Internet Technology

09. Routing on the Internet

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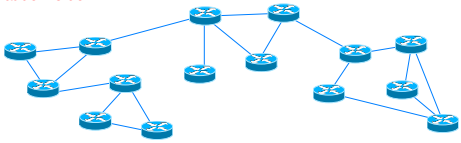
Summary

- Routing
  - Enable a host to determine the next hop on a *least-cost* route to a destination
  - Graph traversal problem
    - Graph $G = (N \text{ nodes}, E \text{ edges}) \Rightarrow$ Network of N hosts and E links
- Global knowledge
  - Link State (LS) = Dijkstra's algorithm
    - Each iteration, replace distances with more accurate values
- Local (neighbor) knowledge
  - Distance-Vector algorithm
  - Construct a distance vector to all nodes
  - Exchange information with neighbors until no changes to vector

A problem of scale

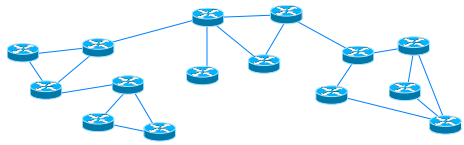
- There are over a billion hosts* on the Internet
  - That's a LOT of routing information to store
  - Sending Link State updates would consume a lot of bandwidth
  - Distance Vector algorithm may never converge
    - Time to converge vs. time between any route changes
- Organizations may not want arbitrary routing through their infrastructure

What do we do?



*https://www.isc.org/network/survey/

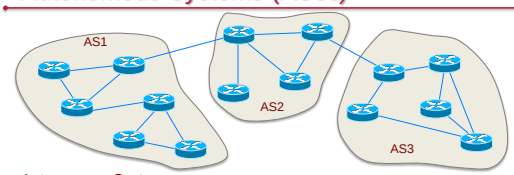
Autonomous Systems (ASes)



Autonomous System

- Collection of routers and hosts that are under common administrative control
  - Typically one network service provider or large company
- Collection of subnets (routing prefixes ⇒ route aggregation)
- Present a common routing policy to the Internet
- Identified by an AS Number:
  - Internet Assigned Numbers Authority (IANA) → Regional Internet Registry (RIR)

Autonomous Systems (ASes)



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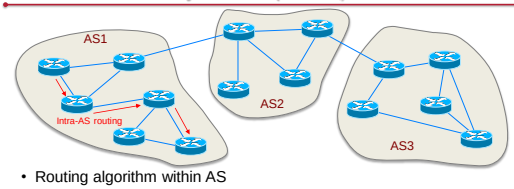
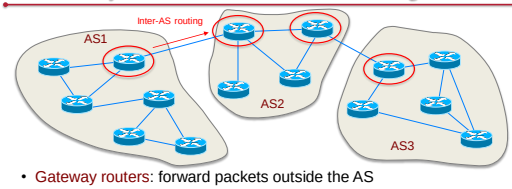
Autonomous System Number	
Number	46
Name	RUTGERS
Handle	AS46
Organization	Rutgers University (RUTGER)
Registration Date	1985-08-16
Last Updated	2000-08-10
Comments	
RESTful Link	https://whois.arin.net/rest/asn/AS46
See Also	Related POC records.
See Also	Organization's POC records.

Autonomous Systems (ASes)



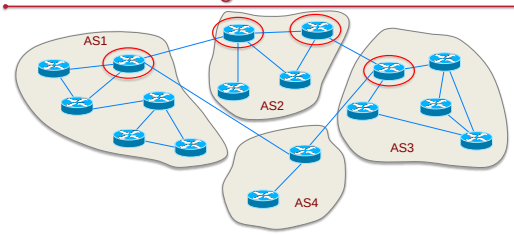
- Routing algorithm within AS
  - Routers in an AS all run the same routing algorithm
  - Routers within an AS know about all the all the routers *inside* the AS
  - Intra-AS routing protocol (either LS or DV)

Gateway Routers & Inter-AS routing



- Gateway routers: forward packets outside the AS
- If there is just one gateway router with one link, the forwarding decision is easy
  … it becomes the other AS's problem
- If multiple gateway routers
  - AS needs to know which destinations are reachable via which AS
  - Configure internal routing tables to route to the appropriate gateway
  - An Inter-AS routing protocol figures this out

Hot-Potato Routing



- What if a subnet is accessible via AS1 & AS3?
  - AS2 can route to either one
  - Send the packet to the gateway router that has the lowest routing cost
  - Hot potato routing: pass traffic onto another AS as quickly as possible

Autonomous system types

- Stub AS
  - Carries only traffic for which it is a source or a destination
  - Does not route traffic between ASes
- Multihomed stub AS
  - Like a stub AS but connected to multiple other ASes
  - Provides fault tolerant connectivity for systems in the AS but does not offer routing from other ASes
- Transit AS
  - Provides connections through itself to other networks

Intra-AS Routing: RIP

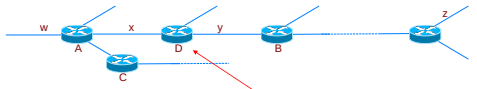
Routing Information Protocol (RIP)

- Intra-AS protocol = Interior Gateway Protocol (IGP)
- RIP: distance-vector routing protocol – used as an IGP
- Hop count is used as a cost metric (cost of each link = 1)
  - Cost = # hops from the source router to a destination subnet (including the subnet)
  - Minimum cost = 1
  - Maximum cost = 15 (to avoid routing loops)

How RIP works

- Each router maintains a routing table
  - Contains the router's distance vector & the forwarding table
    - Each subnet identifies the next router & # hops to the destination
- RIP advertisements
  - Each router sends a a RIP advertisement to its neighbors approximately every 30 seconds
  - UDP port 520
  - The advertisement contains the router's routing table
  - If a router does not hear from a neighbor in 180 seconds
    - It assumes the neighbor is dead or disconnected
    - Removes the neighbor from its routing table & propagates info to neighbors
- Upon receiving an advertisement
  - Merge the received table with your own table
    - Choose the smallest # of hops to each destination
    - Add any new destination subnets

RIP Example

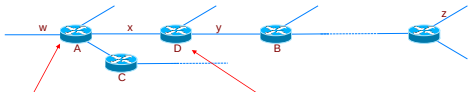


Routing table at router D

Destination subnet	Next router	Hops to destination
y	B	2
z	B	7
x	–	1
…	…	…

from p. 385-387 of the text with small mods

RIP Example



Advertisement from A

Destination subnet	Next router	Hops to destination
z	C	4
w	–	1
x	–	1
…	…	…

Routing table at router D

Destination subnet	Next router	Hops to destination
w	A	2
y	B	2
z	~~A~~	~~5~~
x	–	1
…	…	…

What do we merge?
- Destination z via A is 5 hops vs. 7
- We know of a destination to w (2 hops via A)

Running RIP

- On UNIX/BSD/Linux
  - RIP runs as a background process called *routed* ("route daemon")
  - Application layer process that can modify routing tables
- On routers
  - RIP runs in the control plane
- Downsides of RIP
  - Converges slowly
  - Does not scale to very large networks
  - Insecure (plain text authentication)
- But it's still widely used

Intra-AS Routing: OSPF

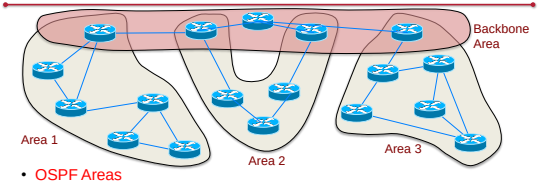
Open Shortest Path First (OSPF)

- Another interior gateway protocol (intra-AS routing)
  - Designed as a successor to RIP
  - Typically used in large enterprise networks
- RIP is based on the Distance-Vector algorithm
- OSPF is based on Dijkstra's shortest-path (Link State) algorithm
  - Each router constructs a complete graph of the entire AS
  - Each router runs Dijkstra's algorithm to determine the shortest path to all subnets with itself as the root node
    - Costs of links are configured by the admin (simplest case: each link = 1)
  - If the link state of a router changes (connectivity or cost)
    - It broadcasts the change to *all* routers in the AS, not just the neighbors
- OSPF implemented as a special upper-layer protocol
  - Protocol 89 in the IP protocol field (TCP=6, UDP=17, ICMP=1)

Features of OSPF

- Security
  - Shared secret key among routers
  - Send MD5 *hash*(OSPF packet content, shared_key)
  - Receiver validates the hash to ensure that the contents have not been modified
  - Each message includes a sequence number to prevent replay attacks
- Allow multiple paths to be used if they have the same cost
- Support multicast routing
- Allow an AS to be configured into a hierarchy: *OSPF Areas*

OSPF Areas: "ASes within an AS"



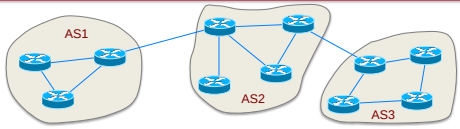
- OSPF Areas
  - Subdivision of an OSPF autonomous system
  - Each area
    - Runs its own OSPF link state routing algorithm
    - Has one or more area border routers (ABR) to route outside the area
- Backbone area:
  - Contains all area border routers in the AS (and possibly others)
  - Inter-area routing
    - route to an ABR, through the backbone, and to the ABR in the destination area

Inter-AS Routing: BGP

Border Gateway Protocol: BGP

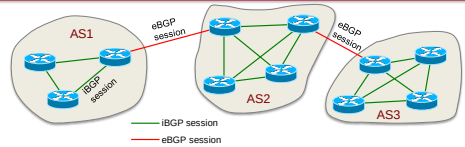
- RIP & OSPF: interior gateway protocols (IGP)
  - intra-AS protocols
- Border Gateway Protocol: exterior gateway protocol (EGP)
  - inter-AS protocol: routes between autonomous systems (AS)
  - BGP version 4 is the standard inter-AS protocol in the Internet

BGP Sessions



- Pairs of routers exchange information via semi-permanent TCP connections
  - One connection for each link between gateway routers
  - Two routers with a BGP connection are BGP peers

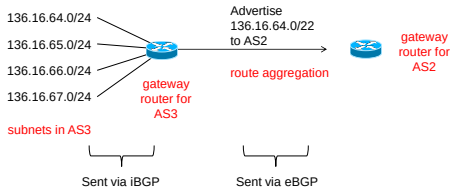
BGP Sessions



- Pairs of routers exchange information via semi-permanent TCP connections
  - One connection for each link between gateway routers
    - External BGP (eBGP) session
  - Two routers with a BGP connection are BGP peers
  - Also BGP TCP connections between routers *inside* an AS
    - Typically between each pair of routers
    - Internal BGP (iBGP) session

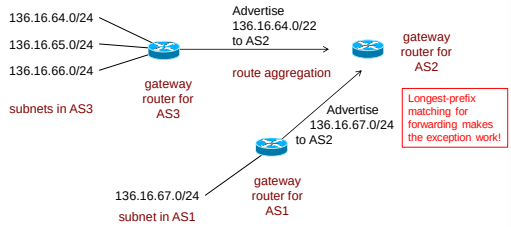
Learning destinations

- BGP destinations are CIDR prefixes
  - Range of IP addresses representing one or more subnets

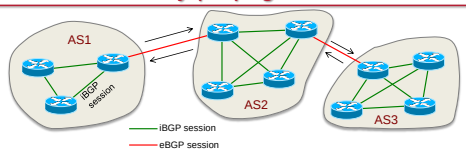


Learning reachable destinations

- What if 136.16.67.0/24 was in AS1?

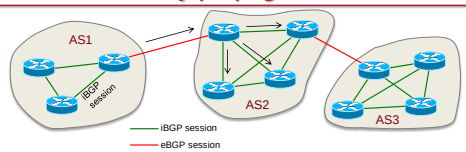


BGP reachability propagation via eBGP



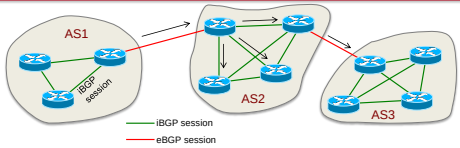
- AS1 sends prefix reachability info to AS2
- AS2 sends prefix reachability info to AS1
- AS3 sends prefix reachability info to AS2
- AS2 sends prefix reachability info to AS3

BGP reachability propagation via iBGP



- When a gateway gets prefix reachability info via eBGP
  - It propagates the information to routers inside the AS via iBGP

Readvertising learned routes



- If a gateway router learns of new prefixes
  - It can re-advertise to its peers via eBGP

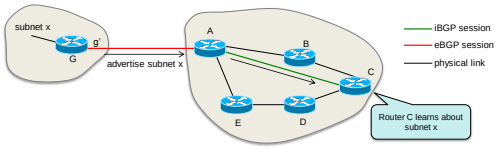
AS identification and BGP routes

- Each AS has a globally unique AS number (ASN)
  - Assigned by ICANN Regional Internet Registries
- BGP routers send route announcements
  - Destination address block (CIDR network)
  - Path of AS numbers the packet will take
  - BGP attributes

BGP peers advertise routes to each other

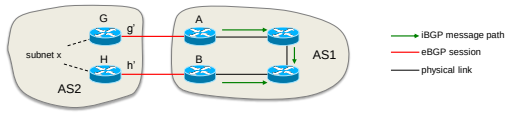
- Key attributes
  - AS-PATH
    - List of ASes through which the advertisement passed
    - If a router sees that its AS is contained in the list ⇒ loop ⇒ reject advertisement
  - NEXT-HOP
    - Identifies the router address outside the AS that sent the advertisement to our AS
      - Intra-AS routing algorithms know routes to internal nodes and attached subnets
      - NEXT-HOP identifies the address on the attached subnet

Use of the NEXT-HOP attribute



1. Router G advertises subnet x on the G-A eBGP session
2. Gateway Router A propagates this route to the intra-AS routers via iBGP
3. Router C needs to add this route to its table
4. NEXT-HOP attribute has the address of G's IP address for the G-A connection (g')
5. C creates a forwarding table entry for subnet x to the G-A link
6. It uses the intra-AS routing algorithm to find the next hop on the least-cost path from C to interface g'

Use of NEXT-HOP to resolve links



- Two peering links between AS1 and AS2; AS2 advertises prefix x
- A router in AS1 can get two route advertisements to a prefix x
  - The routes will have the same AS-PATH to x
  - NEXT-HOP will differ based on the eBGP gateway router on AS2
- Intra-AS routing algorithm can determine the cost of a path to each peering link
  - Choose route to h' or route to g'

BGP route selection

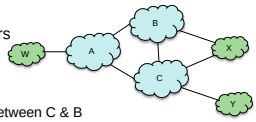
- BGP advertises routes through eBGP and iBGP
  - A gateway router may reject a route based on an import policy
  - A router may learn of multiple routes to a prefix
- Elimination criteria (in sequence order)
  - Pick route with the highest local preference value attribute
    - Local preference is a policy defined by an admin

if multiple routes remaining,
  - Select the route with the shortest AS-PATH
    - BGP would use the distance-vector algorithm if this was the only criteria

if multiple routes remaining,
  - Choose the route with the closest NEXT-HOP router

Policies are a core part of routing

- A, B, C: transit ASes – IPSs
- W, X, Y: stub ASes – customers



- X is a multihomed stub
  - Does not want to route traffic between C & B
  - Even if X knows of a path (e.g., XCY), it will only advertise paths to X
- B knows a path to W: B→A→W
  - Should it tell C?
  - C can route to C→B→A→W: extra burden on B
  - Typically, traffic through an ISP must either originate or terminate at an ISP's address (customer of the ISP)
  - Peering agreements between ISPs can explicitly allow the route

The end