CSCI-1680
Network Layer:
Wrapup

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Based partly on lecture notes by Rodrigo Fonseca, Jennifer Rexford, Rob Sherwood, David Mazières, Phil Levis, John Jannotti

Administrivia

- HW2 due 9am Thursday
  - 0 late days
  - Review in class; solutions posted immediately after class
- Midterm posted after class on Thursday
  - Up to what is covered TODAY
  - Due Friday by 11:59pm
  - Take-home format, designed for ~2hrs
  - Open book, open notes, open Internet
  - No collaboration: no sharing with peers; no posting on StackOverflow, etc.

Administivia

- HTA/UTA apps due Wednesday (Mar 16) by 5pm
  - Interested, but already HTAing? Email me
- Summer work apps due Friday (Mar 18) by 11:59pm
  - Part time or full-time, in-person or remote
  - Don't need to be TA'ing in the fall to do summer work (or vice versa)

Application links on Ed—if you're interested,
please apply and we can talk further!

Warmup

Today: IP Wrap-up

- More on BGP
- IP Service models
  - Unicast, Broadcast, Anycast, Multicast
- Tunneling

BGP Recap

- Key protocol that holds Internet routing together
- Path Vector Protocol among Autonomous Systems (ASes)
- Route selection based on policy, rather than “optimal” routes
- Important security/stability problems
  - Misconfiguration
  - Prefix hijacking

What can be done?

Originally: Internet Routing Registries (IRRs): public database listing IP allocations

```
route: 10.0.0.0/8
descr: University of Blogging
descr: Anytown, USA
origin: AS65099
mnt-by: MNT-UNIVERSITY
notify: person@example.com
changed: person@example.com 20180101
source: RADB
```

But, database not verified and often incomplete/wrong

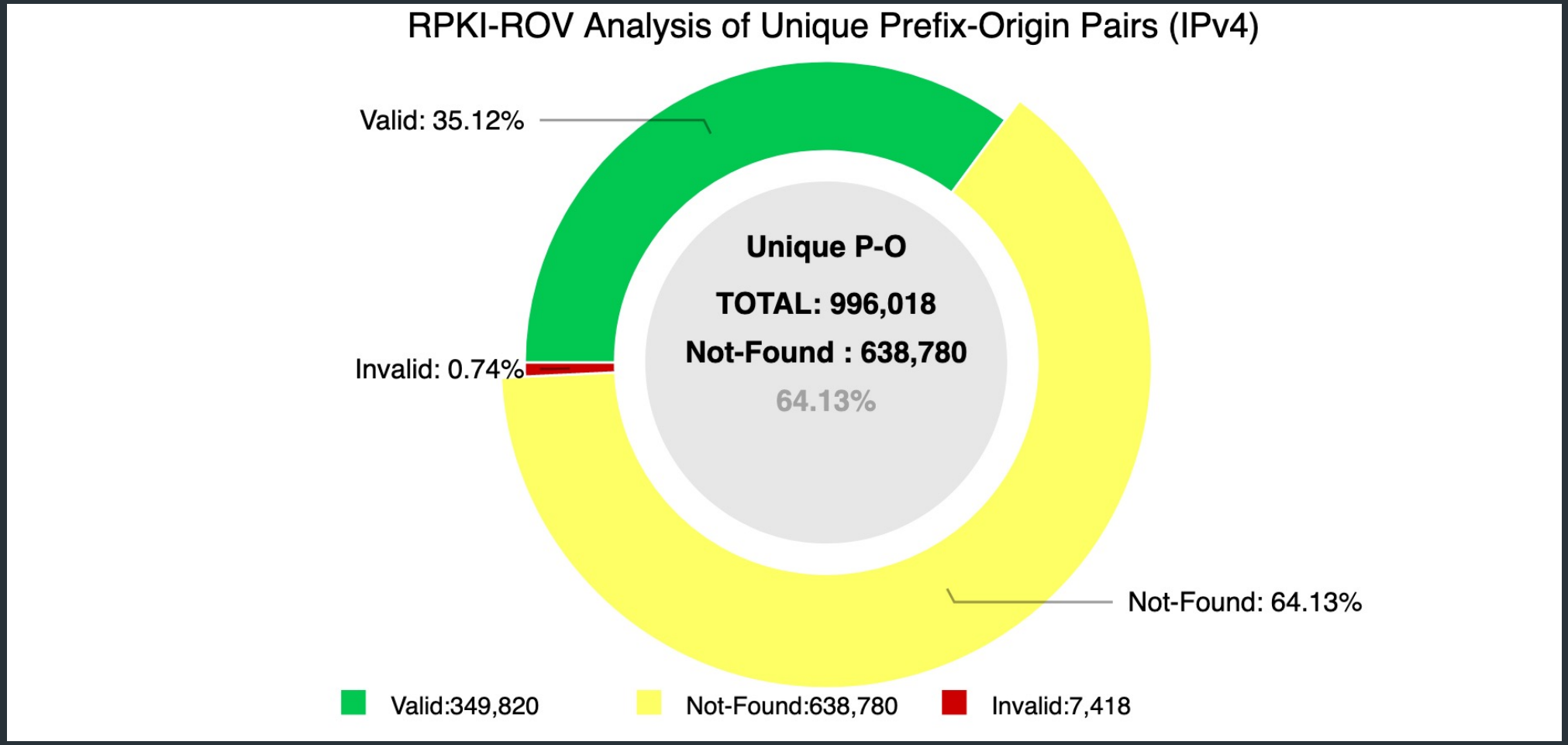
What can be done?

```
$whois -h whois.radb.net AS14325
aut-num:    AS14325
as-name:    ASN-OSHEAN
descr:      OSHEAN, Inc.
import:     from AS14325:AS-MBRS   accept PeerAS
mp-import:  from AS14325:AS-MBRS   accept PeerAS
export:     to AS-ANY   announce AS14325:AS-MBRS
mp-export:  to AS-ANY   announce AS14325:AS-MBRS
admin-c:    Tim Rue
tech-c:     Ventsislav Gotov
notify:     vgotov@oshean.org
mnt-by:     MAINT-AS14325
changed:    vgotov@oshean.org 20210512
source:     RADB
```

Proposed Solution: RPKI

- Based on a public key infrastructure
- Address attestations
  - Claims the right to originate a prefix
  - Signed and distributed out of band, checked on BGP updates
  - Checked through delegation chain from ICANN
- Can avoid
  - Prefix hijacking
  - Addition, removal, or reordering of intermediate ASes

RPKI deployment



RPKI at Brown?

FAILURE

Your ISP (Verizon, AS701) does not implement BGP safely. It should be using RPKI to protect the Internet from BGP hijacks. Tweet this →

▼ Details

```
fetch https://valid.rpki.cloudflare.com
  ✔ correctly accepted valid prefixes

fetch https://invalid.rpki.cloudflare.com
  ✘ incorrectly accepted invalid prefixes
```

Data Plane Attacks

- Routers/ASes can advertise one route, but not necessarily follow it!
- May drop packets
  - Or a fraction of packets
  - What if you just slow down some traffic?
- Can send packets in a different direction
  - Impersonation attack
  - Snooping attack
- How to detect?
  - Congestion or an attack?
  - Can let ping/traceroute packets go through
  - End-to-end checks?
- Harder to pull off, as you need control of a router

Different IP Service Models

- Unicast: send packet to one node
- Broadcast: send a packet to *all* nodes in some subnet. "One to all"
  - 255.255.255.255 : all hosts within any subnet, *never* forwarded by a router
  - Last address in a prefix (host part is all 1's): eg. 192.168.1.0/24 => Bcast: 192.168.1.255
  - Example use: DHCP

Anycast

- Multiple hosts may share the same IP address
- “One to one of many” routing
- Example uses: load balancing, nearby servers
  - DNS Root Servers (e.g. f.root-servers.net)
  - Google Public DNS (8.8.8.8)
  - IPv6 6-to-4 Gateway (192.88.99.1)

Anycast Implementation

- Anycast addresses are /32s
- At the BGP level
  - Multiple ASs can advertise the same prefixes
  - Normal BGP rules choose one route
- At the Router level
  - Router can have multiple entries for the same prefix
  - Can choose among many
- Each packet can go to a different server
  - Best for services that are fine with that (connectionless, stateless)

Multicast

- Send messages to many nodes: “one to many”
- Why?
  - Snowcast, Internet Radio, IPTV
  - Stock quote information
  - Multi-way chat / video conferencing
- What’s wrong with sending data to each recipient?
  - Link stress
  - Have to know address of all destinations

Multicast Service Model

- Receivers join a multicast group G
- Senders send packets to address G
- Network routes and delivers packets to all members of G
- Multicast addresses: class D (start 1110)

  224.x.x.x to 229.x.x.x

  - 28 bits left for group address

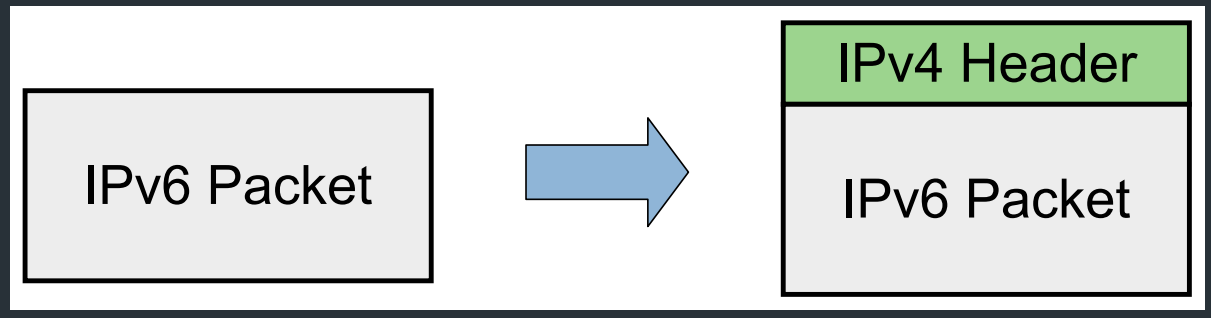
LAN Multicast

- Easy on a shared medium
- Ethernet multicast address range:
  - 01:00:5E:00:00:00 to 01:00:5E:7f:ff:ff
- Set low 23 bits of Ethernet address to low bits of IP address
  - (Small problem: 28-bit group address -> 23 bits)

How about on the Internet?

IP Tunneling

- Encapsulate an IP packet inside another IP packet
- Makes an end-to-end path look like a single IP hop



Other uses for tunneling

- Virtual Private Networks
- Use case: access CS network from the outside
  - Set up an encrypted TCP connection between your computer and Brown's OpenVPN server
  - Configure routes to Brown's internal addresses to go through this connection
- Can connect two remote sites securely

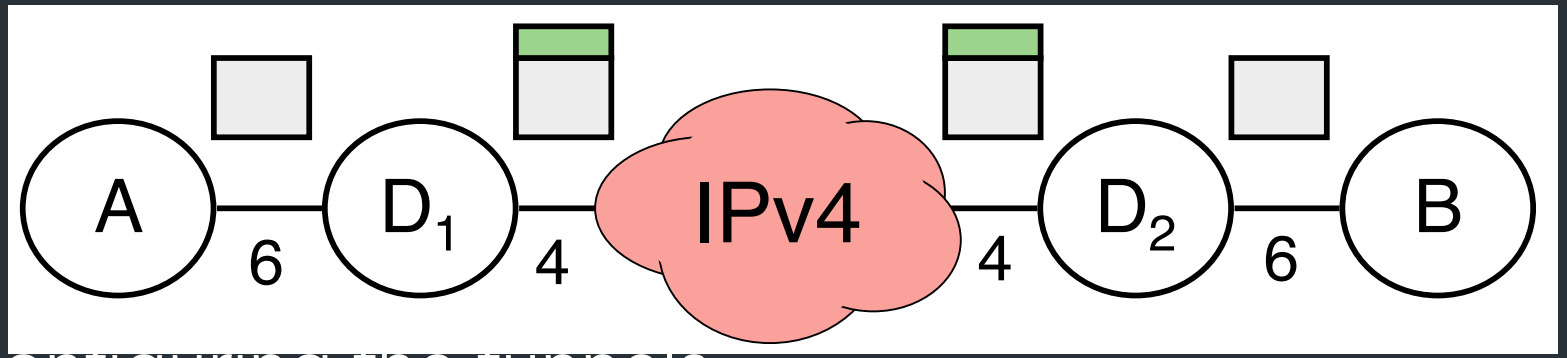
Next time: Transport Layer

- UDP, TCP, Congestion Control
- Application protocols
- …

Extension Headers

- Two types: hop-by-hop and end-to-end
- Both have a next header byte
- Last next header also denotes transport protocol
- Destination header: intended for IP endpoint
  - Fragment header
  - Routing header (loose source routing)
- Hop-by-hop headers: processed at each hop
  - Jumbogram: packet is up to 2^{32} bytes long!

IPv6 in IPv4 Tunneling



- Key issues: configuring the tunnels
  - Determining addresses
  - Determining routes
  - Deploying relays to encapsulate/forward/decapsulate
- Several proposals, not very successful
  - 6to4, Teredo, ISATAP, 6rd
  - E.g., 6to4
    - Deterministic address generation
    - Anycast 192.88.99.1 to find gateway into IPv6 network
    - Drawbacks: voluntary relays, requires public endpoint address

Example Next Header Values

- 0: Hop by hop header
- 1: ICMPv4
- 4: IPv4
- 6:TCP
- 17: UDP
- 41: IPv6
- 43: Routing Header
- 44: Fragmentation Header
- 58: ICMPv6

Fragmentation and MTU

- Fragmentation is supported only on end hosts!
- Hosts should do MTU discovery
- Routers will not fragment: just send ICMP saying packet was too big
- Minimum MTU is 1280-bytes
  - If some link layer has smaller MTU, must interpose fragmentation reassembly underneath