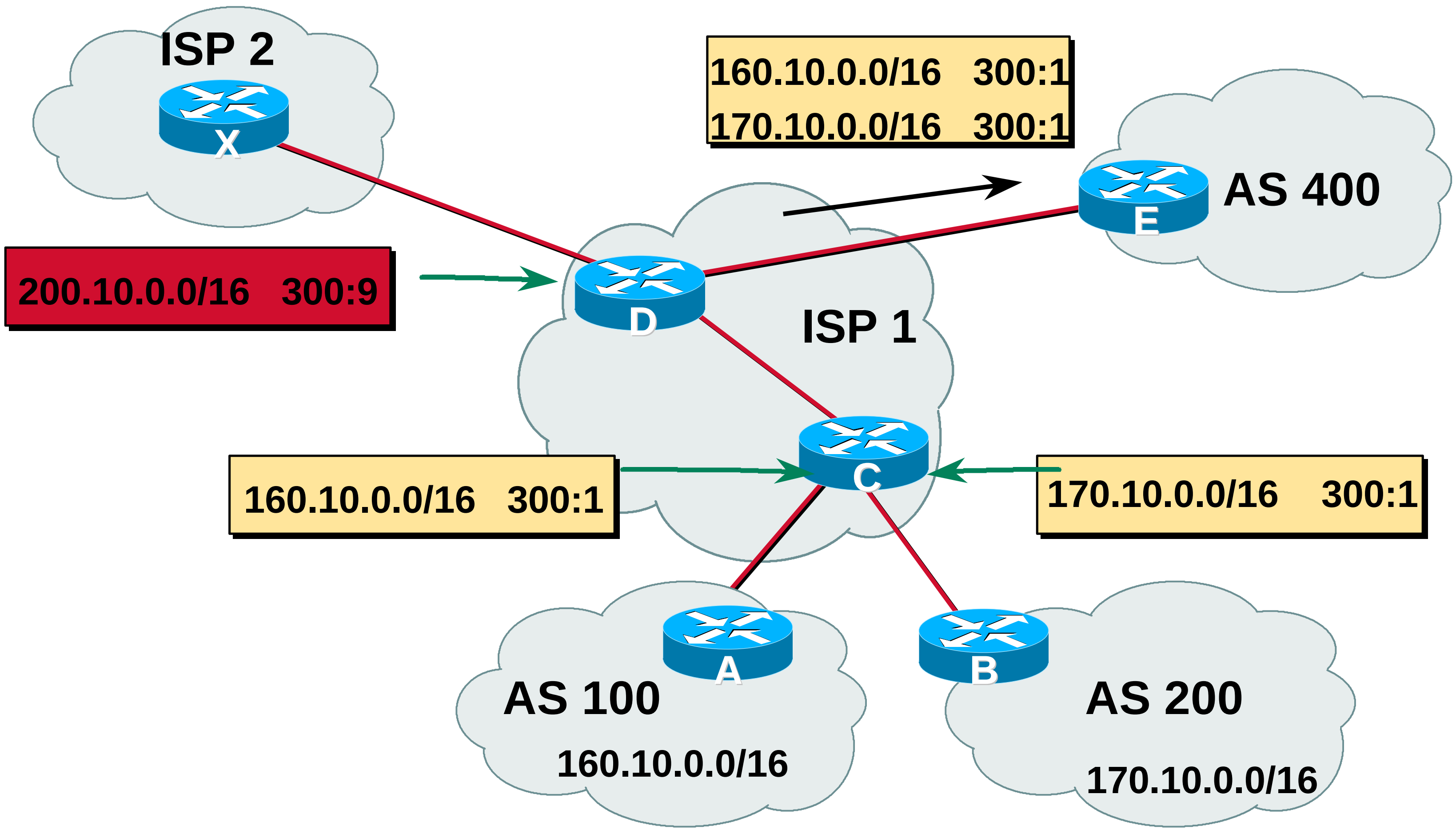
Multi-Exit Discriminator (MED)



Community

- Used to group destinations
- Represented as two 16bit integers
- Each destination could be member of multiple communities
- Community attribute may be carried across AS's
- Useful in applying policies

Community


ISP 2
X
160.10.0.0/16 300:1
170.10.0.0/16 300:1
AS 400
E
200.10.0.0/16 300:9
D
ISP 1
C
160.10.0.0/16 300:1
170.10.0.0/16 300:1
A
B
AS 100
160.10.0.0/16
AS 200
170.10.0.0/16

Communities (Continued)

- Aggregation results in loss of information
- Next hop information is lost
- Normally more specific routes are leaked to neighbouring AS
- More specifics manually filtered in neighbouring AS

Communities (Continued)

- **Well-known communities**

  no-export - don’t send to next AS

  no-advertise - don’t send to a peer

  local-as - keep in local AS

  internet - everything

Origin

- Conveys the origin of the prefix
- Influence best path selection
- Three values - IGP, EGP, incomplete

  IGP - generated from iBGP

  EGP - generated from EGP

  incomplete - generated by other process

BGP Path Selection Algorithm - Cisco Routers

- Do not consider path if no route to next hop
- Highest local preference (global within AS)
- Shortest AS path
- Lowest origin code

  IGP < EGP < incomplete

BGP Path Selection Algorithm (continued)

- **Multi-Exit Discriminator**

  Considered only if paths are from the same AS

- **Prefer eBGP path over iBGP path**
- **Path with shortest next-hop metric wins**
- **Lowest router-id**

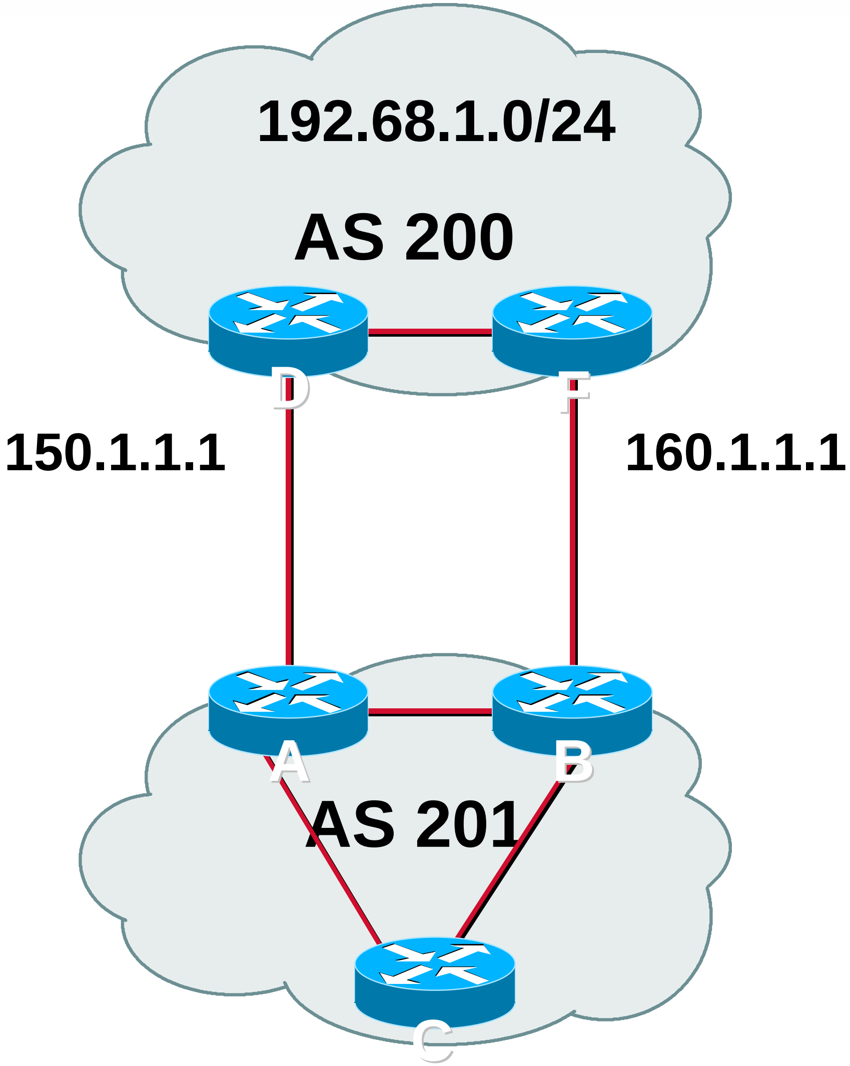
BGP Path Selection

BGP TABLE IN AS-201:
192.68.1.0/24   150.1.1.1
160.1.1.1

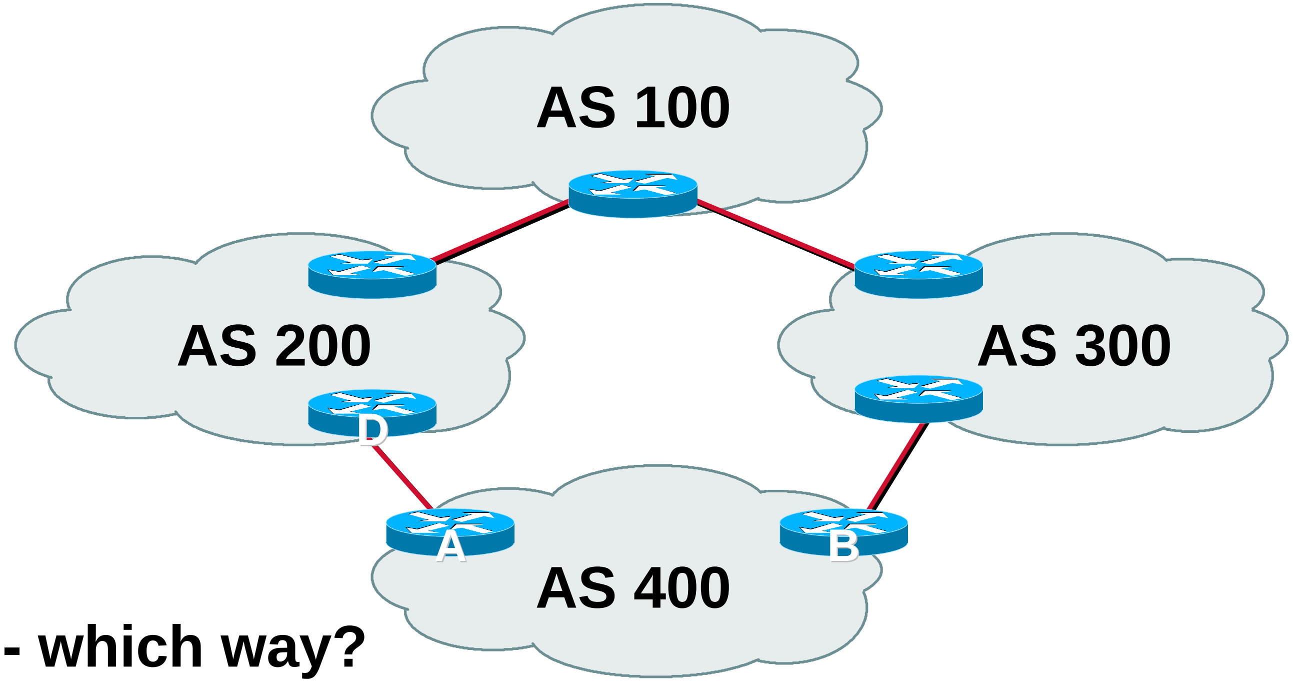
A's IP TABLE:
192.68.1.0/24 150.1.1.1

B's IP TABLE:
192.68.1.0/24 160.1.1.1

C's IP TABLE:
Either one depending on IGP metric to next-hop



BGP Path Selection - more

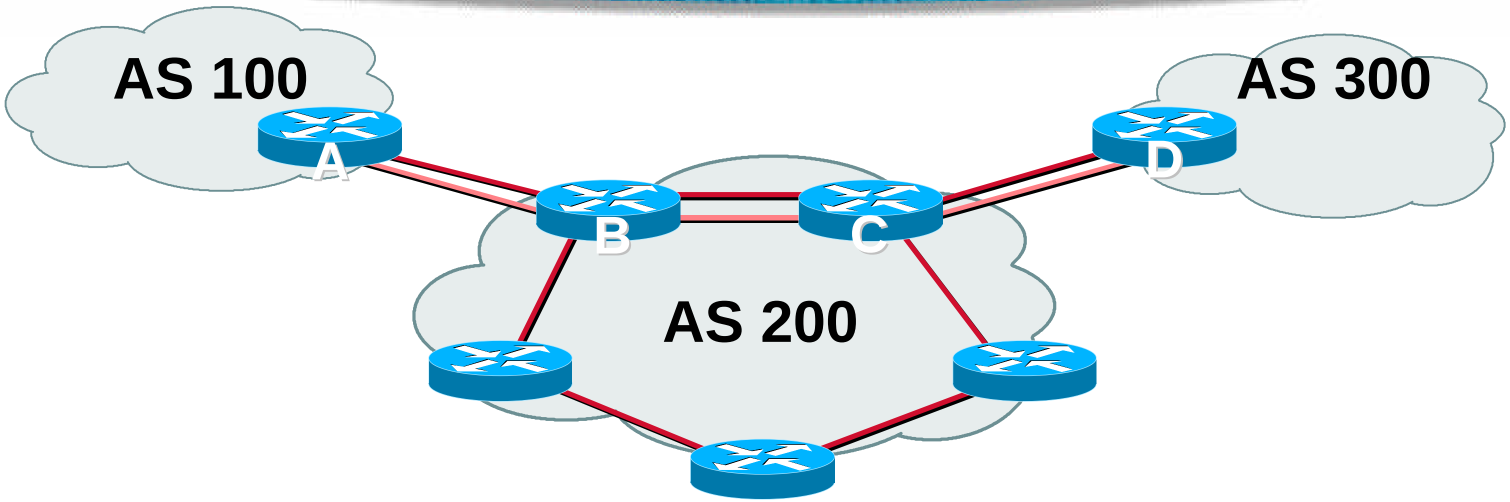


- AS400 -> AS100 - which way?
- AS 200 preferred path
- AS 300 backup
- To achieve this, increase AS path length to AS300 by AS_PATH prepend

Applying Policy with BGP

- Policy-based on AS path, community or the prefix
- Rejecting/accepting selected routes
- Set attributes to influence path selection

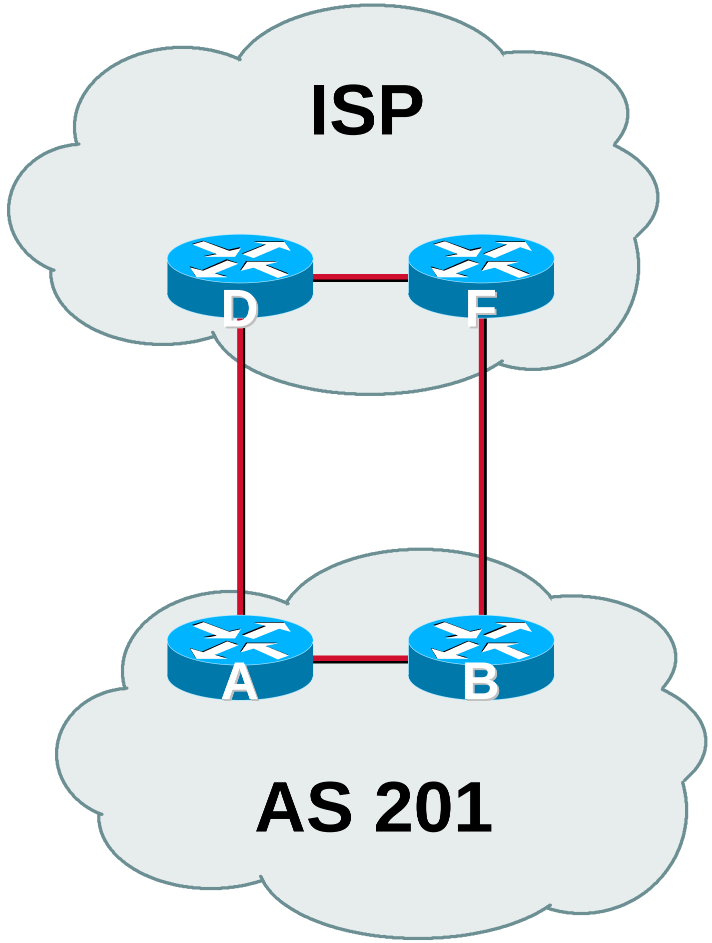
Multi-Homed AS



- **Many situations possible**
  - multiple sessions to same ISP
  - secondary only for backup
  - load-share between primary and secondary
  - selectively use different ISPs

Multiple Sessions to an ISP

- Simplest scheme is to use defaults
- Learn/advertise prefix for better control



Multiple Session to ISPs

- Difficult to achieve load sharing
- Point default towards one ISP
- Learn selected prefixes from second ISP
- Modify the number of prefixes learnt to achieve acceptable load sharing

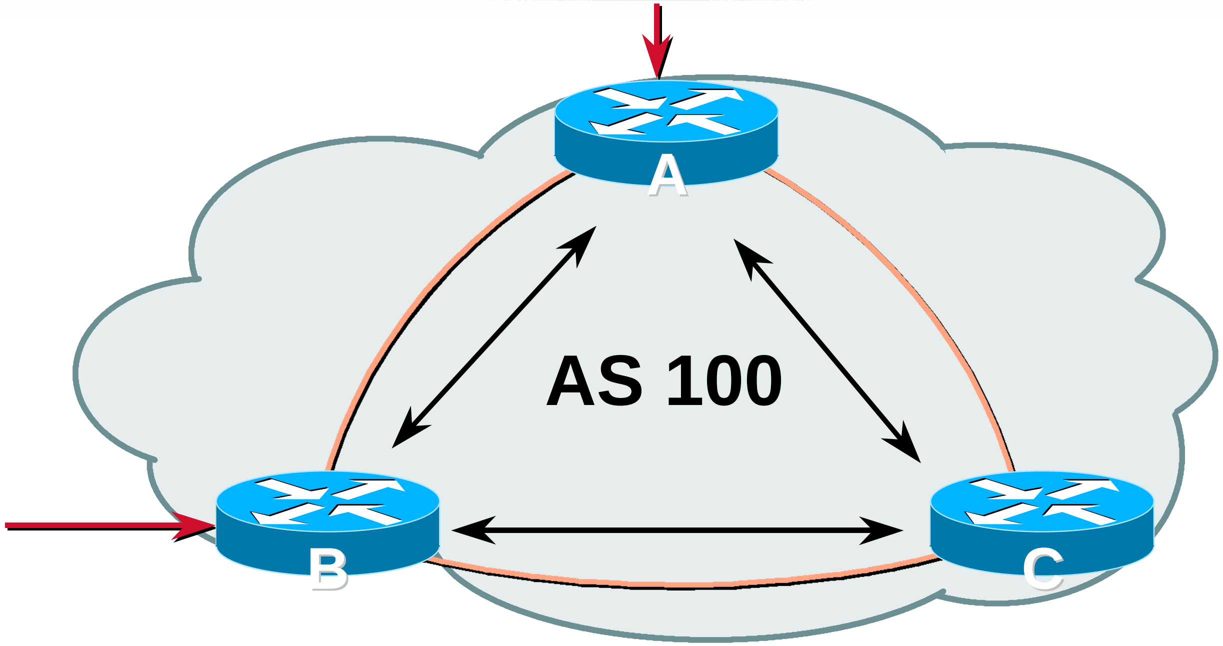
BGP in ISP Backbones

- All routers take part in BGP
- BGP carries some or all of the Internet routing table
- IGPs are used to carry next hop and internal network information
- Routes are never redistributed from BGP into IGP
- Recursive route lookup

Scaling Techniques

- **Administrative scaling**
  - **Communities - already mentioned**
- **Router resource scaling**
  - **Route Reflectors**
  - **Confederations**
  - **Route Flap Dampening**

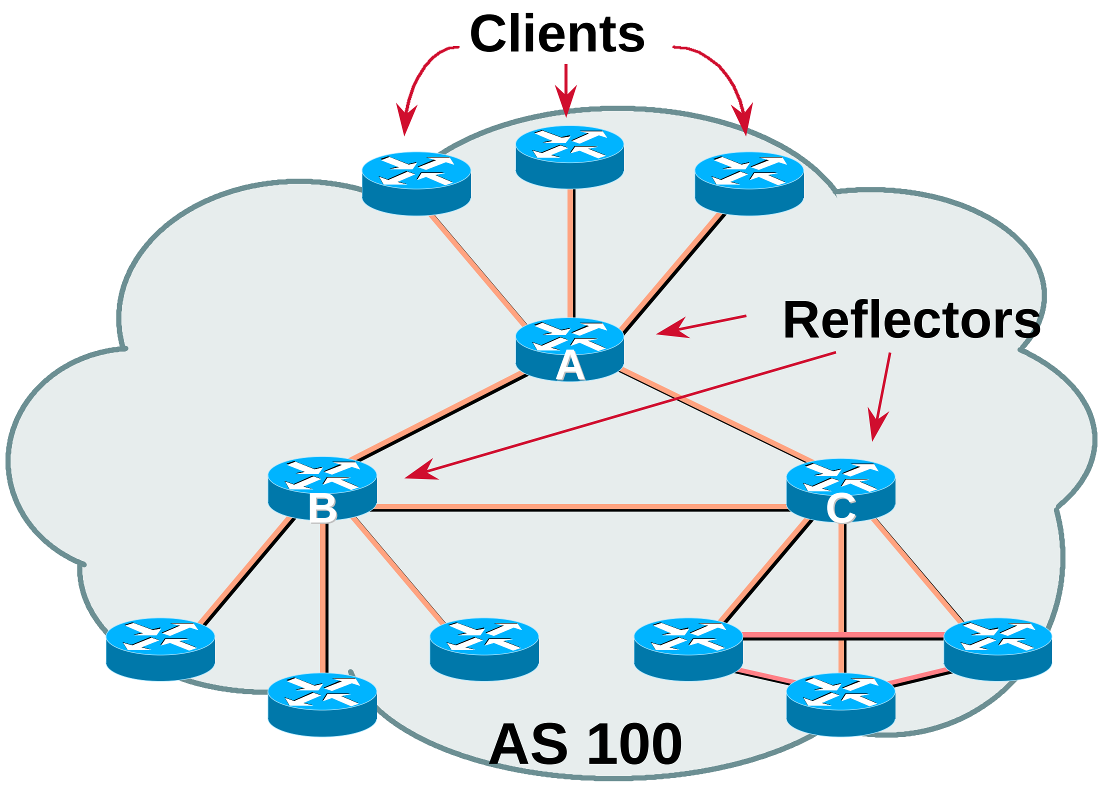
Scaling iBGP mesh



- Need to avoid routing loop
- Solution should not change current behaviour
- Two solutions: route reflector and confederation

Route Reflector

- Reflector receives path from clients and non-clients
- Selects best path
- Best path is from client—reflect to non-clients
- Best path is from non-client—reflect to clients
- Non-meshed clients



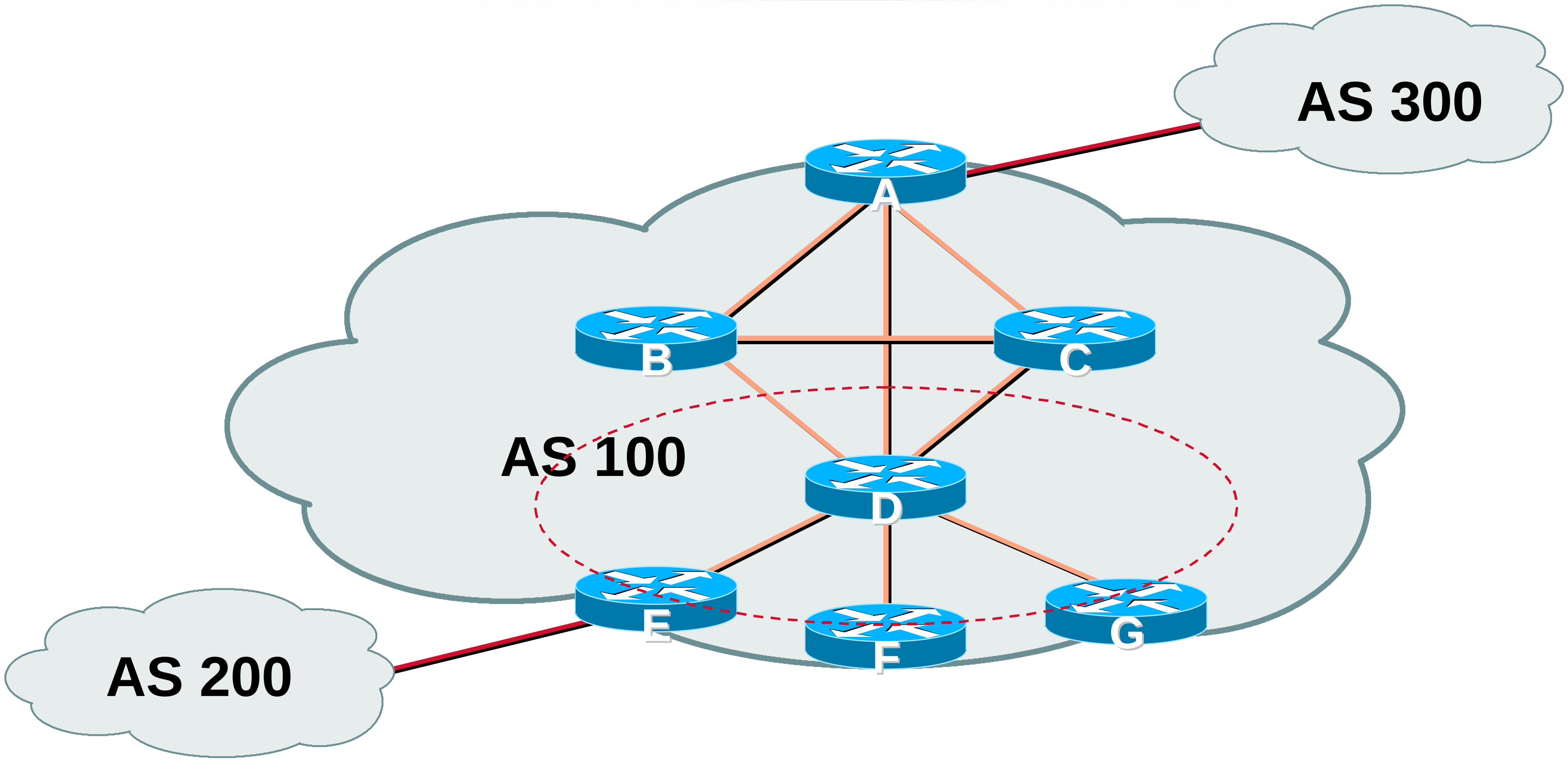
Route Reflector

- Divide the backbone into multiple clusters (hint - build on OSPF/ISIS areas)
- At least one route reflector and few clients per cluster
- Route reflectors are fully meshed
- Clients in a cluster could be fully meshed
- Single IGP to carry next hop and local routes

Route Reflector: Benefits

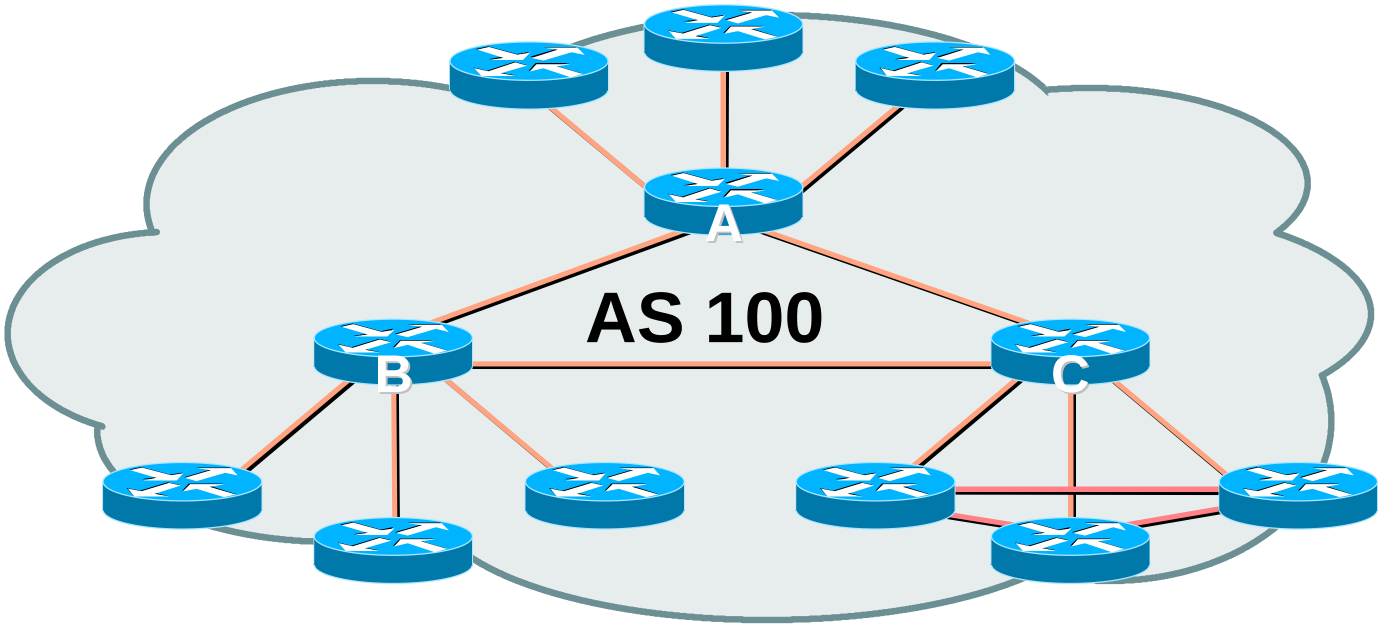
- Solves iBGP mesh problem
- Packet forwarding is not affected
- Normal BGP speakers co-exist
- Multiple reflectors for redundancy
- Easy migration
- Multiple levels of route reflectors

Route Reflector: Migration



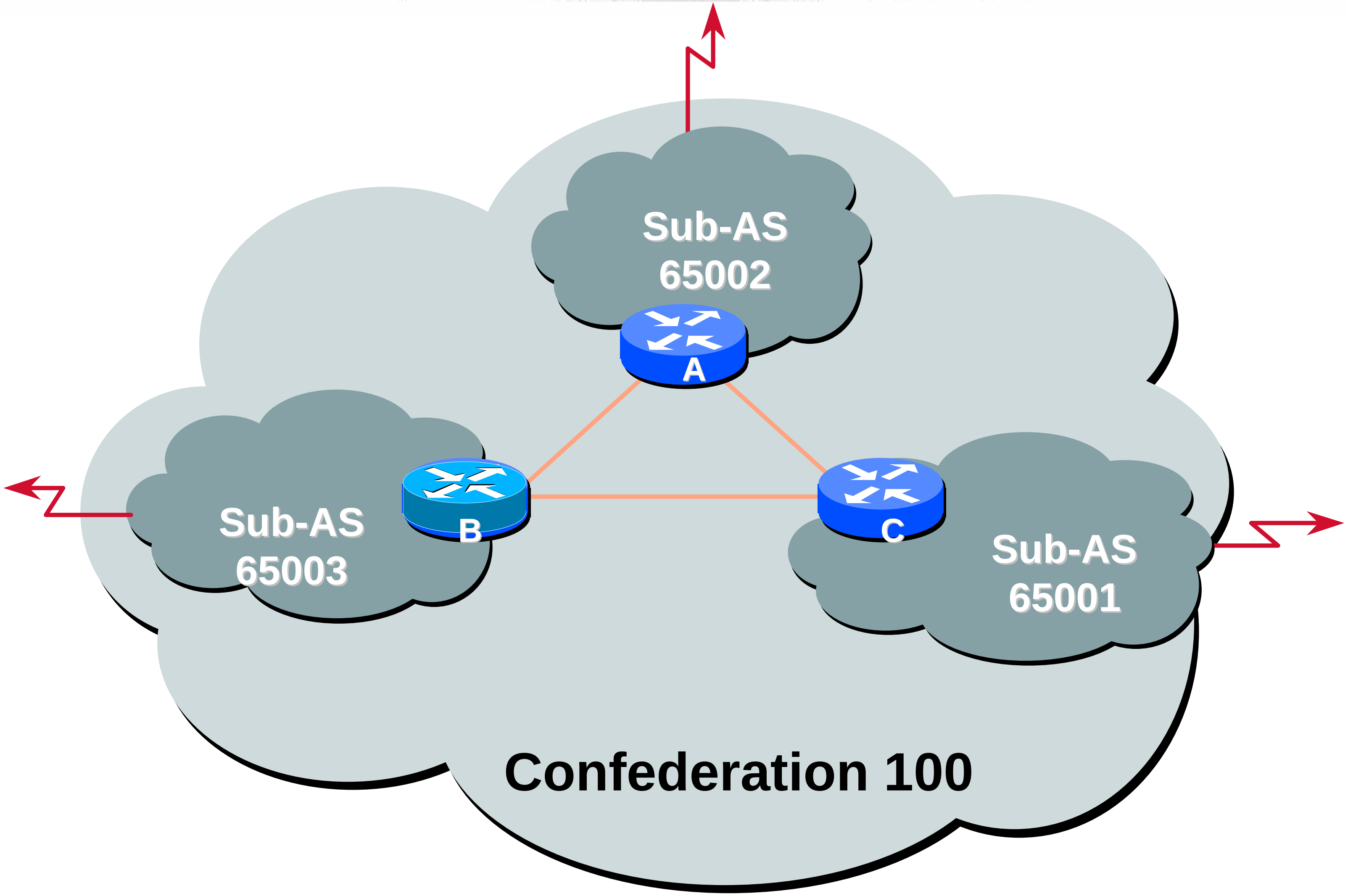
- **Migrate small parts of the network, one part at a time.**

Route Reflector: Path Diversity



- Best path is selected by the route reflector before being passed on to clients.
- Entry points should be in different clusters so the core knows all possible exits.

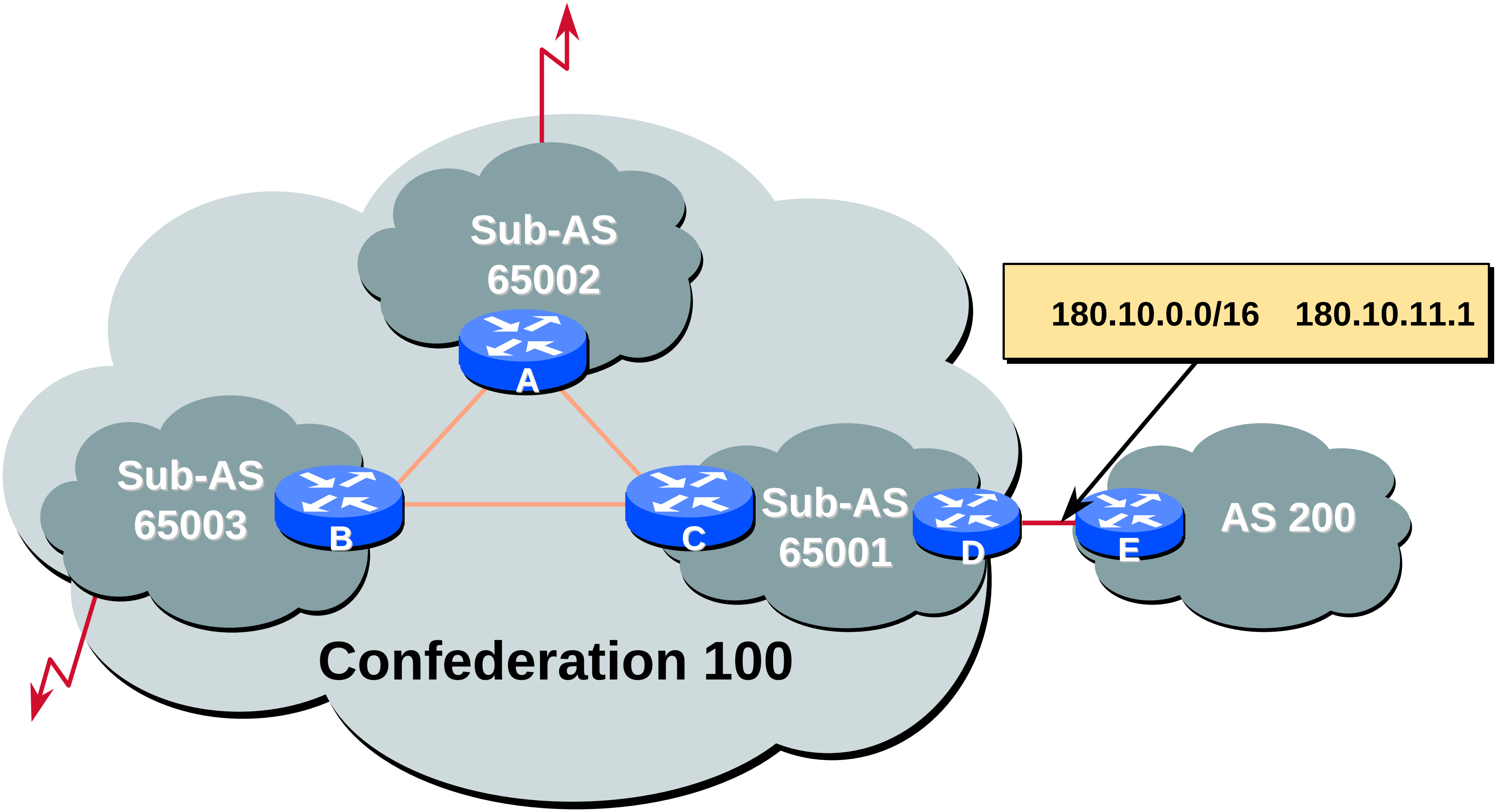
Confederations



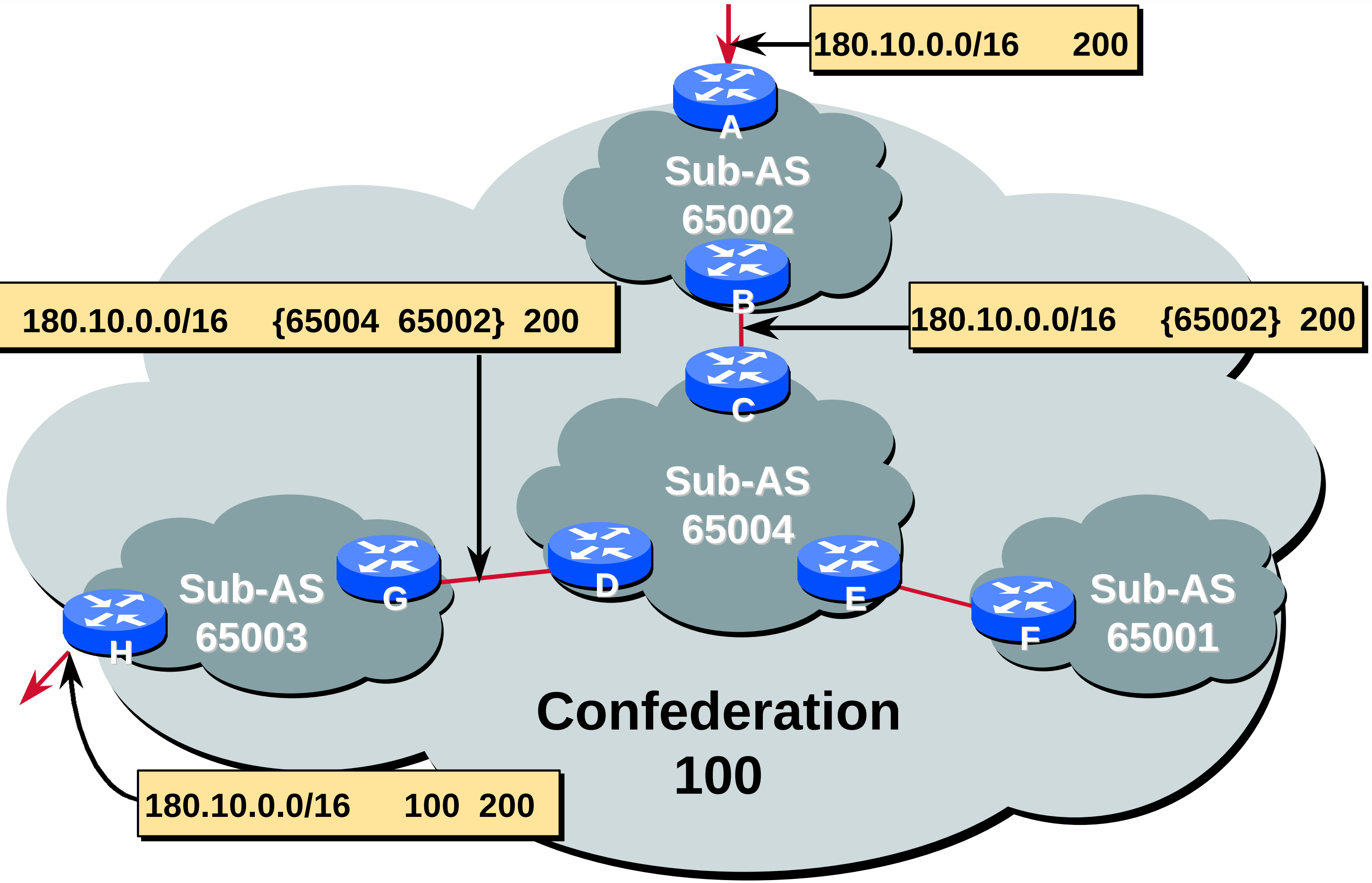
Confederations: Principle

- Best path sent to neighbour sub-AS
- Packet forwarding depends on next hop
- IGP carries next hops and local networks
- Preserve next hop across sub-AS eBGP
- Local preference and MED influence path selection
- Preserve local preference and MED across sub-AS boundary
- Sub-AS eBGP path administrative distance

Confederations: Next Hop



Confederations: AS-Sequence



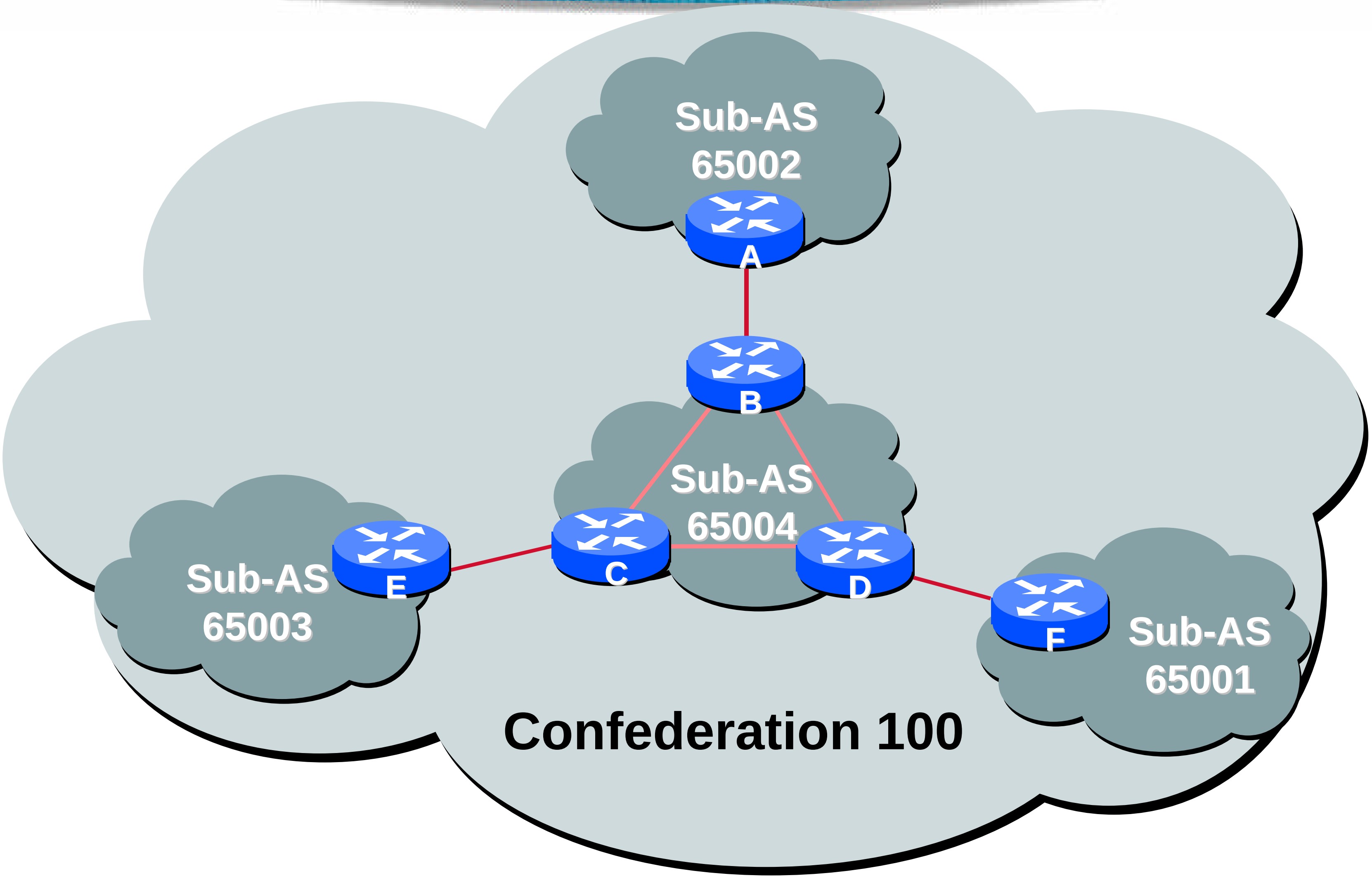
Confederations: Benefits

- Solves iBGP mesh problem
- Packet forwarding not affected
- Can be used with route reflectors
- Policies could be applied to route traffic between sub-AS's

Confederations: Caveats

- Minimal number of sub-AS
- Sub-AS hierarchy
- Minimal inter-connectivity between sub-AS's
- Path diversity

Confederations: Path Diversity



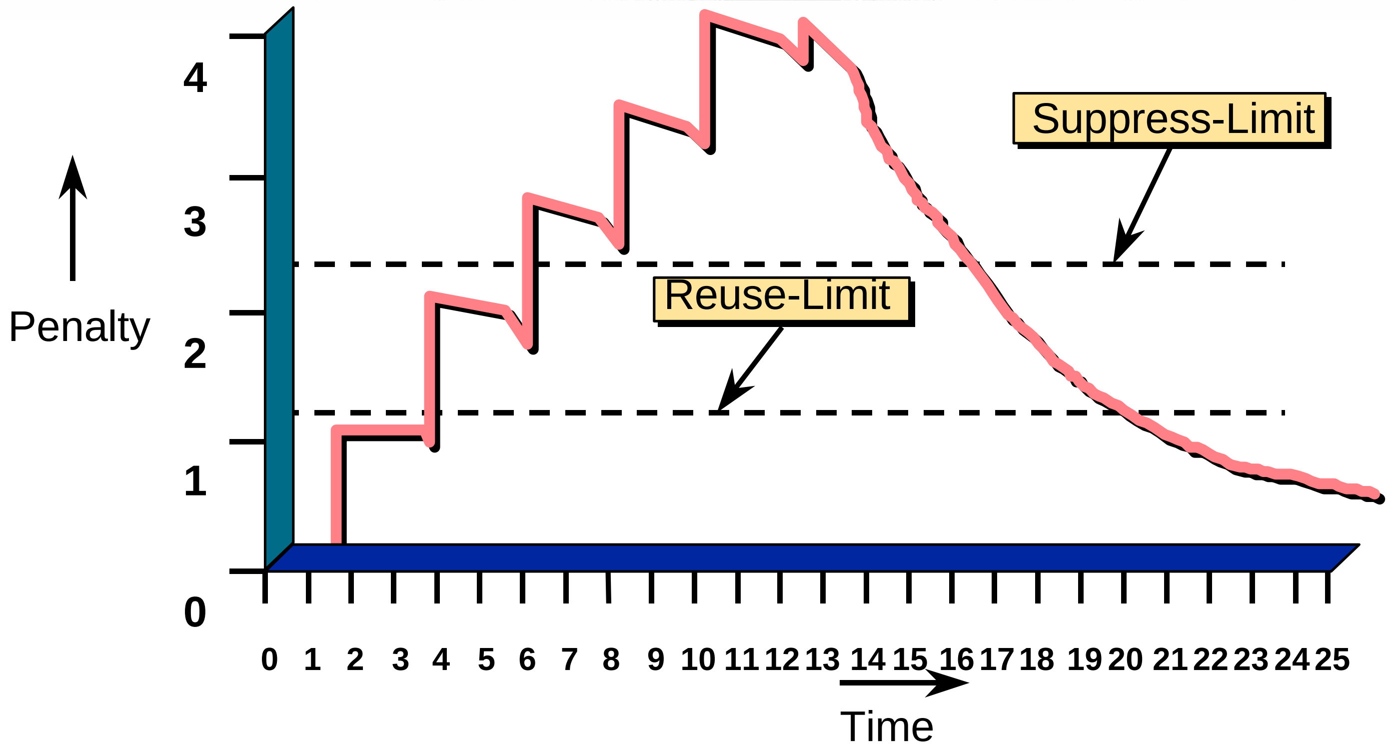
Route Flap Dampening

- Route flap
  - Going up and down of path
  - Change in attribute
- Ripples through the entire Internet
- Wastes CPU
- Reduce scope of route flap propagation

Route Flap Dampening

- Fast convergence for normal route changes
- History predicts future behaviour
- Suppress oscillating routes
- Advertise stable suppressed routes
- Described in RFC2439

Route Flap Dampening



- Add penalty for each flap. Exponentially decay penalty
- Penalty above suppress-limit - do not advertise up route
- Penalty decayed below reuse-limit - advertise route

Route Flap Dampening

- Done only for external path
- Alternate paths still usable
- Suppress-limit, reuse-limit, maximum suppress time, and half-life time give control
- Variable dampening

  see RIPE-178 document for parameters

Soft Reconfiguration

Problem:

- **BGP peering reset after every policy change because the router does not store advertised prefixes that are denied by a filter**
- **BGP peering reset consumes CPU and affects connectivity for all networks**

Soft Reconfiguration

Solution:

- **Soft-reconfiguration**
- **New policy (in and out) is activated without clearing the peering session**
- **Per-neighbour basis**
- **Use more memory to keep prefixes whose attributes have been changed or not accepted**

Future Plans for BGP

- Integration with Tag Switching/MPLS
- Multiprotocol support
  - IPv6 - beta test images available
  - multicast - part of IOS 12.0S
  - CLNS
- Multihoming enhancements

Routing Design for ISPs

Network Design

- Aim for simplicity, scalability and reliability
- Plan the network coverage
- Growth over the next year
- Design the network

Network Coverage

- **Where will you start and how?**
- **Where will it grow?**
  - **One year is a long time in the Internet**
  - **Future PoP sites**
- **How big will it grow?**
  - **Inter-site bandwidth availability**
- **Does it match the business plan?**

Network Design

- Start as you mean to continue
- Design scalability from day one
  - hierarchy
  - separate functions
- Choose your IGP carefully
  - scalability, standards
  - knowledge and expertise

Designed in Redundancy

- Two of everything is a good maxim
- Each site should have at least two backbone WAN connections
- Consider two core routers for each backbone site
- Don’t forget the Out of Band management network
- Documentation!

Address Space

- Approach upstream ISP or RIR for address space
- Supply addressing plan when requested
  - remember Internet is classless
  - addresses assigned according to need not desire
- Assign addresses to backbone and other network layers - remember scalability!

Deploying IGP

- **Keep IGP small!**

  Smaller IGP, faster convergence in case of link problems

- **Use summarisation between areas of network hierarchy**

- **Use ip unnumbered where possible**

External Connections

- Don’t need BGP from day one
  - apply for an AS and deploy BGP only when it is needed i.e. when multihoming
- When deploying BGP
  - iBGP carries customer networks only
  - IGP carries network link information only
  - Do not distribute BGP routes into IGP and vice-versa

Routing Etiquette

Routing Etiquette

- Motivation
- CIDR and aggregation
- "The Swamp"
- Renumbering
- Dampening
- NAT
- Filtering Policies

"Problems on the Internet"

- **Concern about rate of Internet growth**

  http://www.nw.com/zone/WWW/report.html

- **Large number of routes**

  http://www.employees.org/~tbates/cidr.plot.html

- **Routing instability**

  http://www.merit.edu/ipma/reports

- **Difficulties diagnosing problems**
- **Quality of Service**

Effects of CIDR on Internet

- **Currently around 56000 routes**
- **If Internet were unaggregated**

  Would be over 200000 networks

  What size of routers required?

  How stable would the Internet be?

CIDR - Examples

- Announce network block assigned by Registry or upstream ISP
- Do not announce subnets of network block, or subnets of other ISPs' network blocks unless exceptional circumstances
- On Cisco routers use

  redistribute static, or aggregate-address, or network/mask pair

CIDR – Examples

Redistribute static

```
router bgp 1849
 network 194.216.0.0
 redistribute static
! Must have a matching IGP route
ip route 194.216.0.0 255.255.0.0 null0
```

Aggregate address

```
router bgp 1849
 network 194.216.0.0
 aggregate-address 194.216.0.0 255.255.0.0
! More specific route must exist in BGP table
```

Network/mask pair

```
router bgp 1849
 network 194.216.0.0 mask 255.255.0.0
! Must have a matching IGP route
ip route 194.216.0.0 255.255.0.0 null0
```


CIDR - Positive Efforts

- **Many ISPs filter prefixes longer than /24**
- **Some ISPs filter according to policy registered in the Internet Routing Registry**
- **No aggregation or bad aggregation could result in no connectivity**

Aggregation

- Announce aggregate to rest of Internet
- Put it into Routing Registry (route object)
- Keep more specifics internal to network
  - Use iBGP for carrying customer networks
  - Use IGP for carrying backbone addresses
  - Aggregate internally when possible

Aggregation - Good Example

- **Customer link goes down**

  their /26 network becomes unreachable

- **/19 aggregate is still being announced**

  no BGP hold down problems

  no BGP propagation delays

  no dampening by other ISPs

Aggregation - Good Example

- Customer link returns
- Their /26 network is visible again
- The whole Internet becomes visible immediately
- Quality of Service perception

Aggregation - Bad Example

- Customer link goes down
  - Their /23 network becomes unreachable
- Their ISP doesn't aggregate their /19 network block
  - /23 network withdrawal announced to peers
  - starts rippling through the Internet
  - added load on all Internet backbone routers as network is removed from routing table

Aggregation - Bad Example

- Customer link returns
  - Their /23 network is now visible to their ISP
  - Their /23 network is re-advertised to peers
  - Starts rippling through Internet
  - Load on Internet backbone routers as network is reinserted into routing table
  - Some ISP's dampen flaps
  - Internet may take 10-20 min or longer to be visible
  - Quality of Service???

Aggregation - Summary

- **Good example is what everyone should do!**
  - **Adds to Internet stability**
  - **Reduces size of routing table**
  - **Reduces routing churn**
  - **Improves Internet QoS for everyone**
- **Bad example is what many still do!**
  - **Laziness? Lack of knowledge?**

“The Swamp”

- So called areas of poor aggregation
- 192/8 worst offender for routed networks
- 192/3 space has 43500 networks - rest of Internet has 12000 networks

Block	Networks	Block	Networks	Block	Networks	Block	Networks
192/8	6248	198/8	4031	204/8	2708	210/8	402
193/8	2389	199/8	3504	205/8	2577	211/8	0
194/8	2855	200/8	1330	206/8	2858	212/8	672
195/8	1415	201/8	0	207/8	2401	213/8	1
196/8	517	202/8	2269	208/8	1570	214/7	5
197/8	1	203/8	3609	209/8	1151	216/8	905

Swamp Cause

- Early growth of Internet
- Classful network allocation
- No policies to prevent hoarding of address space
- Lack of foresight by all
- Small number of connected networks

Swamp Persists

- Lazy or technically naïve ISPs
- Unannounced allocated networks
- Perceived market impact
- Technical solutions keep ahead of problem so far:

  faster routers, more memory, CIDR

Solutions

- Don’t route 192/8 or other ISP’s address space
- Aggregate!
- Don’t announce subnets of your assigned block
- Be prudent when announcing prefixes smaller than /16 out of former B space

Solutions

- **Encourage other ISPs to be good citizens**

  don’t route their bad citizenship

- **Multihoming**

  fragments address space

  think carefully about set up and requirements

  load balancing versus resilience

  http://infopage.cw.net/Routing

Efforts

- Tony Bates' CIDR report

  sent to nanog, apops and eof mail lists
- Regional Internet Registries
- Many ISPs
- Peer pressure
- YOU!

Renumbering - motivation

- Same as motivation for aggregation

  holes are bad, using swamp space

- First time Internet connection

  legal address space, practical addressing scheme

- New Provider

  renumber into new provider's block

  reduces fragmentation and improves routability

Renumbering - how to?

- **PIER - Procedures for Internet and Enterprise Renumbering**

  http://www.isi.edu/div7/pier/papers.html

- **Be aware of effect on essential services**

  e.g. DNS ttl requires lowering, router filters

- **Use DHCP, secondary addressing**
- **Not difficult but needs planning**

Route Flap Dampening

- **Route Flap**

  technical description earlier

- **Many ISPs now suppress route flaps at network borders**

- **Cisco BGP Case Study at**

  http://www.cisco.com/warp/public/459/16.html

- **Recommended parameters are at**

  http://www.ripe.net/docs/ripe-178.html

Route Flap Dampening - Caution

- Be aware of potential problems
- Unreachability could be due to dampening, not disconnection
- Border routers need more memory and CPU
- Train your staff!

NAT

- **Network Address Translation**

  ftp://ftp.isi.edu/in-notes/rfc1631.txt

- **Used by firewalls and simpler gateway systems**
- **Avoids the need for renumbering**
- **Helps conserve address space**
- **Much concern about the “concept” at IETF and elsewhere**

Filtering Policies

- **Filter announcements by peers**
  - **AS list, prefixes**
- **Only accept what is listed in routing registry**
  - **avoids configuration errors and routing problems**
  - **authorisation?**
- **Only announce what you list in routing registry**
- **Keep routing registry and filters up to date**

Filtering Policies - Prefix

- Don’t announce or accept RFC1918 networks
- Don’t announce or accept Martian networks

```
access-list 110 deny ip 10.0.0.0 0.255.255.255 255.0.0.0 0.0.0.255
access-list 110 deny ip 127.0.0.0 0.0.0.255 255.255.255.0 0.0.0.255
access-list 110 deny ip 169.254.0.0 0.0.255.255 255.255.0.0 0.0.255.255
access-list 110 deny ip 172.16.0.0 0.15.255.255 255.240.0.0 0.15.255.255
access-list 110 deny ip 192.0.2.0 0.0.0.255 255.255.255.0 0.0.0.255
access-list 110 deny ip 192.168.0.0 0.0.255.255 255.255.0.0 0.0.255.255
access-list 110 deny ip 224.0.0.0 31.255.255.255 224.0.0.0 31.255.255.255
access-list 110 deny ip any 255.255.255.128 0.0.0.127
```

Prefix Length Filtering

- **Minimum prefix length filtering**

  most ISPs filter prefixes longer than /24

- **Reduces size of routing table**
- **Smaller prefixes more likely to flap**

The Internet Routing Registry

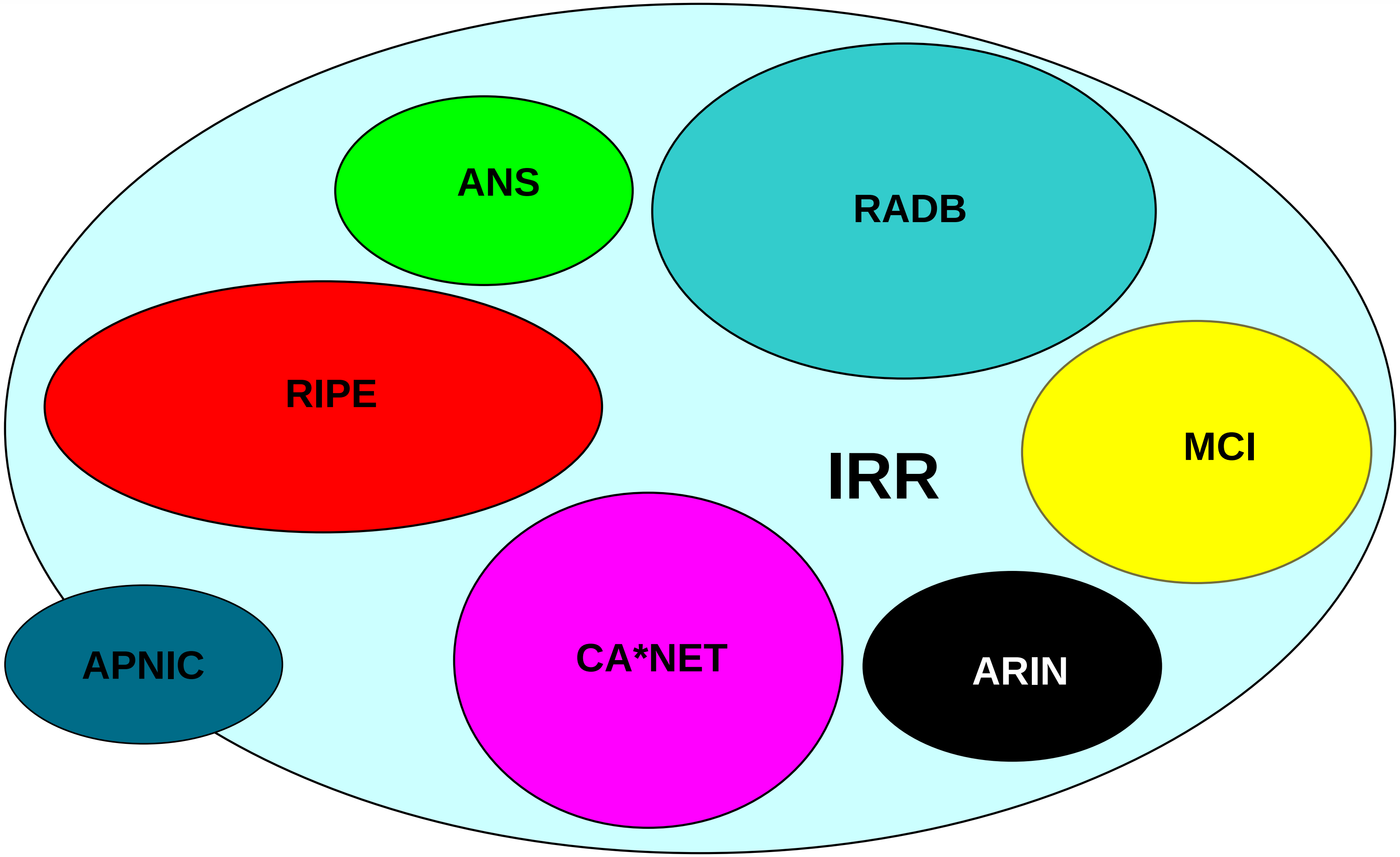
Definition

- “A public an authoritative distributed repository of information”
  - Public databases
  - Distributed repository of information
  - Have authoritative data
  - Vendor independent

Composition

- Routing Policy Details
- Routes and their aggregates
- Topology Linking AS's
- Network components such as routers
- Is separate from other information such as domains and networks

Entities



Relationship Table

Registry	Routing Policy	Routes	Networks	Domains
APNIC	Yes	No	Yes	No
RIPE	Yes	Yes	Yes	Yes
RADB	Yes	Yes	No	No
MCI	Yes	Yes	No	No
ANS	Yes	Yes	No	No
CA*NET	Yes	Yes	No	No
ARIN	Yes	Yes	Yes	No
InterNIC	No	No	No	Yes

Relationships

- MCI, ANS and CA*Net - provider run RRs
- RIPE RR - European providers
- ARIN RR - launched 8 February 1999
- RADB - Default RR for rest of world
- APNIC - plans to be full member of IRR very soon.

Benefits of an IRR

- Operational Support
- Information
- Configuration
- Problem diagnosis
- Improved Service Quality
- Tools for consistency checking

Information

- Routing policy repository
- “Map of global routing topology”
- Routing policy between neighbouring AS’s
- Device independent description of routing policy

Configuration

- Supports network filtering
- Configures routers and policies
- Revision control
- Sanity checking
- Simulation

Improved Quality of Service

All this adds up to improved quality of service

Participation is essential!

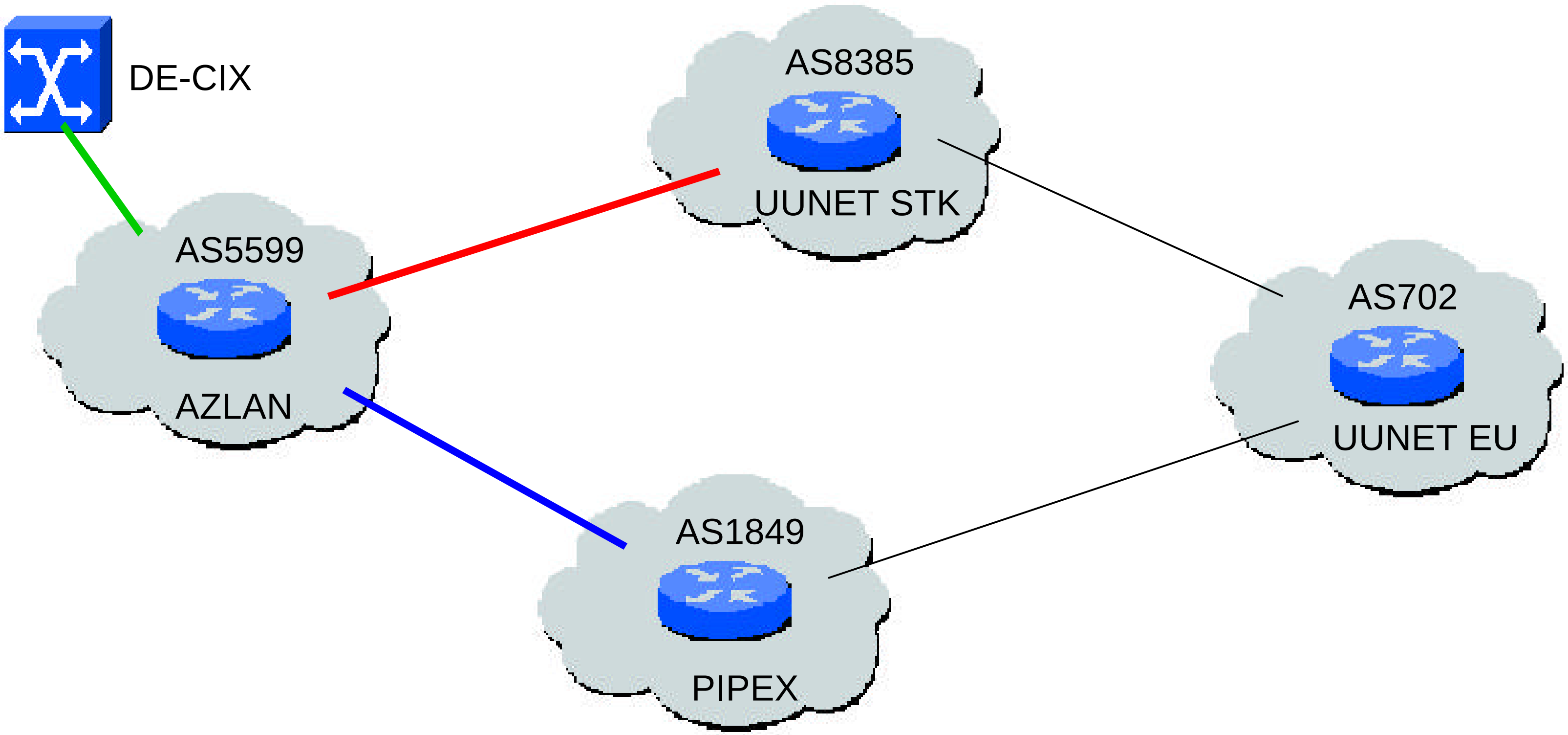
Key Objects and Syntax of RIPE-181

- Representation
- AS Object
- AS Macro
- Route Object
- Authorisation - Maintainer Object

Representation

- ASCII printable
- Attributes by tag:value lines
- Objects separated by empty lines
- RIPE-181
- RPSL (not covered)

Real World Example!



AS-Object

```
aut-num:   AS5599
descr:     Azlan Scandinavia
descr:     Internet Business Unit
descr:     Glostrup NOC
as-in:     from AS1849 100 accept AS-PIPEXEURO
as-in:     from AS1835 100 accept AS1835
as-in:     from AS2863 100 accept AS2863
as-in:     from AS3292 100 accept AS-DKNET AS3292
as-in:     from AS3308 100 accept AS3308
as-in:     from AS5492 100 accept AS5492
as-in:     from AS5509 100 accept AS5509
as-in:     from AS6785 100 accept AS6785
as-in:     from AS6834 100 accept AS6834
as-in:     from AS8526 100 accept AS8526
as-in:     from AS8385 100 accept {146.188.0.0/16}
```

```
as-out:    to AS1849 announce AS5599
as-out:    to AS1835 announce AS5599
as-out:    to AS2863 announce AS5599
as-out:    to AS3292 announce AS5599
as-out:    to AS3308 announce AS5599
as-out:    to AS5492 announce AS5599
as-out:    to AS5509 announce AS5599
as-out:    to AS6785 announce AS5599
as-out:    to AS6834 announce AS5599
as-out:    to AS8526 announce AS5599
as-out:    to AS8385 announce AS5599
default:   AS8385 100
admin-c:   MW89-RIPE
tech-c:    KE30-RIPE
mnt-by:    AS5599-MNT
changed:   klaus@azlan.net 970207
changed:   klaus@azlan.net 971209
source:    RIPE
```

Connection to exchange point
Connection transit provider
Connection to backup provider

Syntax for AS Object

- **Can represent policy using**
  - **Boolean expressions (AND, OR, NOT)**
  - **Keyword ANY - means "everything"**
  - **Communities and AS Macros**
  - **Route lists - {prefixes}**
  - **Cost to indicate preference**
  - **Attribute DEFAULT - accept 0.0.0.0**

Fields in AS Object

- **Mandatory Fields**

  aut-num, descr, admin-c, tech-c, mnt-by, changed, source, as-in, as-out

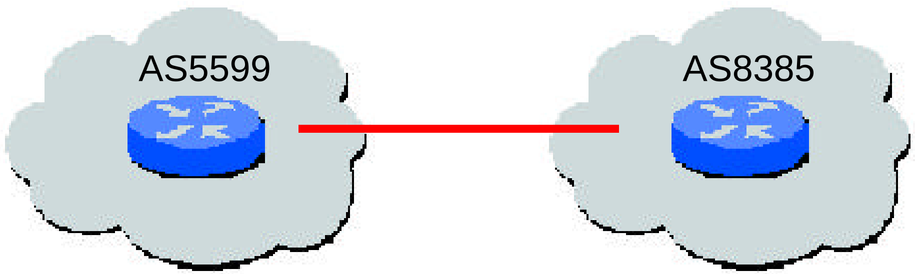
- **Optional Fields**

  as-name, interas-in, interas-out, as-exclude, default, guardian, remarks, notify

IP Routing Policy

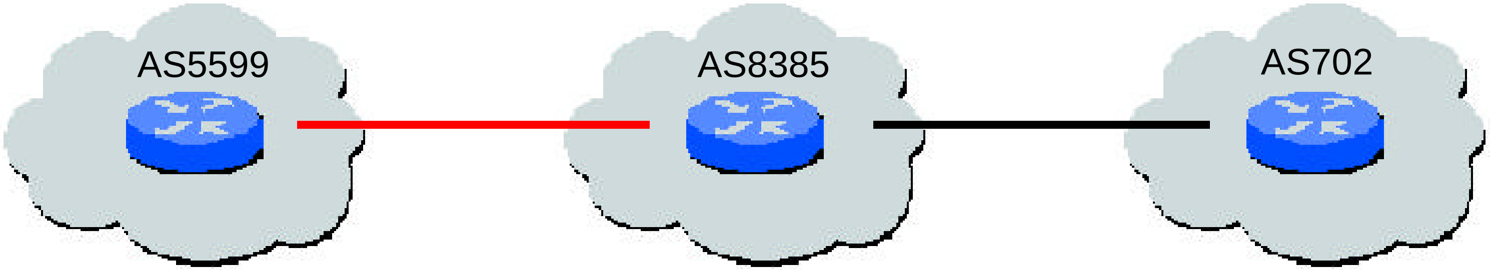
- Relationship between AS’s
- What to announce to each neighbour
- What to accept from each neighbour
- Selection between multiple paths
- Preferred paths
- Use default route?

Basic Policy Example




```
aut-num: AS5599
as-in:   from AS8385 100 accept {146.188.0.0/16}
as-out:  to AS8385 announce AS5599

aut-num: AS8385
as-in:   from AS5599 100 accept AS5599
as-out:  to AS5599 announce {146.188.0.0/16}
```

Transit Policy Example

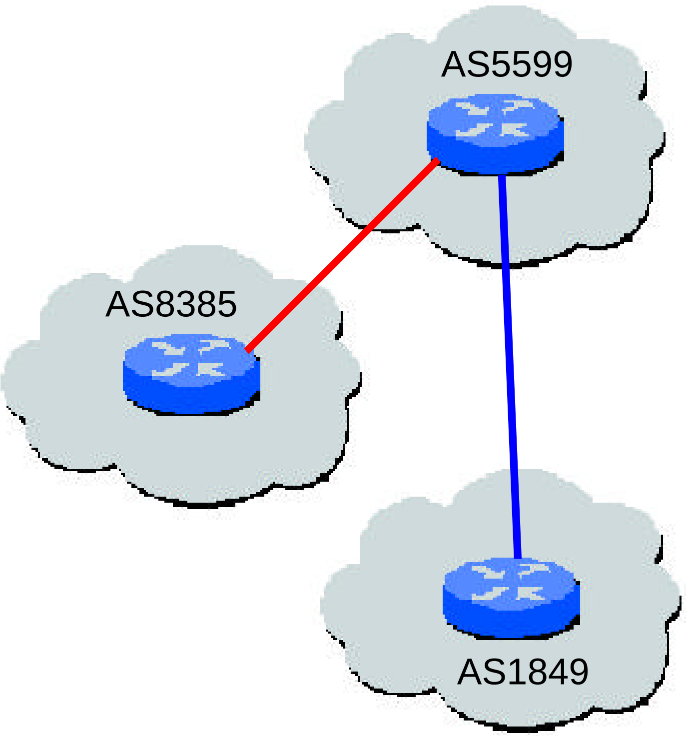


aut-num: AS8385
as-in: from AS702 100 accept ANY
as-in: from AS5599 100 accept AS5599
as-out: to AS702 announce AS8385 AS5599 AS8473 AND NOT {0.0.0.0/0}
as-out: to AS5599 announce {146.188.0.0/16}
default: AS702 50 {146.188.0.0/16}

aut-num: AS702
as-in: from AS8385 100 accept AS8385 AS5599 AS8473
as-out: to AS8385 announce ANY

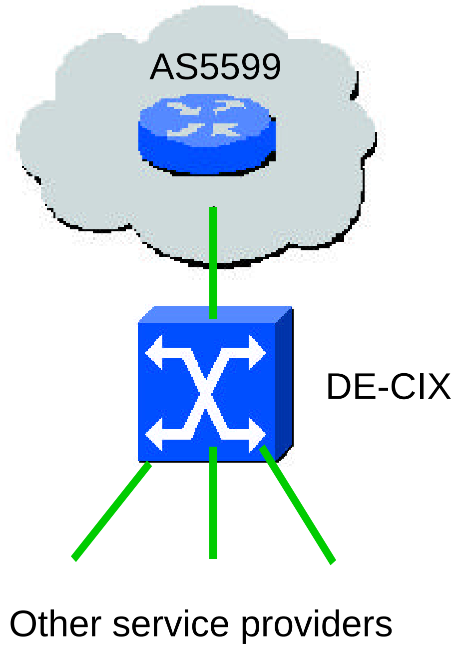
Multihoming Policy Example

```
aut-num: AS5599
as-in:   from AS1849 100 accept AS-PIPEXEURO
as-in:   from AS8385 100 accept {146.188.0.0/16}
as-out:  to AS8385 announce AS5599
as-out:  to AS1849 announce AS5599

aut-num: AS1849
as-in:   from AS5599 100 accept AS5599
as-out:  to AS5599 announce AS-PIPEXEURO

aut-num: AS8385
as-out:  to AS5599 announce {146.188.0.0/16}
as-in:   from AS5599 100 accept AS5599
```



Exchange Point Policy Example

```
aut-num:   AS5599
as-out:    to AS1835 announce AS5599
as-out:    to AS2863 announce AS5599
as-out:    to AS3292 announce AS5599
as-out:    to AS3308 announce AS5599
as-out:    to AS5492 announce AS5599
as-out:    to AS5509 announce AS5599
as-out:    to AS6785 announce AS5599
as-out:    to AS6834 announce AS5599
as-out:    to AS8526 announce AS5599
```



AS Macro

- Collection of AS's or other AS macros
- Describes membership of a set
- Contains no policy info
- Scales better
- Can differentiate between customer and peer routes

Fields in AS Macro

- **Mandatory Fields**

  as-macro, descr, as-list, tech-c, admin-c, mnt-by, changed, source

- **Optional Fields**

  guardian, remarks, notify

AS Macro

as-macro:	AS-UUNETSTK
descr:	UUNET customer routes in Stockholm
as-list:	AS-TAIDE
as-list:	AS-KOLUMBUS
as-list:	AS1759
as-list:	AS8385
as-list:	AS702
tech-c:	KCH251
admin-c:	ES199
remarks:	AS702 Stockholm routes are community tagged
notify:	intl-net-eng@uu.net
mnt-by:	UUNET-MNT
changed:	annel@uu.net 971113
source:	RIPE

Used in

aut-num:	AS702
as-out:	to AS1759 announce AS-UUNETSTK

Route Object

- **Represents a route in the Internet**
- **Contains all membership information**
- **Only one origin possible**
- **Classless (should be aggregated)**
- **Can support holes and withdrawn**

Fields in Route Object

- **Mandatory Fields**

  route, descr, origin, mnt-by, changed, source

- **Optional Fields**

  hole, withdrawn, comm-list, remarks, notify

- **Example:**

```
route:    195.129.0.0/19
descr:    UUNET-NET
origin:   AS702
remarks:  UUNET filter inbound on prefixes longer than /24
notify:   intl-net-eng@uu.net
mnt-by:   UUNET-MNT
changed:  annel@uu.net 970501
source:   RIPE
```

Route Object

```
route:    194.216.0.0/16
descr:    PIPEX-BLOCK194216
origin:   AS1849
hole:     194.216.59.0/24
remarks:  UUNET UK filter inbound on prefixes longer than /24
mnt-by:   AS1849-MNT
changed:  philip@uk.uu.net 19980107
source:   RIPE
```

```
stk-gw1>show ip bgp 194.216.0.0 255.255.0.0 longer-prefixes
BGP table version is 53607058, local router ID is 195.242.36.254
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

   Network          Next Hop            Metric LocPrf Weight Path
*> 194.216.0.0/16   146.188.30.162                       0   702 1849 i
*> 194.216.59.0     146.188.30.162                       0   702 701 3491 5557 i
```

How to register and update information in the IRR

- Frequently used objects
- Update procedures
  - Modifying Objects
  - Deleting Objects
  - Submitting Objects
  - Authorisation/Notification
  - Errors and Warnings
  - NIC handles

Frequently Used Objects

- Person - contact person
- Maintainer - authorisation of objects
- Inetnum - address assignment
- Aut-num - autonomous systems
- AS-macro - set of AS’s
- Route - announced routes

Unique Keys

- Uniquely identifies an object
- Updating object overwrites old entry - need unique key
- Used in querying whois
- Web based full text searches available now

Unique Keys

- Person - name plus NIC handle
- Maintainer - maintainer name
- Inetnum - network number
- Aut-num - AS number
- AS-macro - AS macro name
- Route - route value plus origin

Modifying an Object

Before		Submitted and After	
person:	**Philip F. Smith**	**person:**	**Philip F. Smith**
address:	UUNET UK	address:	Cisco Systems Australia
address:	Internet House	address:	Level 13, 80 Albert Street
address:	332 Science Park	address:	Brisbane 4000
address:	Milton Road	address:	QLD
address:	Cambridge CB4 4BZ	address:	Australia
address:	England, UK	phone:	+61 7 3238 8202
phone:	+44 1223 250100	fax-no:	+61 7 3211 3889
fax-no:	+44 1223 250101	e-mail:	pfs@cisco.com
e-mail:	philip@uk.uu.net	e-mail:	philip@dial.pipex.com
nic-hdl:	**PFS2-RIPE**	**nic-hdl:**	**PFS2-RIPE**
notify:	philip@uk.uu.net	notify:	philip@dial.pipex.com
changed:	philip@uk.uu.net 19971202	changed:	pfs@cisco.com 19980209
source:	RIPE	source:	RIPE

- **Unique keys must stay the same**
- **Remember to use current date**
- **NIC handle mandatory**

Deleting an Object

```
person:   Philip F. Smith
address:  UUNET UK
address:  332 Science Park
address:  Milton Road
address:  Cambridge
address:  England, UK
phone:    +44 1223 250100
fax-no:   +44 1223 250101
e-mail:   philip@uk.uu.net
nic-hdl:  PFS2-RIPE
notify:   philip@uk.uu.net
changed:  philip@uk.uu.net 19971202
source:   RIPE
delete:   philip@dial.pipex.com left company
```

- **delete deletes object from database**
- **current object must be submitted exactly as is, only with extra delete line**
- **If there is a mnt-by line, need the password!**

Submitting Objects

- **Email Interface - eg APNIC**

  auto-dbm@apnic.net

  Robot mail box

  Send all database updates to this mailbox

  Can use LONGACK and HELP in the subject line

  apnic-dbm@apnic.net

  human mailbox

  questions on the database process

Authorisation/Notification

```
route:    194.216.0.0/16
descr:    PIPEX-BLOCK194216
origin:   AS1849
hole:     194.216.59.0/24
remarks:  UUNET UK filter inbound on prefixes longer than /24
mnt-by:   AS1849-MNT
notify:   support@uk.uu.net
changed:  philip@uk.uu.net 19980107
source:   RIPE
```

- **mnt-by** **the maintainer object**
- **notify** **who is notified of changes**

Maintainer Object

- **Who is authorised**
- **Authorisation Method**

  email-from and crypt-pw

- **Mandatory Fields**

  mntner, descr, admin-c, tech-c, upd-to, auth, mnt-by

- **Optional Fields**

  mnt-nfy, changed, notify, source

Maintainer Object

Maintainer Object AS1849-MNT

```
mntner:   AS1849-MNT
descr:    AS 1849 Maintainer - PIPEX UK
admin-c:  PFS2-RIPE
tech-c:   PFS2-RIPE
upd-to:   philip@uk.uu.net
mnt-nfy:  netdev@uk.uu.net
auth:     CRYPT-PW fjOImdmwKsx
mnt-by:   AS1849-MNT
changed:  philip@uk.uu.net 19980109
source:   RIPE
```

Object has to be registered manually

Authorisation/Notification

```
route:     194.216.0.0/16
descr:     PIPEX-BLOCK194216
origin:    AS1849
hole:      194.216.59.0/24
hole:      194.216.136.0/23
remarks:   UUNET UK filter inbound on prefixes longer than /24
mnt-by:    AS1849-MNT
passwd:    c4Ange5
notify:    support@uk.uu.net
changed:   philip@uk.uu.net 19980109
source:    RIPE
```

- **New hole to be added.**
- **passwd field to allow change**
- **<support@uk.uu.net> will be notified of this change**
- **updated changed field**

Warnings and Errors

- **Warnings**
  - **Object corrected then accepted**
  - **Notification of action taken sent in acknowledgement**
- **Errors**
  - **Object not corrected and not accepted**
  - **Diagnostics in acknowledgement**
- **Syntax checking is very strict**

NIC Handles

```
mntner:     AS1849-MNT
descr:      AS 1849 Maintainer - PIPEX UK
admin-c:    PFS2-RIPE
tech-c:     PFS2-RIPE
upd-to:     philip@uk.uu.net
mnt-nfy:    netdev@uk.uu.net
auth:       CRYPT-PW fjOImdmwKsx
mnt-by:     AS1849-MNT
changed:    philip@uk.uu.net 19980109
source:     RIPE
```

- **PFS2-RIPE is the NIC Handle of the person**
- **Only way of avoiding ambiguity in person objects**
- **Mandatory**
- **Format: <initials><number>-<regional registry>**
- **Local differences for obtaining NIC Handles.**

What tools and resources?

- **RAToolset**

  www.isi.edu/ra/RAToolSet

- **RIPE whois**

  ftp.ripe.net/ripe/tools

- **Looking Glasses**

  nitrous.digex.net

RAToolSet

- **Runs on most Unix platforms**
- **Requires g++, tcl and tk**
- **Excellent for housekeeping, debugging and configuration**

RAToolSet Tools

- **RTconfig**

  Generate router configurations

- **AOE - aut-num object editor**

  update aut-num, as-macro objects

- **ROE - route-object editor**

  update route-object

- **CIDRadvisor**

  advice on CIDRisation

ROE Uses

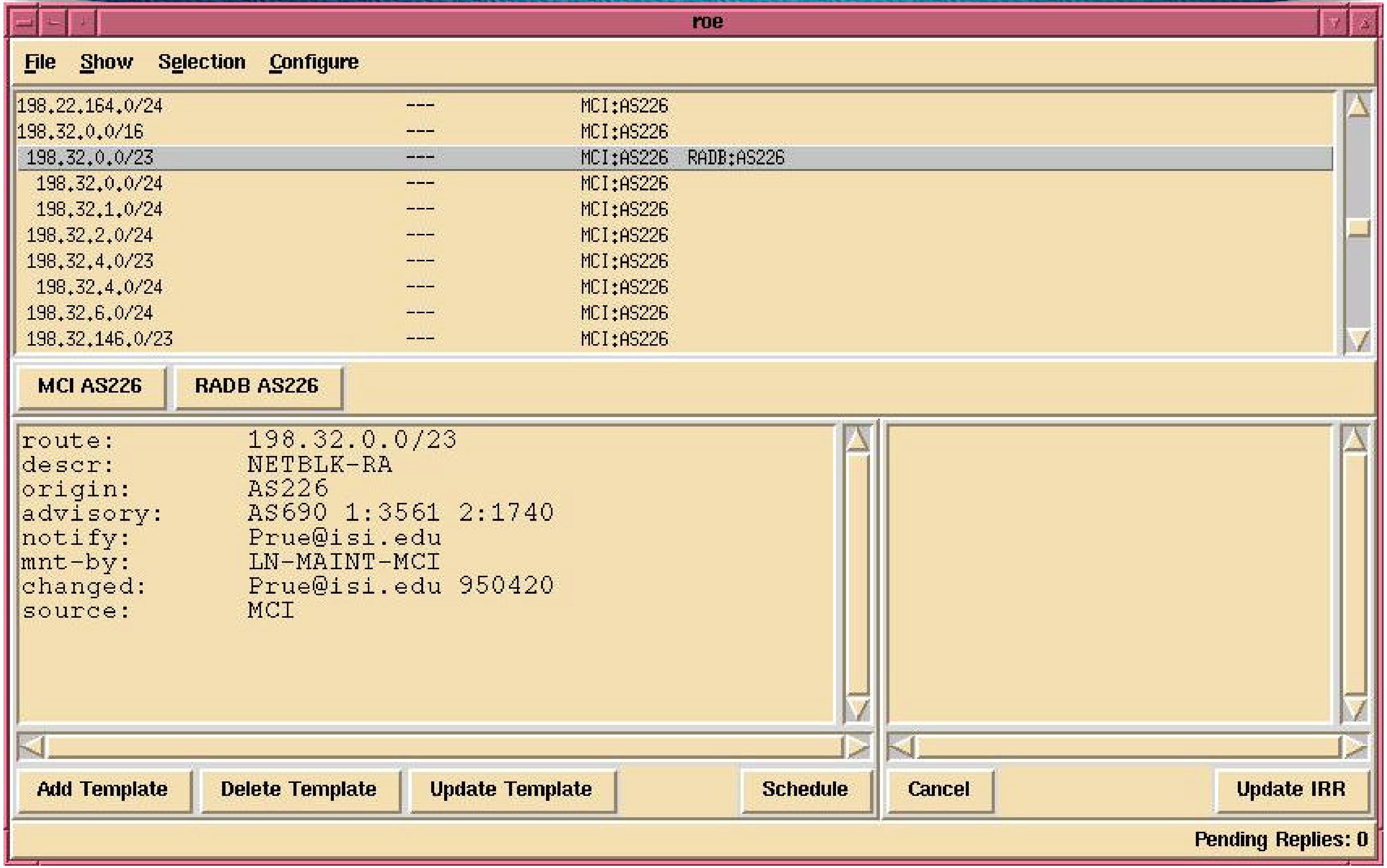
- **Route object editor used to:**

  check for consistency of route objects in IRRs

  synchronise route object entries in different IRRs

  detect missing or unwanted route objects

ROE example


roe
File Show Selection Configure
198.22.164.0/24 --- MCI:AS226
198.32.0.0/16 --- MCI:AS226
198.32.0.0/23 --- MCI:AS226 RADB:AS226
198.32.0.0/24 --- MCI:AS226
198.32.1.0/24 --- MCI:AS226
198.32.2.0/24 --- MCI:AS226
198.32.4.0/23 --- MCI:AS226
198.32.4.0/24 --- MCI:AS226
198.32.6.0/24 --- MCI:AS226
198.32.146.0/23 --- MCI:AS226
MCI AS226
RADB AS226
route: 198.32.0.0/23
descr: NETBLK-RA
origin: AS226
advisory: AS690 1:3561 2:1740
notify: Prue@isi.edu
mnt-by: LN-MAINT-MCI
changed: Prue@isi.edu 950420
source: MCI
Add Template
Delete Template
Update Template
Schedule
Cancel
Update IRR
Pending Replies: 0

AOE Uses

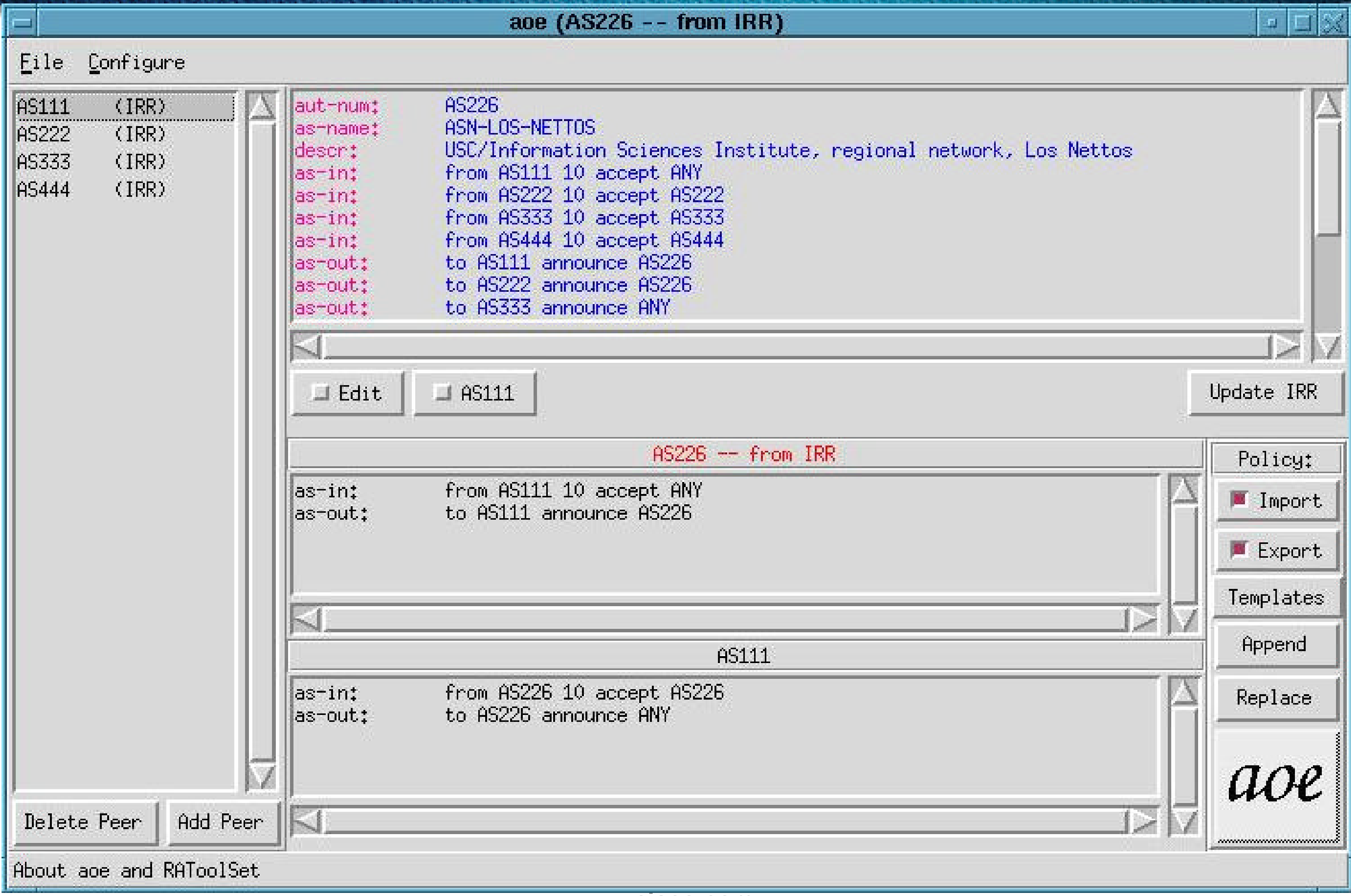
- **AS Object editor used to:**

  generate AS objects and policies as-in and as-out

  check policies listed in AS object on the IRRs

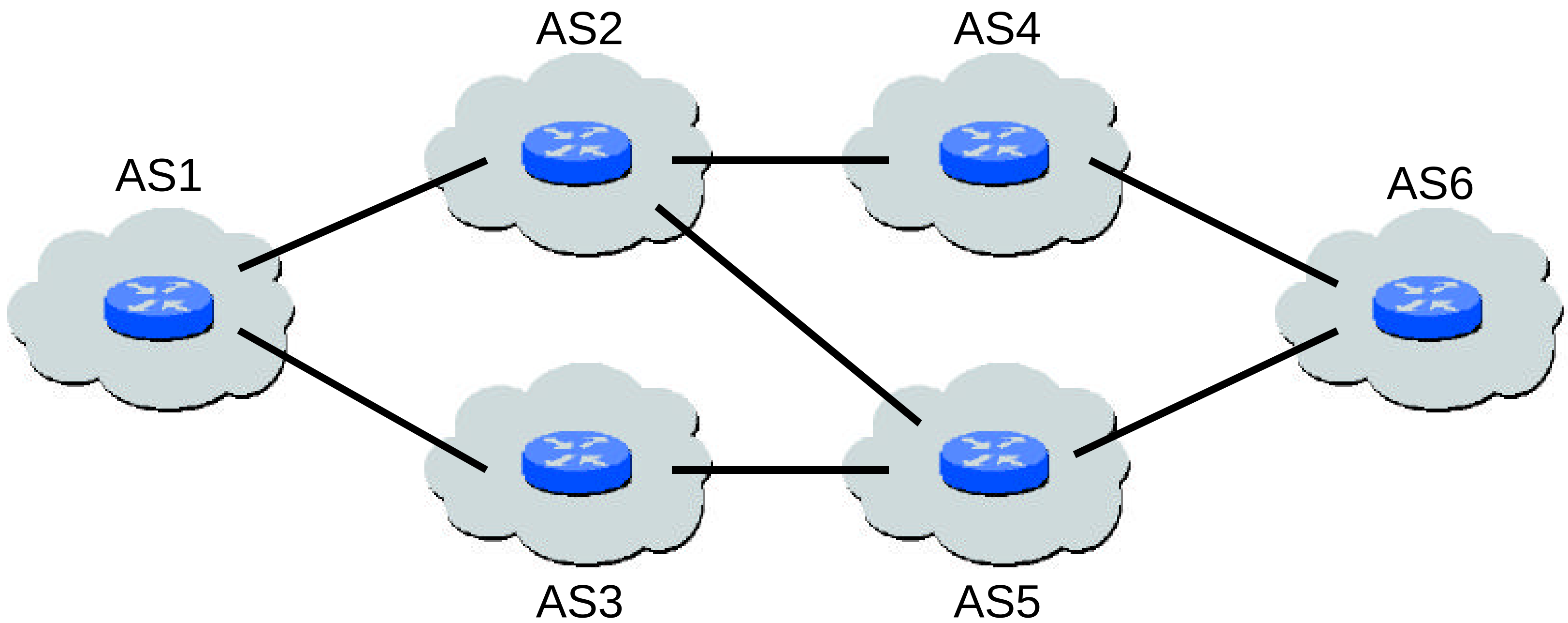
  check policies according to BGP dump

AOE example


aoe (AS226 -- from IRR)
File Configure
AS111 (IRR)
AS222 (IRR)
AS333 (IRR)
AS444 (IRR)
aut-num: AS226
as-name: ASN-LOS-NETTOS
descr: USC/Information Sciences Institute, regional network, Los Nettos
as-in: from AS111 10 accept ANY
as-in: from AS222 10 accept AS222
as-in: from AS333 10 accept AS333
as-in: from AS444 10 accept AS444
as-out: to AS111 announce AS226
as-out: to AS222 announce AS226
as-out: to AS333 announce ANY
Edit
AS111
Update IRR
AS226 -- from IRR
as-in: from AS111 10 accept ANY
as-out: to AS111 announce AS226
AS111
as-in: from AS226 10 accept AS226
as-out: to AS226 announce ANY
Policy:
Import
Export
Templates
Append
Replace
aoe
Delete Peer
Add Peer
About aoe and RAToolSet

PRtraceroute

- **PRIDE modified traceroute which includes AS information and a comparison between the real route and the route according to the IRR.**
- **Cisco IOS trace command refers to BGP table**



PRtraceroute Example

```
% prtraceroute -lv collegepk-cr9.bbnplanet.net
traceroute with AS and policy additions [Jan 13 20:21:19 UTC]

                from  AS109 lovefm.cisco.com (171.68.228.35)
                to     AS86 collegepk-cr9.bbnplanet.net (192.239.103.9)

 1  AS109  al.cisco.com                  171.68.228.3     [I] 4 1 1 ms
 2  AS109  acorn.cisco.com               171.68.0.134     [I] 2 1 1 ms
 3  AS109  gaza-gw2.cisco.com            171.68.0.91      [I] 2 1 1 ms
 4  AS109  sj-wall-2.cisco.com           198.92.1.138     [I] 3 3 2 ms
 5  AS109  barrnet-gw.cisco.com          192.31.7.37      [I] 4 3 2 ms
 6  AS200  paloalto-cisco.bbnplanet.net  131.119.26.9     [?] 4 4 3 ms
 7  AS200  paloalto-br1.bbnplanet.net    131.119.0.193    [I] 7 8 7 ms
 8    AS1  chicago2-br1.bbnplanet.net    4.0.1.2          [E1] 58 59 58 ms
 9    AS1  collegepk-br1.bbnplanet.net   4.0.1.6          [I] 82 73 75 ms
10   AS86  collegepk-cr9.bbnplanet.net   128.167.252.9    [E1] 86 81 ms

AS Path followed: AS109 AS200 AS1 AS86

 AS109 = Cisco Systems
 AS200 = BBN Planet Western Region
   AS1 = BBN Planet backbone
  AS86 = SURAnet Northern AS
```

ERROR	hop should not have been taken
NH ASx	possible NEXT_HOP followed
I	intra AS hop
En	nth choice inter AS hop
Dn	nth choice default hop
C	connected hop
?	No information in IRR

RIPE whois client

- Runs on most (UNIX) platforms
- Easy to install
- Can use to query all other IRR's
- Expanded whois functionality
- Good for housekeeping, debugging, operations
- RECOMMENDED!

Open Issues

- **Why isn't the IRR used more today?**
  - **Ignorance?**
  - **Security fears?**
  - **No local routing registry?**
- **What tools are missing?**

Tool Usage

- Are the available tools too complicated?
- Are there enough tools?
- Are there too many tools?
- Are they not sophisticated enough?

Tool Availability

- Are there other tools which should be available?
- Router to automatically rebuild configuration from routing registries?
- Router changes configuration as information in routing registries change?

Tool Availability

- **Should software be available as a commercial package?**
  - **Better bundled/supported/debugged?**
  - **Better integration/training?**
- **Most tools are freely available public efforts for the good of the "community"**

Routing Registries

- **Belief that the Internet will work with out the IRR.**
  - **It will but for how long?**
  - **Many ISPs rely on the data kept in the registry**
  - **Subset of tools available are being used on a daily basis**

Routing Registries

- **Should each ISP run their own routing registry?**
  - **As mirror of their regional RR?**
  - **As part of the global IRR?**
  - **Must have a customer network database...**
- **Software availability, scalability, data integrity, security, etc...?**

Training

- Is there enough training on the promotion of routability
- Headcount requirement

  depends on organisation

  too easy and cheaper to be irresponsible
- Overall organisational awareness of the issues -> overall efficiency, quality of service and support

Ways forward

- **Support an APNIC routing registry!**
- **AP ISPs use it to:**

  configure border routers

  register networks and routing policy

  debug network and routing problems
- **Service Provider Routing Registries**

Ways forward

- Routing Registry enhancements

    RPSL matches today's BGP capabilities

- Feedback on tool enhancements
- Feedback to vendors on equipment configuration enhancements
- More training, more education, more feedback!

Summary

- ISP networks and terminology
- The application of IGPs and BGP in an Internet network
- Shown tools which help diagnose and solve routing problems more easily
- Application of routing registries

Summary

- **Made you more aware of the issues facing the Internet today**
- **Showed you how to make a positive contribution to the functioning of the Internet**
- **Promoted Routability!**


Thank You!
Any Questions?

Useful URL's & Reading

1. CIDR
   - ftp://ftp.isi.edu/in-notes/rfc{1517,1518,1519}.txt
   - http://www.ibm.net.il/~hank/cidr.html
   - ftp://ftp.uninett.no/pub/misc/eidnes-cidr.ps.Z
   - Network addressing when using CIDR
2. AS numbers
   - ftp://ftp.isi.edu/in-notes/rfc1930.txt
   - Guidelines for creation, selection, and registration of an AS
3. Address Allocation and Private Internets
   - ftp://ftp.isi.edu/in-notes/rfc1918.txt
4. BGP Dampening
   - http://www.cisco.com/warp/public/459/16.html
   - ftp://ftp.ripe.net/ripe/docs/ripe-178.txt
   - European recommendations for route flap dampening
   - ftp://engr.ans.net/pub/slides/nanog/feb-1995/route-dampen.ps
5. Routing Discussion
   - http://www.ripe.net/wg/routing/index.html

Useful URL’s & Reading

6. Traceroute server repository
   http://www.boardwatch.com/isp/trace.htm
7. ISP Tips
   http://www.amazing.com/internet/faq.html
   http://www.cisco.com/public/cons/isp/
8. BGP Table
   http://www.telstra.net/ops/bgptable.html
   http://www.employees.org/~tbates/cidr.hist.plot.html
   http://www.merit.edu/ipma/reports
9. Route server views
   http://www.caida.org
10. NANOG archive
   http://www.merit.edu/mail.archives/html/nanog/maillist.html

IRR Reading List

1. RFC1786 “Representation of IP Routing Policies in a Routing Registry”
   ftp://ftp.isi.edu/in-notes/rfc1786.txt
2. RATools and RSPL
   ftp://ftp.apnic.net/ietf/rfc/rfc2280.txt
   Tools http://www.isi.edu/ra/*
   Mailing List <ratoolset@isi.edu>
3. PRIDE
   Slides ftp://ftp.ripe.net/pride/docs/course-slides
   Guide ftp://ftp.ripe.net/pride/docs/guide-2.0txt.{ps}.tar.gz
   Tools ftp://ftp.ripe.net/pride/tools/*
4. IRR authorisation/notification
   ftp://ftp.ripe.net/ripe/docs/ripe-120.txt
5. RADB pointers
   http://www.ra.net
   http://www.ra.net/.faq.htm
6. ISP run RR User documents
   http://infopage.cw.net/Routing