Active measurements: networks

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Outline

- Organization of Internet routing
- Types of domains
- Intra- and inter-domain routing
- Intra-domain routing
- Inter-domain routing
- Organization of the Internet
A map of the Internet in 2000
Organization of Internet Routing

- More than 30,000 autonomous routing domains:
  A domain (or autonomous system, denoted AS) is a set of routers, links, hosts and local area networks under the same administrative control.

- Domains size: from one PC to millions of hosts

- Interconnections between domains are complex
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Types of domains

- **Transit:**
  A transit domain allows other domains to use its infrastructure to send packets to other domains

- Implicit hierarchy of transit domains acc. to “size”

- Examples: AT&T, UUNet, Level3, KPN, ...

- 15% of all ASes
Tier-1: UUNET (large ISP, Verizon)
Tier-2: GEANT (European, academic)
Types of domains

- **Stub:**
  
  A *stub domain does not allow other domains to use its own infrastructure to send packets to other domains*

- A stub is connected to at least one transit domain

- Content stub domains: Yahoo, Google, MSN, BBC, ...

- Access stub domains: ISPs providing Internet access via CATV, DSL, ...

- 85% of all ASs
SURFNET (Dutch, academic)
BELNET (Belgian, academic)
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Intra- and inter-domain routing

- **Interior Gateway Protocol (IGP):**
  - Routing of IP packets *inside each domain*
  - Only knows topology of its domain

- **Exterior Gateway Protocol (EGP):**
  - Routing of IP packets *between domains*
  - Each domain is considered as an atomic structure
Intra- and inter-domain routing

Inter-domain link
Intra-domain link
Advertizing a prefix

Inter-domain link
Intra-domain link

AS 5

AS 1

AS 2

AS 3

AS 4

AS 6
Traffic paths

Traffic path
Inter-domain link
Intra-domain link
Inter-domain is not shortest-paths!

AS 5

AS 1

AS 2

AS 3

AS 4

AS 6

Effect of policy

AS path
Inter-AS edge
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Intra-domain routing

- **Goal:** allow routers to transmit IP packets along the **best path** towards their destination
  - best path usually means **shortest path**
  - find alternate routes in case of failures

- **Behavior:** all routers exchange routing information
  - each router in the domain obtains routing information for the whole domain
  - the network operator or the routing protocol selects the cost of each link
Types of IGPs

- **Static routing:** only useful in very small domains
- **Distance-vector routing:**
  - Routing Information Protocol (RIP)
    - Still widely used in small domains despite its limitations
- **Link-state routing:**
  - Open Shortest Path First (OSPF): widely used in enterprise networks
  - Intermediate System – Intermediate System (IS-IS): widely used by ISPs
Distance–vector routing

- Each router sends periodically a distance vector containing, for each known prefix:
  1. the IP prefix
  2. the distance between itself and the destination
     - the distance vector is a summary of the router's routing table
- Each router receives the distance vectors of its neighbors and builds its routing table based on those vectors
Link-state routing

● Each router builds link state packets containing its local topology
  ● link state packets are created at regular intervals and when the local topology changes

● Link state packets are reliably flooded to all routers inside the domain

● Each router knows the complete domain topology by maintaining a LSP database
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Inter-domain routing

- **Goal:** allow to transmit IP packets along the best path towards their destination
  - From an interdomain viewpoint, best path often means cheapest path

- **Behavior:**
  - Each domain specifies inside its routing policy the domains for which it agrees to provide a transit service and the method it uses to select the best path to reach each destination
  - Each router of the domain chooses its best path according to the routing policies, and advertises them to its neighboring routers
Inter-domain routes redistribution

- **Between domains (eBGP):**
  - **Goal:** propagate external reachability to neighbors
  - **Implementation:** private peerings, public interconnection points

- **Inside a domain (iBGP):**
  - **Goal:** propagate the routes learned from neighbors to other routers inside the domain
  - **Implementation:** full-mesh between BGP routers, route-reflection, or confederations
Conceptual operation of a BGP router

BGP Routing Information Base
Contains all the acceptable routes learned from all Peers + internal routes

- **BGP decision process** selects _the best route_ towards each destination
Path selection in a domain
Routing policies

- BGP allows each domain to define its own routing policy
- Some policies are common:
  - customer-provider peering
  - Customer C buys Internet connectivity from provider P
  - shared-cost peering
  - Domains x and y agree to exchange packets by using a direct link or through an interconnection point
Routing policies

- Routing policies implement business relationships between domains
- The routing policy of a domain is implemented via the route filtering mechanism on BGP routers:
  - **Inbound filtering**: Upon reception of a route from a peer, a BGP router decides whether the route is acceptable, and if so whether to change some of its attributes.
  - **Outbound filtering**: Before sending a best route, a BGP router decides which peers should receive this route and whether to change some of its attributes before sending it.
Customer–provider peering

- **Customer** sends to its provider its internal routes and the routes learned from its own customers => **Provider** will advertise those routes to the entire Internet to allow anyone to reach the customer.

- **Provider** sends to its customers all known routes => **Customer** will be able to reach anyone on the Internet.
**Shared-cost peering**

- **Peer X** sends to **Peer Y** its internal routes and the routes learned from its own customers
  - **Peer Y** will use shared link to reach **Peer X** and **Peer X's** customers
  - **Peer X's** providers are not reachable via the shared link
- **Peer Y** sends to **Peer X** its internal routes and the routes learned from its own customers
  - **Peer X** will use shared link to reach **Peer Y** and **Peer Y's** customers
  - **Peer Y's** providers are not reachable via the shared link
Business relationships and BGP

• Relationships between ASs stem from their mutual interest:
  • if interest **is not balanced**, customer–provider will typically arise
  • if interest **is balanced**, peer–peer or other partial agreement will arise

• As long as business relationships remain so important, the inter-domain routing protocol does not matter so much, i.e. technical changes in BGP should not affect inter-domain routing so much
Classical iBGP

• **iBGP full-mesh:**
  • connect all routers
  • each router knows all the best routes of all other routers

• **Redistribution rules:**
  • Redistribute best route to all peers except the one from which the route was received
  • Do not redistribute a best route if it was learned from an iBGP peer (iBGP peers must have learned this route directly from the concerned peer)
Path selection in iBGP full-mesh
Route-reflection

• When ASs become large (hundred of routers), full-mesh does not scale ⇒ route-reflection
• 2 types of route-reflector peers: client and non-client [RFC2796]
• Implicit hierarchy:
  • clients are “down”
  • non-clients are either “peer” or “up”
• Redistribution rules:
  • Best route received from client or eBGP peer ⇒ redistribute to clients and non-client peers (down, peer and up)
  • Best route received from non-client peer ⇒ redistribute to clients only (down only)
• iBGP graph is generally not a forest ⇒ prevent looping of routes (cluster-ID)
Route-reflection

- eBGP peering
- Best BGP route
- Physical link
- BGP router
- Route-reflector
iBGP and loss of path diversity
iBGP: summary

- **iBGP full-mesh:**
  - Pro‘s: full visibility of external routes, small convergence time
  - Con: $N(N-1)/2$ iBGP sessions

- **Route-reflection:**
  - Pro: $\#$ iBGP sessions $\sim$ $\#$ physical links
  - Con‘s: opaqueness of best route selection, slow convergence, route oscillations

For more details:


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Internet hierarchical structure

- Tier-1 ISPs
  - About 20 large ISPs
  - Provide transit service
- Tier-2 ISPs
  - Regional or National ISPs
  - Customers of T1 ISP(s)
  - Providers of T3 ISP(s)
- Tier-3 ISPs
  - Smaller ISPs, Corporate Networks, Content providers
  - Customers of T2 or T1 ISPs