Routing

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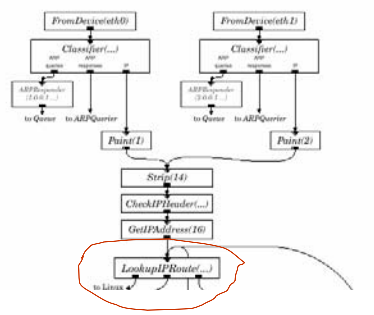
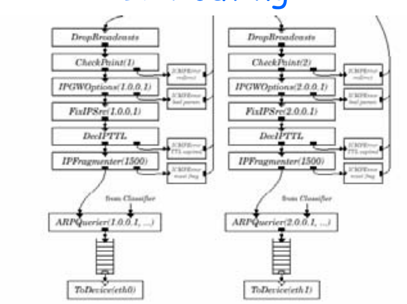
IP Routing



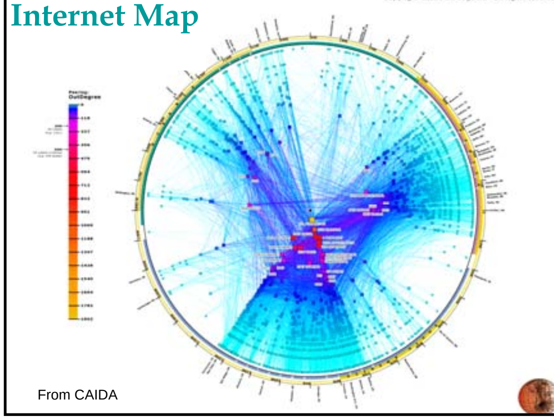
From Click

IP Routing



From Click

Internet Map



From CAIDA

IP Address Allocation

- Originally ("classful" addrs), 4 address classes
  - "A": 0 | 7 bit network | 24 bit host (1M each)
  - "B": 10 | 14 bit network | 16 bit host (64K)
  - "C": 110 | 21 bit network | 8 bit host (255)
  - "D": 1110 | 28 bit multicast group #
- Assign net # centrally, host # locally
  - IBM has class A address
  - Duke has class B address
- What is a network "prefix"?

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IP Address Issues

- We can run out
  - 4B IP addresses; 4B microprocessors in 1997
- We'll run out faster if sparsely allocated
  - Rigid structure causes internal fragmenting
  - E.g., assign a class C address to site with 2 computers
    - Waste 99% of assigned address space
- Need address aggregation to keep tables small
  - 2 million class C networks
  - Entry per network in IP forwarding tables
    - Scalability?

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Efficient IP Address Allocation

- Subnets
  - Split net addresses between multiple sites
- Supernets
  - Assign adjacent net addresses to same organization
  - Classless routing (CIDR)
    - Combine routing table entries whenever all nodes with same prefix share same hop
- Hardware support for fast prefix lookup

Physical Networks and IP Addresses

- Originally: network part of IP address identifies exactly one physical network
  - What about large campuses with many physical networks?

Subnetting

- Subnetting: introduce *subnet masks*
  - All hosts on same network already have same network #
  - Subnet mask: hosts on one network have same subnet #
  - Subnet mask: 255.255.255.128, IP: 128.96.34.15
    - This says top 25-bits identify the network
    - Class B: 16-bits for network #, 9-bits for subnet
    - Logical AND Host and mask for Subnet #
    - 128.96.34.15 AND 255.255.255.128 ➔ 128.96.34.0

Subnetting and Forwarding

- Task of forwarding changes:
  - Hosts check if on same subnet (using mask)
- Task of routers change:
  - Replace <network #, next hop> with (must send prefix):
    - <subnet #, subnet mask, next hop>
  - For each dest IP addr
    - Perform logical AND of IP addr with mask
    - Compare to subnet #
  - How to do this efficiently?

CIDR

- Classless Interdomain Routing (CIDR)
  - Balances between need for fewer entries in forwarding tables and need to efficiently distribute IP address space
- Example: site that requires 16 class-C IP addresses
  - Use 16 contiguous class C addrs, e.g., 192.4.16-192.4.31
  - Top 20 bits are identical
  - Between a class B and class C addr
    - "Classless"
- Need routing protocols to recognize CIDR

On Network Prefixes

- All these network addresses describe the same network
  - 152.3.128.0/17
  - 152.3.128.15/17
  - 152.3.128/17
  - 152.3.128.0/255.255.128.0
  - 152.3.128.75/255.255.128.0
- This network has a prefix of 17 (most significant bits in address)

Subnetting vs. Supernetting

- Subnetting attempts to share one address among multiple physical networks
- Supernetting attempts to collapse multiple addresses assigned to single Autonomous System (AS) onto one address
- CIDR essentially discards all class-based addressing
  - Use prefix notation now

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Interdomain Routing

- Two kinds of networks/domains
  - Stub
  - Transit (ISP)
- Three kinds of relationships for each hop destination:
  - Provider: transit provides service for a stub or another transit. (uphill: +1)
  - Peer: two networks exchange traffic. (sideways: 0)
  - Customer. (downhill: -1)
- Valley-free paths
  - Type 1: {+1}*{-1}*
  - Type 2: {+1}*0{-1}*

Routes

- BGP speakers know of three kinds of routes:
  - My routes (for traffic destined to me)
  - Routes learned from a provider
  - Routes learned from a peer
  - Routes learned from a customer
- Specific relationships
  - Sibling is a kind of peer (same owner, exchange all routes).
  - Backup: peer or provider that is less preferred, for use only when the primary path fails.

Export Rules

- Driven by self-interest
  - I want to get good service for my customers.
  - I want you to have good service too, but not at my expense.
- Exporting to provider or peer
  - My routes and my customer routes
  - Not routes from peers or other providers
- Exporting to a customer
  - All routes I know

Malicious Routers

- Can a router suppress paths advertised by its neighbors?
- Can a router lie about its own identity?
- Can a router synthesize a fake path to an origin?
  - Hijacking
  - Lie about neighbor advertisements
- Can a router modify the paths advertised by its neighbors?
- Can colluding routers advertise a fake path between them? Why would they do such a thing?
- What defenses do we have against these attacks?

Defenses

- Prevent routers from lying about what someone else has said to them.
- Prevent adversaries from interposing on communication between routers.
- Detect inconsistent paths and suppress paths through the likely adversary?
- How to identify the source of a problem?

Whisper

- Simple hashing can prevent an adversary from faking a shorter path to an origin than the adversary itself has.
- However, an adversary can modify advertised paths as long is it does not change their length.
- "Strong whisper" enables detection of modified paths as "inconsistent" by any other router that learns of multiple paths to the same origin.

Suppressing Bogus Paths

- Problem: whisper cannot identify the adversary, or even which route in an inconsistent pair is bogus.
- Solution: guess.
- The adversary is always present in the AS path for a bogus route.
- Its neighbors can always guarantee this property.
  - (If the neighbor fails to do this then we can consider the neighbor as an adversary.)
- Downgrade the reputation of all AS IDs on any path that is part of an inconsistent pair.
- Avoid paths through disreputable Autonomous Systems.

Listen

- Identify black holes by watching for completed TCP connections.
- Problem: may only see one direction of flow.
- Solution: if you see data after a SYN, it's probably OK.
- Problem: An adversary can fake completed connections.
- Solution: drop some packets and see if it notices.
- Problem: it can pretend to notice.
- Solution: monitor to see if it is pretending…