CSCI-1680
Network Layer:
Inter-domain Routing

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Today

• **Last time: Intra-Domain Routing (IGP)**
  – RIP distance vector
  – OSPF link state

• **Inter-Domain Routing (EGP)**
  – Border Gateway Protocol
  – Path-vector routing protocol
Why Inter vs. Intra

• Why not just use OSPF everywhere?
  – E.g., hierarchies of OSPF areas?
  – Hint: scaling is not the only limitation

• BGP is a policy control and information hiding protocol
  – intra == trusted, inter == untrusted
  – Different policies by different ASs
  – Different costs by different ASs
Types of ASs

• Local Traffic – source or destination in local AS
• Transit Traffic – passes through an AS
• Stub AS
  – Connects to only a single other AS
• Multihomed AS
  – Connects to multiple ASs
  – Carries no transit traffic
• Transit AS
  – Connects to multiple ASs and carries transit traffic
AS Relationships

• How to prevent X from forwarding transit between B and C?
• How to avoid transit between CBA?
  – B: BAZ -> X (“B advertises BAZ to X”)
  – B: BAZ -> C? (=> Y: CBAZ and Y:CAZ)

Example from Kurose and Ross, 5th Ed
Choice of Routing Algorithm

• **Constraints**
  – Scaling
  – Autonomy (policy and privacy)

• **Link-state?**
  – Requires sharing of complete information
  – Information exchange does not scale
  – Can’t express policy

• **Distance Vector?**
  – Scales and retains privacy
  – Can’t implement policy
  – Can’t avoid loops if shortest path not taken
  – Count-to-infinity
Path Vector Protocol

• **Distance vector algorithm with extra information**
  – For each route, store the complete path (ASs)
  – No extra computation, just extra storage (and traffic)

• **Advantages**
  – Can make policy choices based on set of ASs in path
  – Can easily avoid loops
BGP - High Level

• Single EGP protocol in use today
• Abstract each AS to a single node
• Destinations are CIDR prefixes
• Exchange prefix reachability with neighbors
  – E.g., “I can reach prefix 128.148.0.0/16 through ASes 44444 3356 14325 11078”
  – May choose to not advertise some paths to some neighbors

• Select a single path by routing policy

• Critical: learn many paths, propagate one
  – Add your ASN to advertised path
BGP Implications

- **Explicit AS Path == Loop free**
  - Except under churn, IGP/EGP mismatch
- **Not all ASs know all paths**
- **Reachability not guaranteed**
  - Decentralized combination of policies
- **AS abstraction -> loss of efficiency**
- **Scaling**
  - 55K ASs
  - 685K+ prefixes
  - ASs with one prefix: 21292
  - Most prefixes by one AS: 5551 (AS4538 ERX-CERNET-BKB - China Education and Research Network Center).

Source: cidr-report 17Oct2017
Why study BGP?

- **Critical protocol: makes the Internet run**
  - Only widely deployed EGP

- **Active area of problems!**
  - Efficiency
  - Cogent vs. Level3: Internet Partition
  - Spammers use prefix hijacking
  - Pakistan accidentally took down YouTube
  - Egypt disconnected for 5 days
BGP Example

Only 1 Router Per AS (for now)
BGP Example

1.2.0.0/16: AS 1

Only 1 Router Per AS (for now)
BGP Example

AS 1
1.2.0.0/16

AS 2
1.2.0.0/16: AS 2 1

AS 3

AS 4

AS 5
1.2.0.0/16: AS 5 1

Only 1 Router Per AS (for now)
BGP Example

AS 1
1.2.0.0/16

AS 2

AS 3
AS: 4 5 1

AS 4

AS 5
AS: 3 2 1

Only 1 Router
Per AS (for now)
BGP Example

AS 1
1.2.0.0/16

Only 1 Router Per AS (for now)
BGP Protocol Details

- **Separate roles of speakers and gateways**
  - Speakers talk BGP with other ASs
  - Gateways are routes that border other ASs
  - Can have more gateways than speakers
  - Speakers know how to reach gateways

- **Speakers connect over TCP on port 179**
  - Bidirectional exchange over long-lived connection
BGP Table Growth

Source: bgp.potaroo.net
BGP Table Growth for v6

Source: bgp.potaroo.net
Integrating EGP and IGP

• **Stub ASs**
  – Border router clear choice for default route
  – Inject into IGP: “any unknown route to border router”

• **Inject specific prefixes in IGP**
  – E.g., Provider injects routes to customer prefix

• **Backbone networks**
  – Too many prefixes for IGP
  – Run internal version of BGP, iBGP
  – All routers learn mappings: Prefix -> Border Router
  – Use IGP to learn: Border Router -> Next Hop
iBGP

AS 1
1.2.0.0/16

Only 1 Router
Per AS (for now)

AS 2
AS 3
AS 4
AS 5
iBGP

AS 1
1.2.0.0/16

AS 2

AS 3

AS 4

AS 5

Multiple Peering Points!

iBGP keeps AS consistent
BGP Messages

• **Base protocol has four message types**
  – **OPEN** – Initialize connection. Identifies peers and must be first message in each direction
  – **UPDATE** – Announce routing changes (most important message)
  – **NOTIFICATION** – Announce error when closing connection
  – **KEEPALIVE** – Make sure peer is alive

• **Extensions can define more message types**
  – E.g., ROUTE-REFRESH [RFC 2918]
Anatomy of an UPDATE

• Withdrawn routes: list of withdrawn IP prefixes
• Network Layer Reachability Information (NLRI)
  – List of prefixes to which path attributes apply
• Path attributes
  – ORIGIN, AS_PATH, NEXT_HOP, MULTI-EXIT-DISC, LOCAL_PREF, ATOMIC_AGGREGATE, AGGREGATOR, ...
  – Each attribute has 1-byte type, 1-byte flags, length, content
  – Can introduce new types of path attribute – e.g., AS4_PATH for 32-bit AS numbers
Example

- **NLRI**: 128.148.0.0/16
- **AS Path**: ASN 44444 3356 14325 11078
- **Next Hop IP**: same as in RIPv2
- **Knobs for traffic engineering**:  
  - Metric, weight, LocalPath, MED, Communities  
  - Lots of voodoo
BGP State

- BGP speaker conceptually maintains 3 sets of state
  - **Adj-RIB-In**
    - “Adjacent Routing Information Base, Incoming”
    - Unprocessed routes learned from other BGP speakers
  - **Loc-RIB**
    - Contains routes from Adj-RIB-In selected by policy
    - First hop of route must be reachable by IGP or static route
  - **Adj-RIB-Out**
    - Subset of Loc-RIB to be advertised to peer speakers
Demo

• Route views project: [http://www.routeviews.org](http://www.routeviews.org)
  – telnet route-views.linx.routeviews.org
  – show ip bgp 128.148.0.0/16 longer-prefixes

• All paths are learned internally (iBGP)
• Not a production device
Next class

• BGP Policy Routing and Security