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

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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)

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
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
- Keep_alive
  - Sent periodically (but before hold timer expires) to peers to ensure connectivity.
- 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

**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: DNS**

- How to resolve names like www.google.com into IP addresses