15-441 Computer Networking

Inter-Domain Routing

BGP (Border Gateway Protocol)

Routing Review

- The Story So Far…
  - Routing protocols generate the forwarding table
  - Two styles: distance vector, link state
  - Scalability issues:
    - Distance vector protocols suffer from count-to-infinity
    - Link state protocols must flood information through network
- Today's lecture
  - How to make routing protocols support large networks
  - How to make routing protocols support business policies

Outline

- Routing hierarchy
- Internet structure
- External BGP (E-BGP)

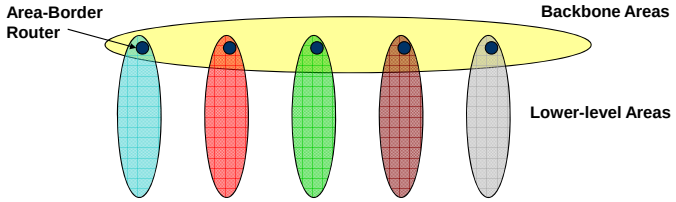
Routing Hierarchies

- Flat routing doesn't scale
  - Storage → Each node cannot be expected to store routes to every destination (or destination network)
  - Convergence times increase
  - Communication → Total message count increases
- Key observation
  - Need less information with increasing distance to destination
  - Need lower diameters networks
- Solution: area hierarchy

Areas

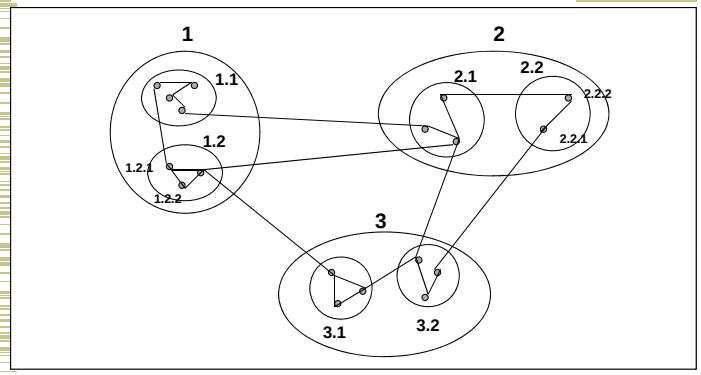
- Divide network into areas
  - Areas can have nested sub-areas
- Hierarchically address nodes in a network
  - Sequentially number top-level areas
  - Sub-areas of area are labeled relative to that area
  - Nodes are numbered relative to the smallest containing area

Routing Hierarchy



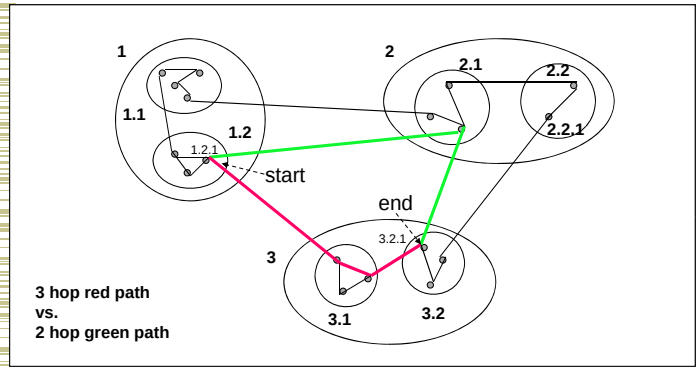
- Partition Network into "Areas"
  - Within area
    - Each node has routes to every other node
  - Outside area
    - Each node has routes for other top-level areas only
    - Inter-area packets are routed to nearest appropriate border router
- Constraint: no path between two sub-areas of an area can exit that area

Area Hierarchy Addressing



Path Sub-optimality

- Can result in sub-optimal paths



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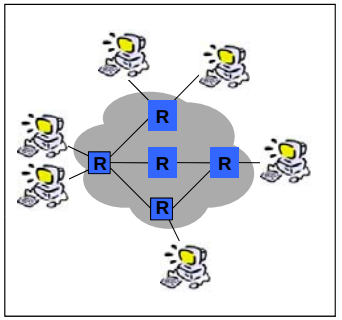
A Logical View of the Internet?

- After looking at RIP/OSPF descriptions
  - End-hosts connected to routers
  - Routers exchange messages to determine connectivity
- NOT TRUE!



Internet's Area Hierarchy

- What is an Autonomous System (AS)?
  - A set of routers under a single technical administration, using an *interior gateway protocol (IGP)* and common metrics to route packets within the AS and using an *exterior gateway protocol (EGP)* to route packets to other AS's
- Each AS assigned unique ID
- AS's peer at network exchanges

AS Numbers (ASNs)

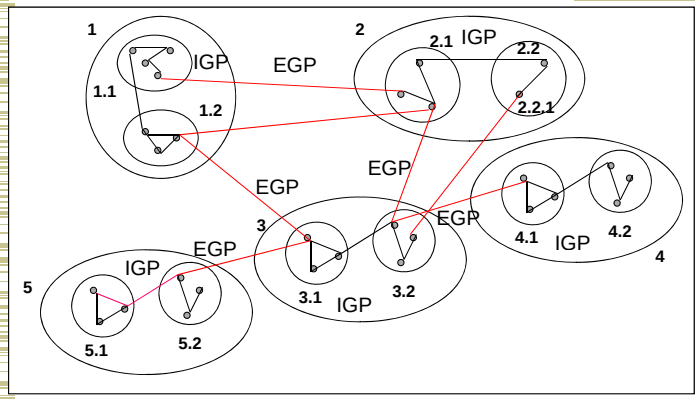
ASNs are 16 bit values 64512 through 65535 are "private"

Currently over 15,000 in use

- Genuity: 1
- MIT: 3
- CMU: 9
- UC San Diego: 7377
- AT&T: 7018, 6341, 5074, …
- UUNET: 701, 702, 284, 12199, …
- Sprint: 1239, 1240, 6211, 6242, …
- …

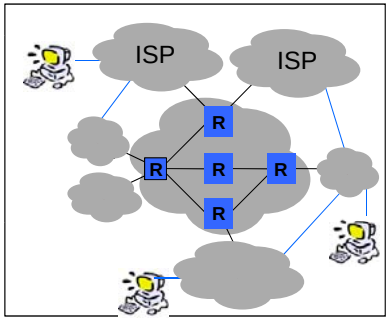
ASNs represent units of routing policy

Example



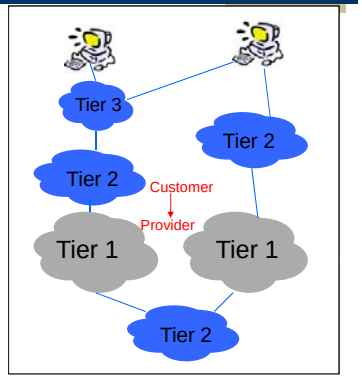
A Logical View of the Internet?

- RIP/OSPF not very scalable → area hierarchies
- NOT TRUE EITHER!
- ISP's aren't equal
  - Size
  - Connectivity

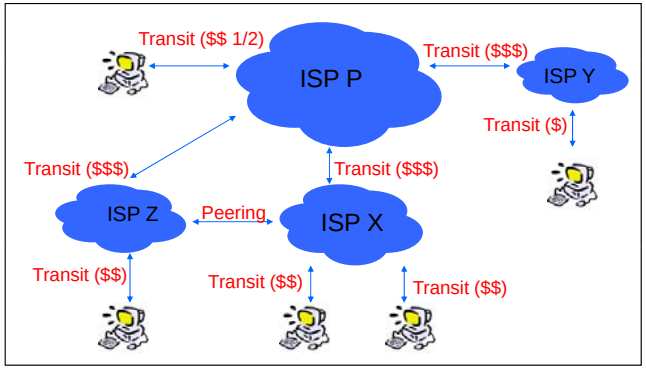


A Logical View of the Internet

- Tier 1 ISP
  - "Default-free" with global reachability info
- Tier 2 ISP
  - Regional or country-wide
- Tier 3 ISP
  - Local



Transit vs. Peering



Policy Impact

- "Valley-free" routing
  - Number links as (+1, 0, -1) for provider, peer and customer
  - In any path should only see sequence of +1, followed by at most one 0, followed by sequence of -1
- WHY?
  - Consider the economics of the situation

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Choices

- Link state or distance vector?
  - No universal metric – policy decisions
- Problems with distance-vector:
  - Bellman-Ford algorithm may not converge
- Problems with link state:
  - Metric used by routers not the same – loops
  - LS database too large – entire Internet
  - May expose policies to other AS's

Solution: Distance Vector with Path

- Each routing update carries the entire path
- Loops are detected as follows:
  - When AS gets route, check if AS already in path
    - If yes, reject route
    - If no, add self and (possibly) advertise route further
- Advantage:
  - Metrics are local - AS chooses path, protocol ensures no loops

Interconnecting BGP Peers

- BGP uses TCP to connect peers
- Advantages:
  - Simplifies BGP
  - No need for periodic refresh - routes are valid until withdrawn, or the connection is lost
  - Incremental updates
- Disadvantages
  - Congestion control on a routing protocol?
  - Poor interaction during high load

Hop-by-hop Model

- BGP advertises to neighbors only those routes that it uses
  - Consistent with the hop-by-hop Internet paradigm
  - e.g., AS1 cannot tell AS2 to route to other AS's in a manner different than what AS2 has chosen (need source routing for that)
- BGP enforces policies by choosing paths from multiple alternatives and controlling advertisement to other AS's

Examples of BGP Policies

- A multi-homed AS refuses to act as transit
  - Limit path advertisement
- A multi-homed AS can become transit for some AS's
  - Only advertise paths to some AS's
- An AS can favor or disfavor certain AS's for traffic transit from itself

BGP Messages

- Open
  - Announces AS ID
  - Determines hold timer – interval between keep_alive or update messages, zero interval implies no keep_alive
- Keep_alive
  - Sent periodically (but before hold timer expires) to peers to ensure connectivity.
  - Sent in place of an UPDATE message
- Notification
  - Used for error notification
  - TCP connection is closed *immediately* after notification

BGP UPDATE Message

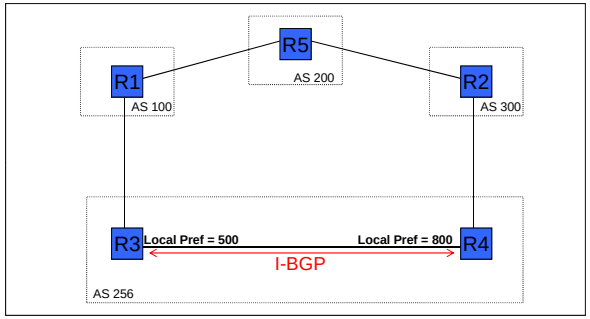
- List of withdrawn routes
- Network layer reachability information
  - List of reachable prefixes
- Path attributes
  - Origin
  - Path
  - Metrics
- All prefixes advertised in message have same path attributes

Path Selection Criteria

- Attributes + external (policy) information
- Examples:
  - Hop count
  - Policy considerations
    - Preference for AS
    - Presence or absence of certain AS
  - Path origin
  - Link dynamics

LOCAL PREF

- Local (within an AS) mechanism to provide relative priority among BGP routers (e.g. R3 over R4)

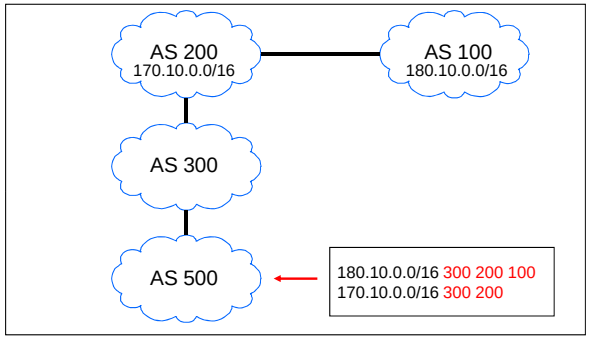


LOCAL PREF – Common Uses

- Peering vs. transit
  - Prefer to use peering connection, why?
- In general, customer > peer > provider
  - Use LOCAL PREF to ensure this

AS_PATH

- List of traversed AS's

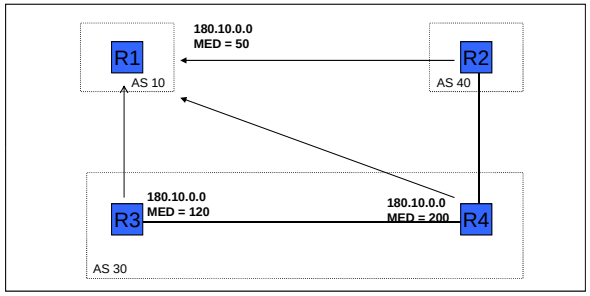


Multi-Exit Discriminator (MED)

- Hint to external neighbors about the preferred path into an AS
  - Non-transitive attribute
    - Different AS choose different scales
- Used when two AS's connect to each other in more than one place

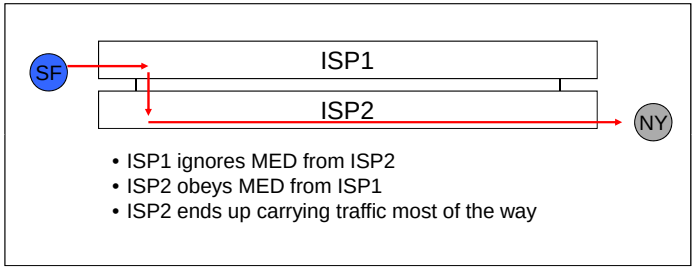
MED

- Hint to R1 to use R3 over R4 link
- Cannot compare AS40's values to AS30's



MED

- MED is typically used in provider/subscriber scenarios
- It can lead to unfairness if used between ISP because it may force one ISP to carry more traffic:



Decision Process

- Processing order of attributes:
  - Select route with highest LOCAL-PREF
  - Select route with shortest AS-PATH
  - Apply MED (if routes learned from same neighbor)

Important Concepts

- Wide area Internet structure and routing driven by economic considerations
  - Customer, providers and peers
- BGP designed to:
  - Provide hierarchy that allows scalability
  - Allow enforcement of policies related to structure
- Mechanisms
  - Path vector – scalable, hides structure from neighbors, detects loops quickly

Next Lecture: IP Hodgepodge…

- IPv6
  - Addressing and more
- Tunneling
  - How anything new gets added to the Internet
- NAT
  - Making do with not enough IP addresses
- VPN
  - How to make your own network