Middleboxes

EE 122: Intro to Communication Networks
Fall 2006 (MW 4-5:30 in Donner 155)

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Goals of Today’s Lecture

• QoS as leading to questions of network neutrality
• Elements of control: Middleboxes
  – Network address translators (NATs)
  – Firewalls
  – Tunneling
  – Application gateways
• Middleboxes introduce new problems while solving existing ones
  – Erosion of end-to-end semantics
  – Connections become more brittle
  – New apps harder to deploy (impairs innovation)

Discussion: Limited QoS Deployment

• A lot of mechanism developed for reliable performance
  – Scheduling algorithms (fair queuing, max-min fairness)
  – Traffic descriptions (token bucket)
  – Resource reservations & admission control
  – Intserv for fine-grained QoS
  – Diffserv for aggregate QoS
• But to date it has not proven viable end-to-end
  – Issue #1: complexity of payment
  – Issue #2: the alternative of overprovisioning

Exploiting Lack of End-to-End QoS

• Suppose an ISP offers their own Internet service
  – E.g., Portal (ala’ Yahoo), search engine (ala’ Google)
• Then it’s in their interest that performance to
  Yahoo or Google is inferior
  – So customers prefer to use their value-added services
• ISP can
  – recognize traffic to competitor and demote it
  – charge competitor if they want well-provision paths
  – just not put effort/$ into high-capacity interconnects w/
    other ISPs; congestion provides traffic demotion directly
• Works particularly well for large providers w/ lots of
  valuable content

Network Neutrality

• Network neutrality = notion that ISPs supply non-discriminatory IP connectivity
• Opposite counterpoint: a Walled Garden
  – Provider only allows you to access their (often
    value-added) services
  – E.g., AOL’s captive Web portal/email/IM
• Highly contentious; potential legal fray
  – E.g., ISPs blocking Voice-over-IP (VOIP)
    – As does China, Panama, Costa Rica
  – E.g., ISPs blocking 25/tcp (SMTP) to curb spammers

Announcements

• Reminder, phase 1 of Project #3 due this
tomorrow evening with no slip days
• Section this Friday and next Tues/Weds will
discuss phase 2 of Project #3
• No lecture next Weds, Nov 22
• My office hours Weds Nov 22 are by request:
i.e., send email in advance (don’t be shy!)
Network Neutrality, con’t

• Is Internet access something that ISPs provide as “common carriers”?
  – Transporting goods as service to common public
• Or: will free market forces serve to shape ISP favoritism efficiently?
  – Is there a danger of monopolies emerging?
• Many QoS-sensitive apps can be written in an adaptive style to deal with uncertainties
• But what about stricter apps?
  – Standard example: telesurgery

Network-Layer Principles

• Globally unique identifiers
  – Each node has a unique, fixed IP address
  – … reachable from everyone and everywhere
• Simple packet forwarding
  – Network nodes simply forward packets
  – … rather than modifying or filtering them

Internet Reality

• Host mobility
  – Changes in IP addresses as hosts move
• IP address depletion
  – Dynamic assignment of IP addresses
  – Use of private addresses
• Security/policy concerns
  – Discarding suspicious or unwanted packets
  – Monitoring activity
• Performance concerns
  – Controlling how link bandwidth is allocated
  – Storing popular content near the clients
  – Network neutrality, or lack thereof

Middleboxes

• Middleboxes are intermediaries
  – Interposed in-between the communicating hosts
  – Often without knowledge of one or both parties
    • “hidden”
• Examples
  + Network address translators (NATs)
  + Firewalls
  – Traffic shapers / performance boosters
  – Intrusion detection/prevention systems
  – Transparent Web proxy caches
  – Sign-on “capture” pages

Two Views of Middleboxes

• An abomination
  – Violation of layering
  – Cause confusion in reasoning about the network
  – Responsible for many subtle bugs
• A necessity
  – Solving real and pressing problems
  – Needs that are not likely to go away

Network Address Translation (NAT)
Motivation Behind NATs

- IP address space depletion
  - Clear in early 90s that $2^{32}$ addresses not enough
  - Work began on a successor to IPv4
- In the meantime...
  - Share addresses among numerous devices
  - ... without requiring changes to existing hosts
- Meant to provide temporary relief
  - But ease-of-deployment often wins long-term
  - Now, NATs very widely deployed
  - ... much more so than IPv6

Active Component in the Data Path

IP Header Translators

- Local network addresses not globally unique
  - E.g., private IP addresses (in 10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16; see RFC 1918)
- NAT box rewrites IP addresses
  - Make the “inside” look like a single IP address
  - ... and change header checksums accordingly
- Outbound traffic: from inside to outside
  - Rewrite the source IP address
- Inbound traffic: from outside to inside
  - Rewrite the destination IP address

Using a Single Source Address

What if Both Hosts Contact Same Site?

- Suppose hosts contact the same destination
  - E.g., both hosts open a socket with local port 3345 to destination 128.119.40.186 on port 80
- NAT gives packets same source address
  - All packets have source address 138.76.29.7
- Problems
  - Can destination differentiate between senders?
  - Can return traffic get back to the correct hosts?
- How can we fix this?

Port-Translating NAT

- Map outgoing packets
  - Replace source address with NAT address
  - Replace source port number with a new port number
  - Remote hosts respond using (NAT address, new port #)
- Maintain a translation table
  - Store map of (source address, port #) ⇔ (NAT address, new port #)
- Map incoming packets
  - Consult the translation table
  - Map the destination address and port number
  - Local host receives the incoming packet
Network Address Translation Example

1. Host 10.0.0.1 sends datagram to 128.119.40.186, 80
2. NAT router changes destination source addr from 10.0.0.1, 3345 to 138.76.29.7, 5001
3. NAT router changes datagram destination address from 138.76.29.7, 5001 to 10.0.0.1, 3345
4. Host 10.0.0.1 sends datagram to 128.119.40.186, 80

Maintaining the Mapping Table

- Create entry upon seeing outbound packet
  - Packet with new (source addr, source port) pair
- Eventually, need to delete the map entry
  - But when to remove the binding?
- If no packets arrive within a time window
  - Then delete the mapping to free up the port #s
- Yet another example of “soft state”
  - i.e., removing state if not refreshed for a while
- Makes Internet connectivity more brittle

The Problem is Broader

- Do IP addresses only appear in IP headers?
- Also appear in application payloads to facilitate rendezvous (subsequent conn’s)
  - E.g., http://141.16.9.1/good_stuff.html
  - E.g., PORT 141,16,9,1,4,21 (FTP)
- NAT needs to fix these up too
  - Otherwise the application breaks
- How hard is that?

Modifying Addresses Gets Messy

- Problem #1: what if replacement has different number of bytes than original?
  - Okay, we must adjust TCP sequence numbers
  - And: rewrite ACKs
- Problem #2: what if revised packet > MTU?
  - Um, send multiple pkts (or allow fragmentation)
- Problem #3: what if we don’t know where in the payload the app embeds addresses?
  - Oops: the app won’t work through the NAT
- NATs make it harder to deploy new apps

Servers Behind a NAT

- NATs undermine using port #s to address processes
- NAT needs binding in advance for incoming SYNs
- 10.0.0.1
  - Requests to 138.76.29.7 on port 80
- 138.76.29.7

Objections Against NAT

- Difficult to support peer-to-peer applications
  - P2P needs a host to act as a server
- Layering violation (hence messiness)
- NAT violates the end-to-end principle
  - Network nodes should not modify the packets
- Connections become brittle
- Barrier to deployment of new apps
- IPv6 is a cleaner solution
  - Better to migrate than to limp along with a hack
Where is NAT Implemented?

- Home router (e.g., Linksys box)
  - Integrates router, DHCP server, NAT, etc.
  - Use single IP address from the service provider
  - ... and have a bunch of hosts hiding behind it
- Campus or corporate network
  - NAT at the connection to the Internet
  - Share a collection of public IP addresses
  - Avoid complexity of renumbering end hosts and local routers when changing service providers

5 Minute Break

Questions Before We Proceed?

Firewalls

- Isolates organization’s internal net from Internet
- Allows some packets to pass, blocks others
  - (Refinement: shape some traffic, allow other unimpeded)
- Twin goals: security and policy enforcement

Packet Filtering

- Firewall filters packet-by-packet, based on:
  - Source IP address, destination IP address
  - TCP/UDP source and destination port numbers
  - ICMP message type
  - TCP SYN and ACK bits
- Simpler versions are stateless
  - But increasingly they need to be stateful

Packet Filtering Examples

- Block all packets with IP protocol field = 17 or with either source or dest port = 22.
  - All incoming and outgoing UDP flows blocked
  - All SSH connections blocked
- Block inbound TCP with SYN but no ACK
  - Prevents external clients from initiating TCP connections to internal hosts
  - But allows internal clients to connect to outside
- Block all packets with TCP port of Doom3
  - (Oops, let’s hope no other app uses that port)
- Block all packets with “reserved” bits set
  - Oops - there goes ECN deployment
Firewall Configuration

- Firewall applies a set of rules to each packet
  - To decide whether to permit or deny the packet
- Each rule is a test on a packet’s header fields
  - Test yields permit or deny
- Order matters: first matched rule wins
- E.g.: Alice runs a network in 222.33.0.0/16
  - Wants to let Bob’s site access certain hosts
    - Bob is on 111.55.0.0/16
    - Alice’s special hosts on 222.33.44.0/24
  - Alice doesn’t trust Trudy, inside Bob’s network
    - Trudy is on 111.55.66.0/24
  - Alice doesn’t want any other traffic from the Internet

Firewall Configuration, con’t

- Alice’s firewall rules
  - #1: Don’t let Trudy machines in
    - Deny <src = 111.55.66.0/24, dst = 222.33.0.0/16>
  - #2: Let rest of Bob’s network in to special dsts
    - Permit <src=111.55.0.0/16, dst = 222.33.44.0/24>
  - #3: Block the rest of the world
    - Deny <src = 0.0.0.0/0, dst = 0.0.0.0/0>

- It’s easy to introduce subtle errors …
  - And production firewalls can have 1000s of rules

Subverting Firewalls

- How can we fool a firewall?
- Method #1: abuse its statelessness
  - Consider the rule of “no SYNs w/o ACKs” as a way to prevent connections initiated inbound
  - How can we mislead a firewall about setting of TCP flag bits?

Checking TCP Header for Initial SYN

<table>
<thead>
<tr>
<th>Source port</th>
<th>Destination port</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence number</td>
<td></td>
</tr>
<tr>
<td>Acknowledgment</td>
<td></td>
</tr>
<tr>
<td>HdrLen</td>
<td>SYN</td>
</tr>
<tr>
<td>Checksum</td>
<td>Urgent pointer</td>
</tr>
<tr>
<td>Options (variable)</td>
<td></td>
</tr>
<tr>
<td>Data</td>
<td></td>
</tr>
</tbody>
</table>

Firewall will check here, 14 bytes into transport header just after IP header

Misleading Stateless Inspection

Split into two fragments. First is just 8 bytes of IP payload, i.e., here

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Second fragment starts 8 bytes later covering all of this

Firewall looks 14 bytes into payload, i.e., here, which is under the control of the attacker
Subverting Firewalls, con’t

• How might a firewall defend against this?
  – Defense #1: reassemble fragments
    • But this costs state
  – Defense #2: deny small initial fragments
    • But: legit traffic has these, hence collateral damage

• Subversion Method #2: abuse ports
  – Who says that e.g. port 22/tcp = SSH?
    • Why couldn’t it be say Skype or BitTorrent?
    • Just requires that client & server agree on app proto

Hiding on Other Ports

• Method #1: use port allocated to another service (how can this be detected?)
• Method #2: tunneling
  – Encapsulate one protocol inside another
  – Receiver of “outer” protocol decapsulates interior tunneled protocol to recover it
  – Pretty much any protocol can be tunneled over another (with enough effort)
• E.g., tunneling IP over SMTP
  – Just need a way to code an IP datagram as an email message (either mail body or just headers)

Example: Tunneling IP over Email

From: doesnt-matter@bogus.com
To: my-buddy@tunnel-decapsulators.R.us
Subject: Here’s my IP datagram
IP-header-version: 4
IP-header-len: 5
IP-ID: 11234
IP-src: 1.2.3.4
IP-dst: 5.6.7.8
IP-payload: 0xa144bf2c0102...

Program receives this legal email and builds an IP packet corresponding to description in email body …
… injects it into the network
How can a firewall detect this??

Tunneling, con’t

• E.g., IP-over-ICMP:
  – Encode an IP datagram as the payload of a “ping” packet
• E.g., Skype-over-HTTP:
  – Encode Skype message in URL of requests or header fields (or cookies) of replies
• Note #1: to tunnel, the sender and receiver must both cooperate
• Note #2: tunneling has many legitimate uses too
  – E.g., overlay networks that forward packets along paths different from what direct routing would pick
  – E.g., Virtual Private Networks (VPNs)
    • Make a remote machine look like it’s local to its home network
    • Tunnel encrypts traffic too for privacy

Application Gateways

• Middlebox can insert itself between client and server
  – Client deals with middlebox (application gateway), not server
  – Server deals with middlebox, not client
  – Can be done explicitly or transparently
• Example: Web proxy
• Example: SSH gateway
  – Require all SSH in/out of site to go through gateway
  – Gateway logs authentication, inspects decrypted text
  – Site’s firewall configured to prohibit any other SSH access

SSH Gateway Example
Conclusions

• Middleboxes address important problems
  – Using fewer IP addresses
  – Blocking unwanted traffic
  – Monitoring activity
  – Shaping use of network resources
  – Improving/controlling performance (vs. network neutrality)

• Middleboxes cause problems of their own
  – Connectivity erodes
    • Notion of addresses, ports weakened
    • Middlebox state management can lead to connection termination
  – Harder to deploy new apps

• Next lecture
  – Security mechanisms, attacks & defenses