Internet Control Message Protocol (ICMP)
Topic

• Problem: What happens when something goes wrong during forwarding?
  • Need to be able to find the problem

What happened?  

Yikes!

XXXXXXX
Internet Control Message Protocol

• ICMP is a companion protocol to IP
  • They are implemented together
  • Sits on top of IP (IP Protocol=1)

• Provides error report and testing
  • Error is at router while forwarding
  • Also testing that hosts can use
ICMP Errors

• When router encounters an error while forwarding:
  • It sends an ICMP error report back to the IP source
  • It discards the problematic packet; host needs to rectify
ICMP Message Format (2)

- Each ICMP message has a Type, Code, and Checksum
- Often carry the start of the offending packet as payload
- Each message is carried in an IP packet
### Example ICMP Messages

<table>
<thead>
<tr>
<th>Name</th>
<th>Type / Code</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dest. Unreachable (Net or Host)</td>
<td>3 / 0 or 1</td>
<td>Lack of connectivity</td>
</tr>
<tr>
<td>Dest. Unreachable (Fragment)</td>
<td>3 / 4</td>
<td>Path MTU Discovery</td>
</tr>
<tr>
<td>Time Exceeded (Transit)</td>
<td>11 / 0</td>
<td>Traceroute</td>
</tr>
<tr>
<td>Echo Request or Reply</td>
<td>8 or 0 / 0</td>
<td>Ping</td>
</tr>
</tbody>
</table>

Testing, not a forwarding error: Host sends Echo Request, and destination responds with an Echo Reply
Traceroute

• IP header contains TTL (Time to live) field
  • Decremented every router hop, with ICMP error at zero
  • Protects against forwarding loops
Traceroute (2)

• Traceroute repurposes TTL and ICMP functionality
  • Sends probe packets increasing TTL starting from 1
  • ICMP errors identify routers on the path
Network Address Translation (NAT)
Problem: Internet Growth

• Today, Internet connects
  • 4B people
  • ~50B devices

• And we’re using 32-bit addresses!
  • ~2B unique addresses
The End of New IPv4 Addresses

- Now running on leftover blocks held by the regional registries; much tighter allocation policies

IANA (All IPs)

Exhausted on 4/11 and 9/12!

ARIN (US, Canada)
APNIC (Asia Pacific)
RIPE (Europe)
LACNIC (Latin Amer.)
AfriNIC (Africa)

ISPs
Companies

Exhausted on 2/11!

End of the world? 12/21/12?
A market for IPv4 addresses

https://auctions.ipv4.global/prior-sales
Solution 1: Network Address Translation (NAT)

- Basic idea: Map many “Private” IP addresses to one “Public” IP.
- Allocate IPs for private use (192.168.x, 10.x)

I’m a NAT box too!
Layering Review

• Remember how layering is meant to work?
  • “Routers don’t look beyond the IP header.” Well ...
Middleboxes

- Sit “inside the network” but perform “more than IP” processing on packets to add new functionality
  - NAT box, Firewall / Intrusion Detection System
Middleboxes (2)

- **Advantages**
  - A possible rapid deployment path when no other option
  - Control over many hosts (IT)

- **Disadvantages**
  - Breaking layering interferes with connectivity
    - strange side effects
  - Poor vantage point for many tasks
NAT (Network Address Translation) Box

• NAT box maps an internal IP to an external IP
  • Many internal hosts connected using few external addresses
  • Middlebox that “translates addresses”

• Motivated by IP address scarcity
  • Controversial at first, now accepted
NAT (2)

• Common scenario:
  • Home computers use “private” IP addresses
  • NAT (in AP/firewall) connects home to ISP using a single external IP address

[Diagram showing unmodified computers at home connected to ISP through a NAT box, looking like one computer outside.]
How NAT Works

• Keeps an internal/external translation table
  • Typically uses IP address + TCP port
  • This is address and port translation

<table>
<thead>
<tr>
<th>Internal IP:port</th>
<th>External IP : port</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.168.1.12 : 5523</td>
<td>44.25.80.3 : 1500</td>
</tr>
<tr>
<td>192.168.1.13 : 1234</td>
<td>44.25.80.3 : 1501</td>
</tr>
<tr>
<td>192.168.2.20 : 1234</td>
<td>44.25.80.3 : 1502</td>
</tr>
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</table>

• Need ports to make mapping 1-1 since there are fewer external IPs
How NAT Works (2)

• Internal → External:
  • Look up and rewrite Source IP/port

<table>
<thead>
<tr>
<th>Internal source</th>
<th>Internal IP:port</th>
<th>External IP : port</th>
</tr>
</thead>
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External destination
IP=X, port=Y

Src =
Dst =

Src =
Dst =

NAT box
How NAT Works (3)

• External → Internal
  • Look up and rewrite Destination IP/port

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How NAT Works (4)

- Need to enter translations in the table for it to work
- Create external name when host makes a TCP connection

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External destination IP=X, port=Y

Src = Dst =

NAT box

Src = Dst =
NAT in action

```
Ratuls-MacBook-Pro:19wi ratul$ ifconfig en0
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
    ether f0:18:98:a5:f9:cc
    inet6 fe80::440:e511:c06f:78f9%en0 prefixlen 64 secured scopeid 0xa
    inet 192.168.88.14 netmask 0xffffff00 broadcast 192.168.88.255
    nd6 options=201<PERFORMNU,DAD>
    media: autoselect
    status: active
```

[whatismyipaddress search results]

66.171.178.94
Your public IP address
NAT Downsides

• Connectivity has been broken!
  • Can only send incoming packets after an outgoing connection is set up
  • Difficult to run servers or peer-to-peer apps (Skype)
• Doesn’t work if return traffic by passes the NAT
• Breaks apps that expose their IP addresses (FTP)
NAT Upsides

• Relieves much IP address pressure
  • Many home hosts behind NATs
• Easy to deploy
  • Rapidly, and by you alone
• Useful functionality
  • Firewall, helps with privacy
• Kinks will get worked out eventually
  • “NAT Traversal” for incoming traffic
IPv6
IP Version 6 to the Rescue

• Effort started by the IETF in 1994
  • Much larger addresses (128 bits)
  • Many sundry improvements

• Became an IETF standard in 1998
  • Nothing much happened for a decade
  • Hampered by deployment issues, and a lack of adoption incentives
  • Big push ~2011 as exhaustion looms
IPv6

• Features large addresses
  • 128 bits, most of header

• New notation
  • 8 groups of 4 hex digits (16 bits)
  • Omit leading zeros, groups of zeros

Ex: 2001:0db8:0000:0000:0000:ff00:0042:8329
→ 2001:db8::ff00:42:8329
IPv6 (2)

• Lots of other changes
  • Only public addresses
    • No more NAT!
  • Streamlined header processing
    • No checksum (why’s that faster?)
  • Flow label to group of packets
  • IPSec by default
• Better fit with “advanced” features (mobility, multicasting, security)
IPv6 Stateless Autoconfiguration (SLAAC)

- Replaces DHCP (sorta...)
- Uses ICMPv6
- Process:
  - Send broadcast message
  - Get prefix from router
  - Attach MAC to router Prefix
IPv6 Transition

• The Big Problem:
  • How to deploy IPv6?
  • Fundamentally incompatible with IPv4

• Dozens of approaches proposed
  • Dual stack (speak IPv4 and IPv6)
  • Translators (convert packets)
  • Tunnels (carry IPv6 over IPv4)
Tunneling

- Native IPv6 islands connected via IPv4
- Tunnel carries IPv6 packets across IPv4 network
Tunneling (2)

• Tunnel acts as a single link across IPv4 network
Tunneling (3)

- Tunnel acts as a single link across IPv4 network
- Difficulty is to set up tunnel endpoints and routing