CSE 127: Intro to Computer Security

WI24

Lecture 12 - Network Defenses

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Announcements

HW/PA 3 Due 2/21

HW/PA5 Released Thursday

HW/PA4 (Getting fixed)

91% (5 people to blame)

Reminder: Review scribe notes and do course readings

Which attack happens where an attacker has sufficient access to observe and inject traffic which through timing/bandwidth is consumed by the victim before the legitimate reply arrives but cannot block packets?

A. Man on the side
B. Man in the middle
C. Physical access
D. Off-path
E. None of the above

Which attack happens when there is a third party that's monitoring and controlling a conversation between two parties, with the latter completely unaware of the situation?

A. SQL Injection
B. Man in the middle
C. Physical access
D. Off-path
E. None of the above

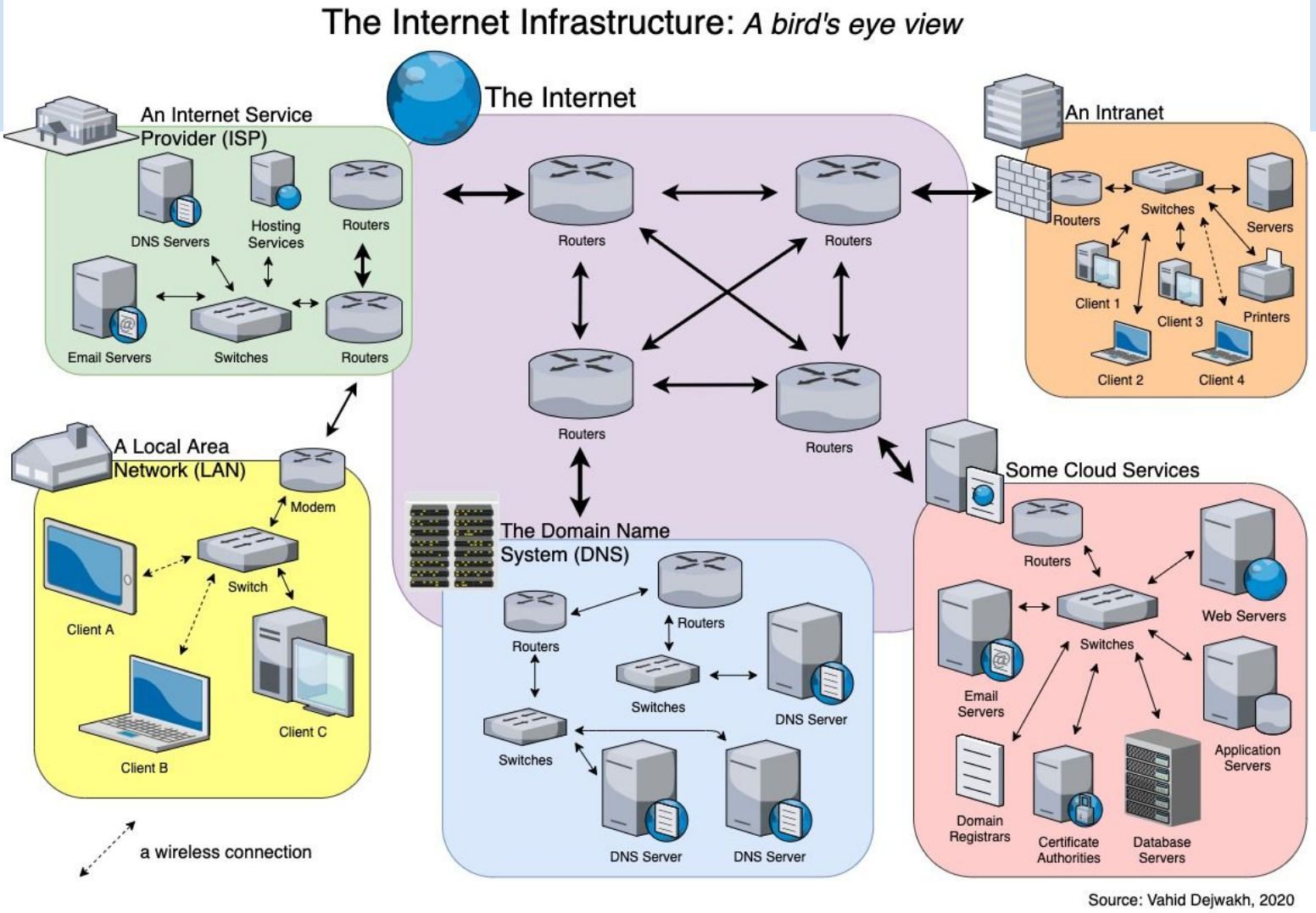
Which type of attack happens where a malicious actor sends falsified ARP (Address Resolution Protocol) messages over a local area network. This results in the linking of an attacker's MAC address with the IP address of a legitimate computer or server on the network.

A. ARP Spoofing
B. DNS Spoofing
C. DHCP Spoofing
D. BGP Hijacking
E. None of the above

Which attack affects most ISPs and happens when attackers maliciously reroute Internet traffic.

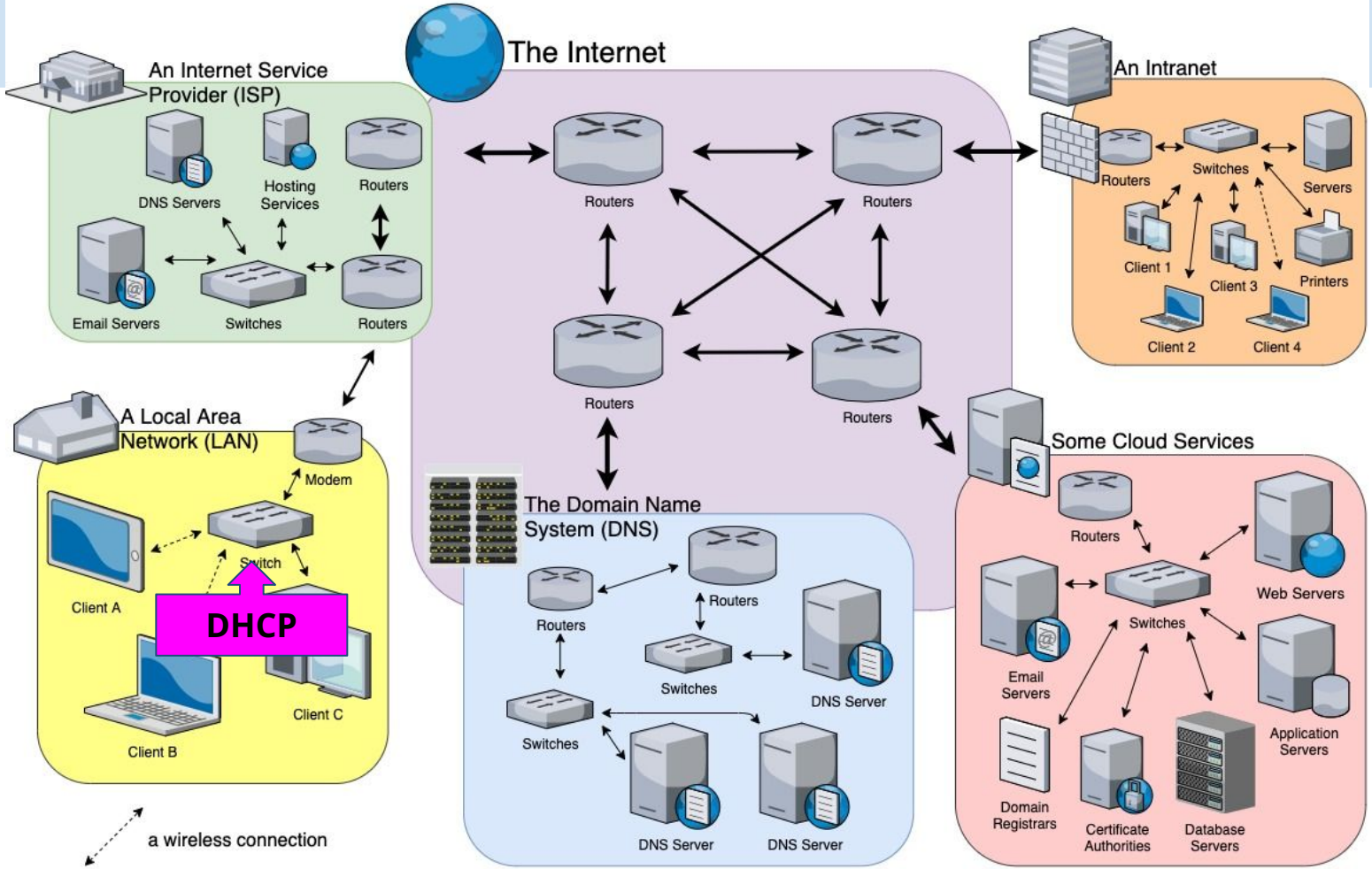
A. ARP Spoofing
B. DNS Spoofing
C. DHCP Spoofing
D. BGP Hijacking
E. None of the above

Recall



Source: Vahid Dejwakh, 2020

The Internet Infrastructure: *A bird's eye view*



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Defending Networks

- How do you harden a set of systems against external attack?
  - The more network services your machines run, the greater the risk (i.e., the attack surface is larger)
- One approach: Turn off unnecessary network services on each system
- Why is this hard?

Defending Networks

- How do you harden a set of systems against external attack?
  - The more network services your machines run, the greater the risk (i.e., the attack surface is larger)
- One approach: Turn off unnecessary network services on each system
- Why is this hard?
  - Requires knowing all the services that are running
  - What if you have hundreds or thousands of systems?
  - Systems may have different OSes, hardware, and users

Network Perimeter Defense

- Idea: Network defenses on “outside” of organization (e.g. between org and Internet)
  - Assumption?

- Typical elements:
  - Firewalls
  - Network Address Translation
  - Application Proxies (e.g., Web Application Firewalls)
  - Network Intrusion Detection Systems (NIDS)

Firewalls

- Problem: Protecting or isolating one part of the network from other parts
  - Typically: Protect your network from global Internet
  - Sometimes: Protect Internet from infected machines in your network
- Need to filter or otherwise limit network traffic

- Questions:
  - What information do you use to filter?
  - Where do you do the filtering?

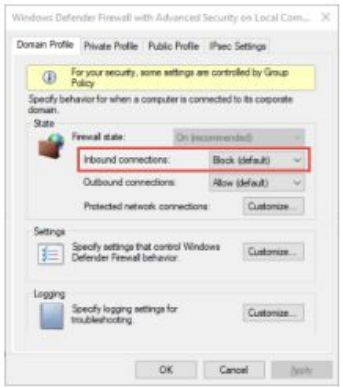
Kinds of Firewalls

- Single packet may not contain sufficient data to make access control decision
  - Stateful: allows historical context consideration
  - Firewall collects data over time
    - e.g.,TCP packet is part of established session
- Firewalls can affect network traffic
  - Transparent: appear as a single router (network)
  - Proxy: receives, interprets, and reinitiates communication (application)
  - Transparent good for speed (routers), proxies good for complex state (applications)

Kinds of Firewalls

- Personal firewalls
  - Run on end-hosts
  - Has application/user-specific information

- Network firewalls
  - Intercept communications from many hosts



Network firewalls

Kinds of Firewalls

- Personal firewalls
  - Run on end-hosts
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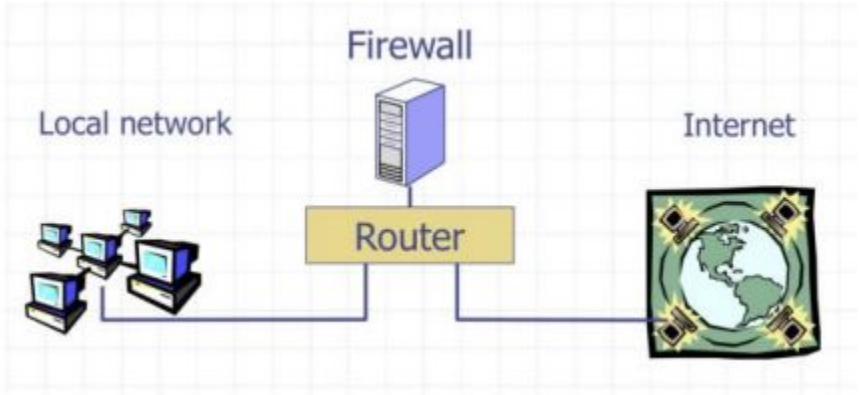
- Network firewalls
  - Intercept communications from many hosts
- Filter-based
  - Operates by filtering on packet headers
- Proxy-based
  - Operates at the level of the application
  - e.g. HTTP web proxy

Network Firewalls



- Filters protect against “bad” communications.
- Protect services offered internally from outside access.
- Provide outside services to hosts located inside.

Access Control Policies

- A firewall enforces an access control policy
  - Who is talking to whom and accessing what service?

- Distinguish between inbound and outbound connections
  - Inbound: Attempts by external users to connect to services on internal machines
  - Outbound: Internal users to external services

Access Control Policies

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  - Who is talking to whom and accessing what service?
- Distinguish between inbound and outbound connections
  - Inbound: Attempts by external users to connect to services on internal machines
  - Outbound: Internal users to external services
- Conceptually simple access control policy:
  - Permit users inside to connect to any service
  - External users are restricted
    - Allow connections to services meant to be external
    - Deny connections to services not meant to be external

Access Control Policies

How to treat traffic not mentioned in policy?

Default allow

- Permit all services, shut off for specific problems

Default deny

- Permit only a few well-known services

Access Control Policies

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In general, default deny is safer. Why?

- Conservative design
- Flaws in default deny get noticed more quickly

Example Firewall Policy

- Configure: Only allow SSH.

  # ufw default deny
  # ufw allow from 100.64.0.0/24
  # ufw allow ssh

- Status: Only allow SSH.

  # ufw status
  Status: active

To	Action	From
22	ALLOW	Anywhere
Anywhere	ALLOW	100.64.0.0/24
22 (v6)	ALLOW	Anywhere (v6)

Question

What port is typically used for ssh?

A.80
B. 53
C. 22
D. 43
E. 200

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Uncomplicated Firewall, is a simplified firewall management interface that hides the complexity of lower-level packet filtering technologies such as iptables and nftables

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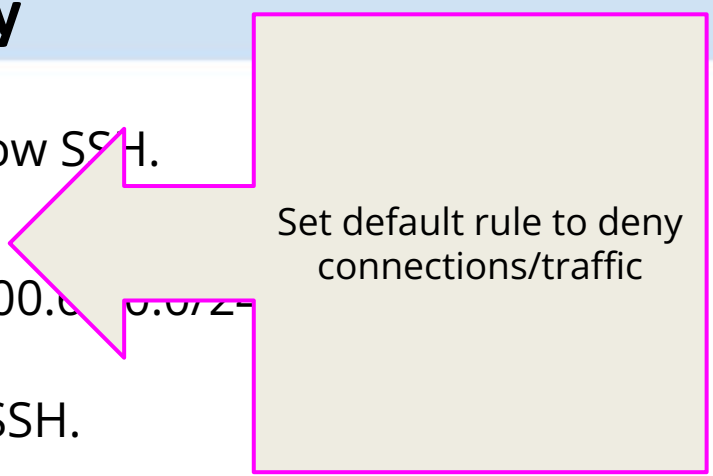

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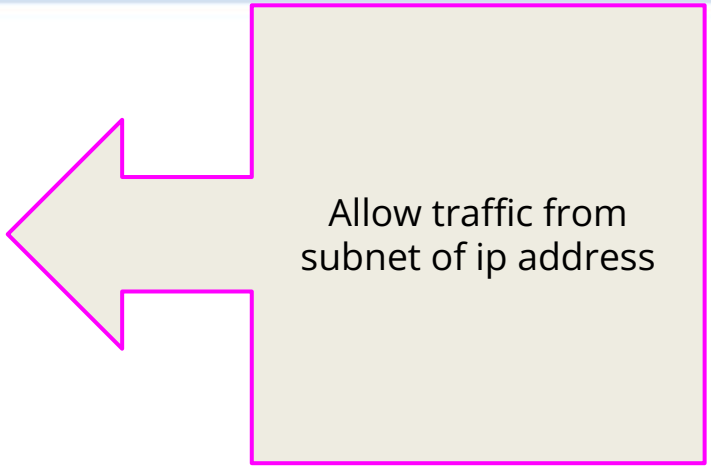

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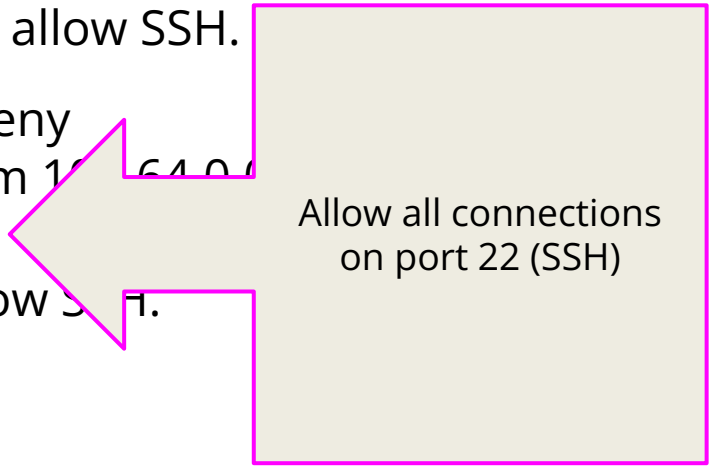

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Allow traffic on 22 from Anywhere with IPv6

Question

Based on the firewall policy, someone with the ip address will be able to access thebsystem on port 54

Packet Filtering Firewalls

- Define list of access-control rules
- Check every packet against rules and forward or drop
- Packet-filtering firewalls can take advantage of the following information from network and transport layer headers:
  - Source IP
  - Destination IP
  - Source Port
  - Destination Port
  - Flags (e.g. ACK)

Example packet filtering rules

- Block incoming DNS (port 53) except known trusted servers
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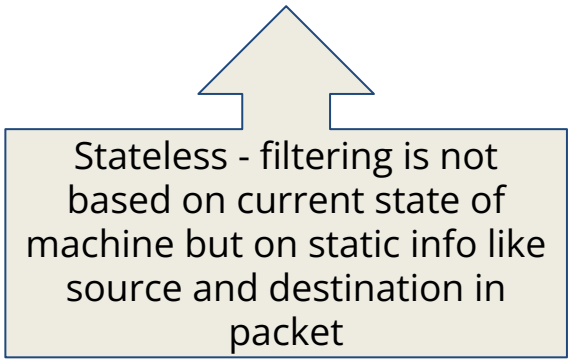

Example packet filtering rules

- Block incoming DNS (port 53) except known trusted servers
- Block incoming HTTPS (port 443) except to company IP addresses
- Block outgoing packets with forged internal addresses

Limitations of stateless filtering:

- Can’t distinguish packets associated with a connection from those that are not.

Some firewalls keep state about open TCP connections.

- Allows conditional filtering rules of the form “if internal machine has established the TCP connection, permit inbound reply packets”.

Circumventing simple firewall rules

Idea 1: Send traffic on a port usually allocated for another service.

Circumventing simple firewall rules

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Idea 2: Tunneling

- Encapsulate one protocol inside another
- Recipient of outer protocol decapsulates to recover inner protocol
- Examples:
  - iodine IP over DNS
  - ssh tunnel
  - VPN (Virtual Private Network)

Circumventing simple firewall rules

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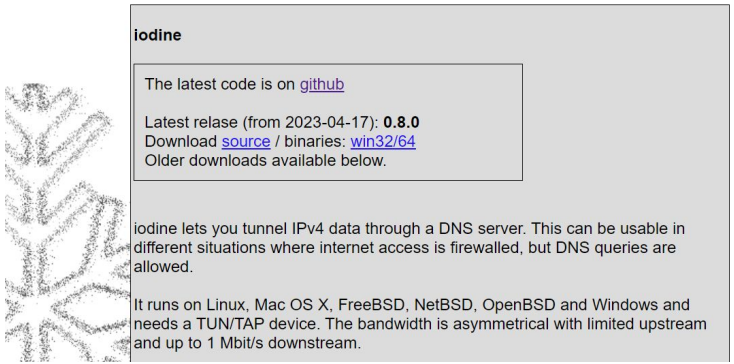

over DNS

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ual Private Network)

Stateful Packet Filtering Example

Suppose you want to allow inbound connections to a server, but block any attempts to log in as “root”.

- How would you do this?
- What state do you need to keep?

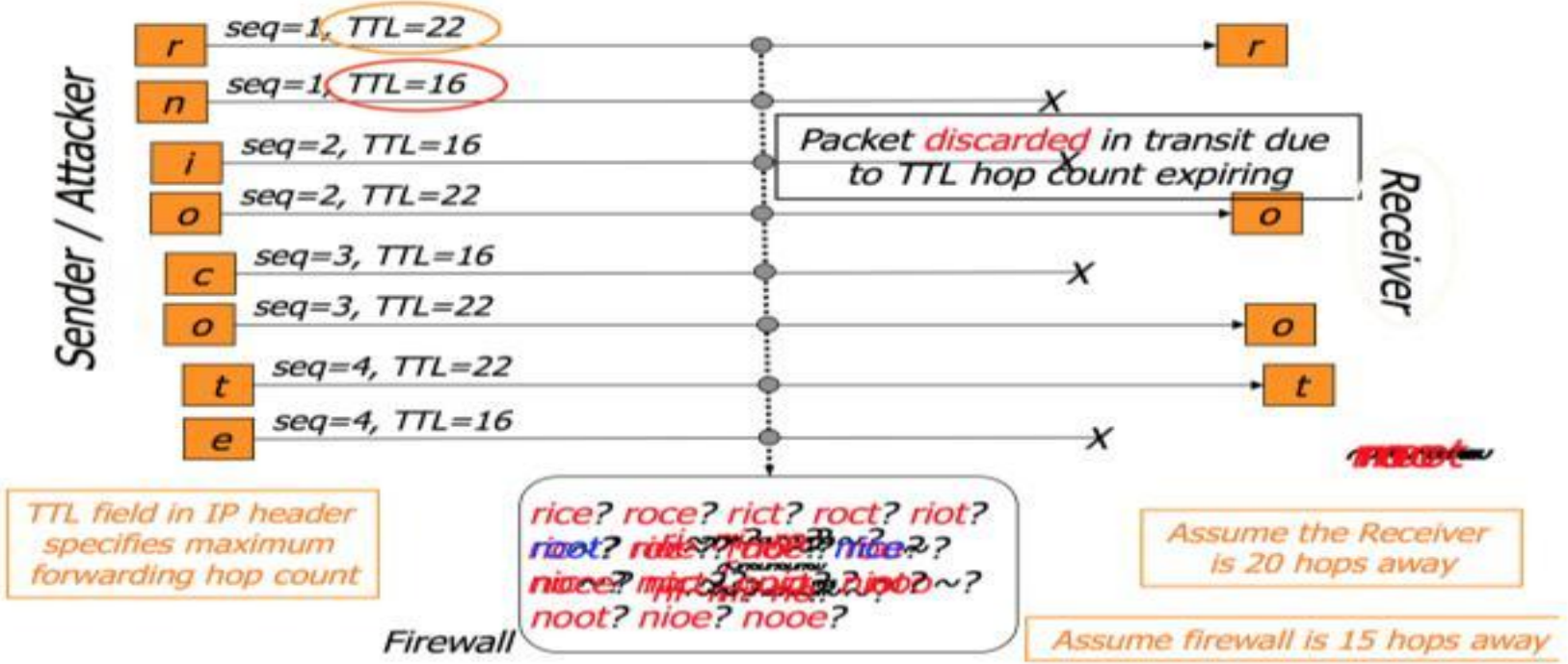
Stateful Packet Filtering is Hard

- Sender might try to sneak through firewall
- “root” might span packet boundaries

- Packets might be reordered

Stateful Packet Filtering is Hard

- TTL evasion: send more packets than will make it to host



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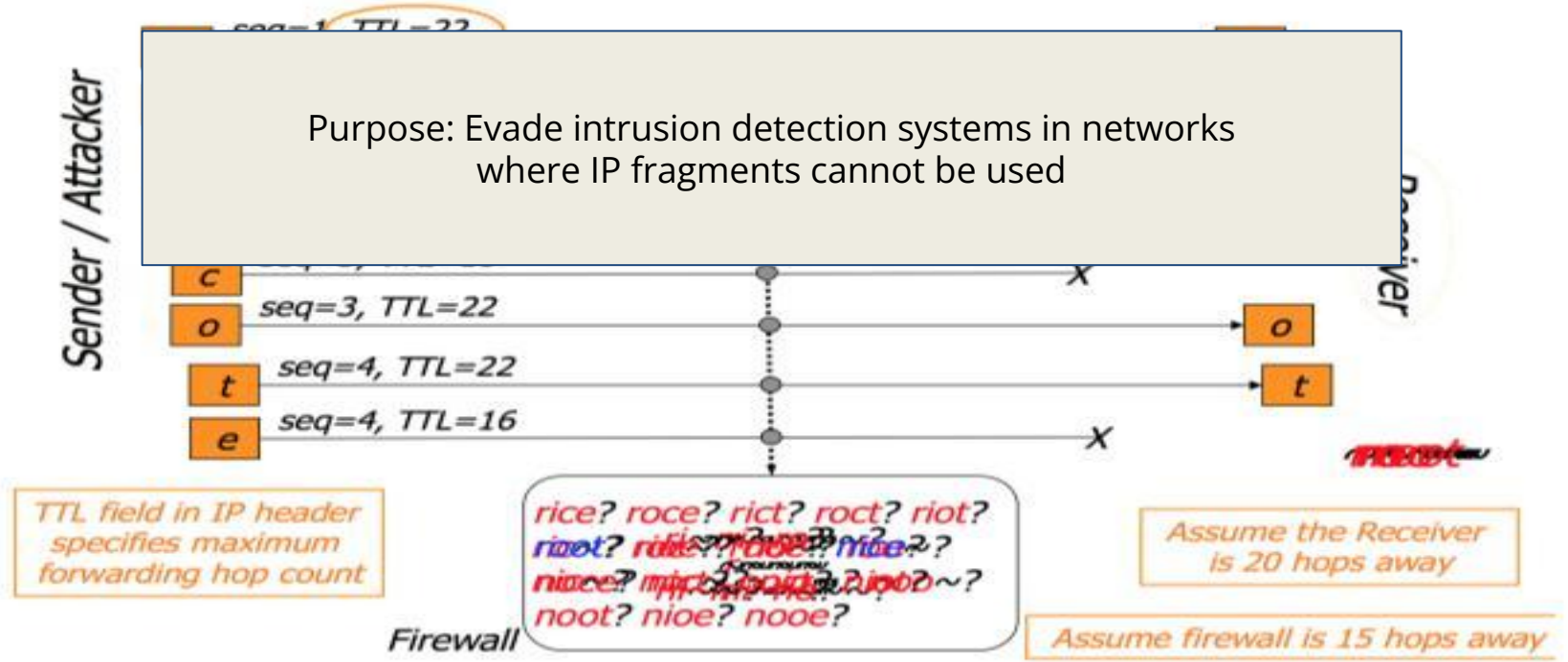

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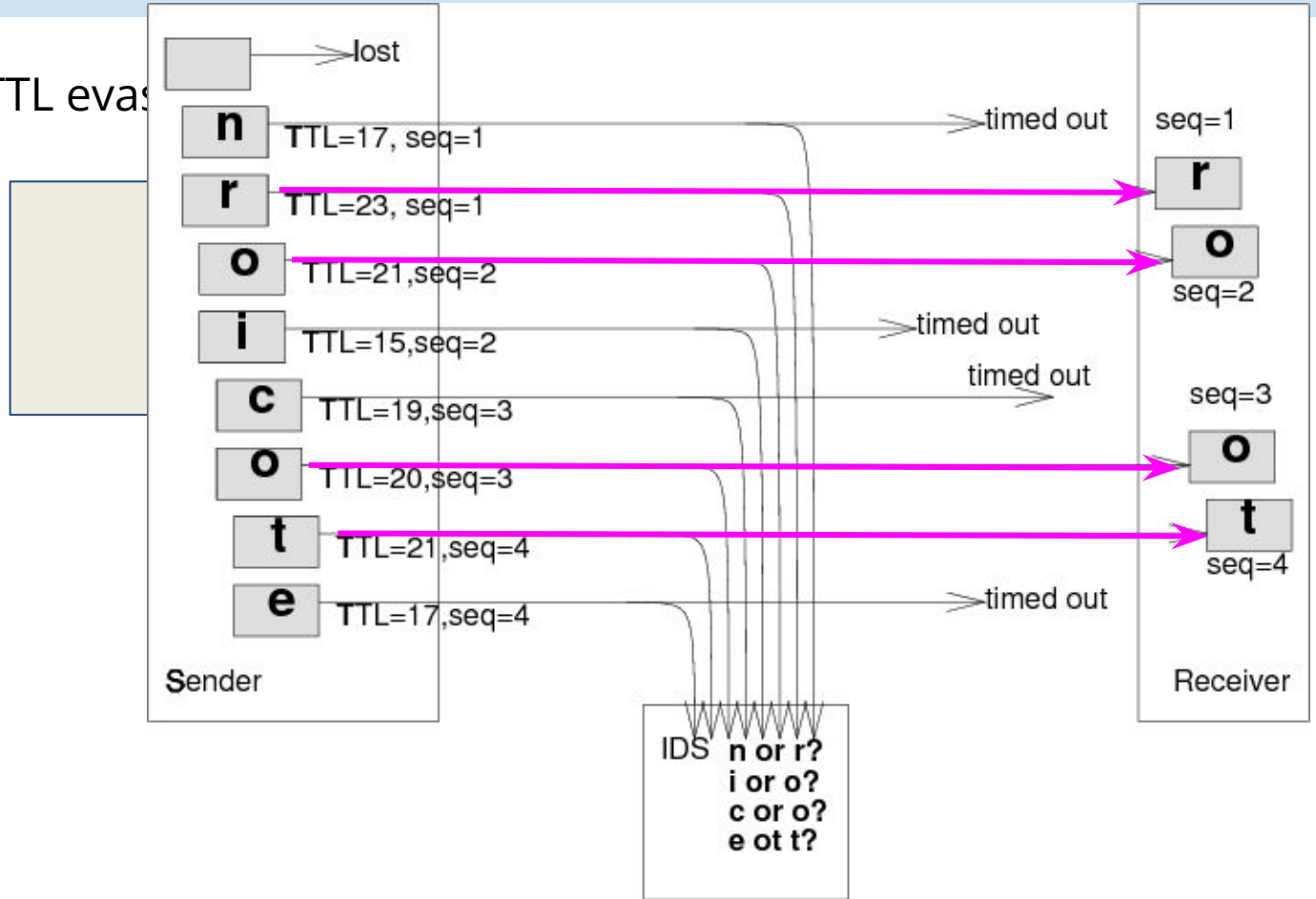
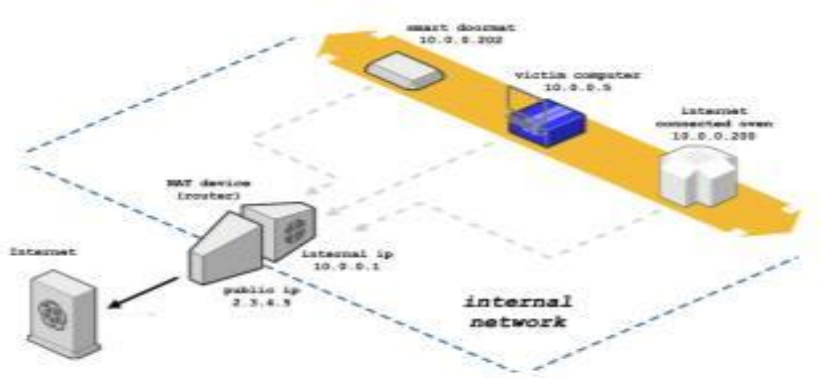


Network Address Translation (NAT)

- Idea: IP addresses do not need to be globally unique
- NATs map between two different address spaces.
- Most home routers are NATs and firewalls.



Private Subnets

10.0.0.0–10.255.255.255

172.16.0.0–172.31.255.255

192.168.0.0–192.168.255.255

https://samy.pl/slipstream/

Typical NAT Behavior

- NAT maintains a table of the form:

  <client IP> <client port> <NAT ID>

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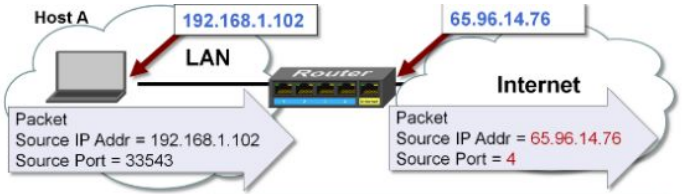
  - If not found, allocate a new NAT ID and replace source port with NAT ID
  - Replace source address with NAT address



NAT Translation Table

	Local IP Address	Source Port #		Internet IP Address	Source Port #
process X, Host A →	192.168.1.101	54,847	=	65.96.14.76	1
Host B →	192.168.1.103	24,123	=	65.96.14.76	2
process Y, Host A →	192.168.1.101	42,156	=	65.96.14.76	3
Host C →	192.168.1.102	33,543	=	65.96.14.76	4

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  - Replace source address with NAT address
- Incoming packets (on NAT port)
  - Look up destination port as NAT ID in port mapping table
  - If found, replace destination address and port with client entries from the mapping table
  - If not found, the packet should be rejected
- Table entries expire after 2–3 minutes of no activity to allow them to be garbage collected

NAT Pros and Cons

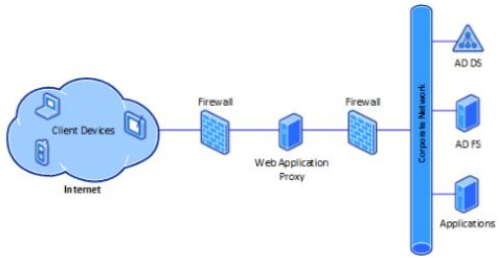
- Pros
  - Only allows connections to the outside that are established from inside.
    - Hosts from outside can only contact internal hosts that appear in the mapping table, and they're only added when they establish the connection.
  - Don't need as large an external address space
    - i.e. 10 machines can share 1 IP address
- Costs
  - Breaks some protocols
    - e.g., in FTP IP address appear in the content of the packet
    - e.g., some streaming protocols have client invoke server and then server opens a new connection to the client
  - Vulnerable to NAT slipstream attack (https://samy.pl/slipstream/)

Application Proxies

Idea: Control apps by requiring them to pass through proxy

- Proxy is application-level man-in-the-middle
- Enforce policy for specific protocols:
  - SMTP: Scan for viruses, reject spam
  - SSH: Log authentication, inspect encrypted text
  - HTTP: Block forbidden URLs

Companies inspect outbound traffic, will install root certificates on employee workstations to monitor TLS traffic.



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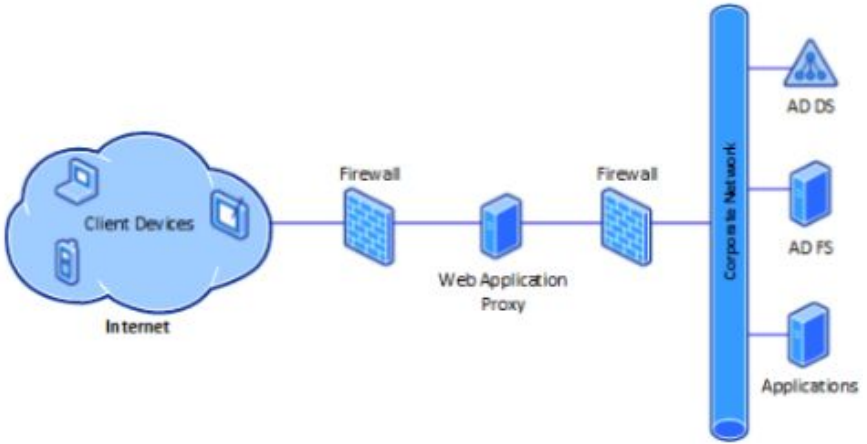
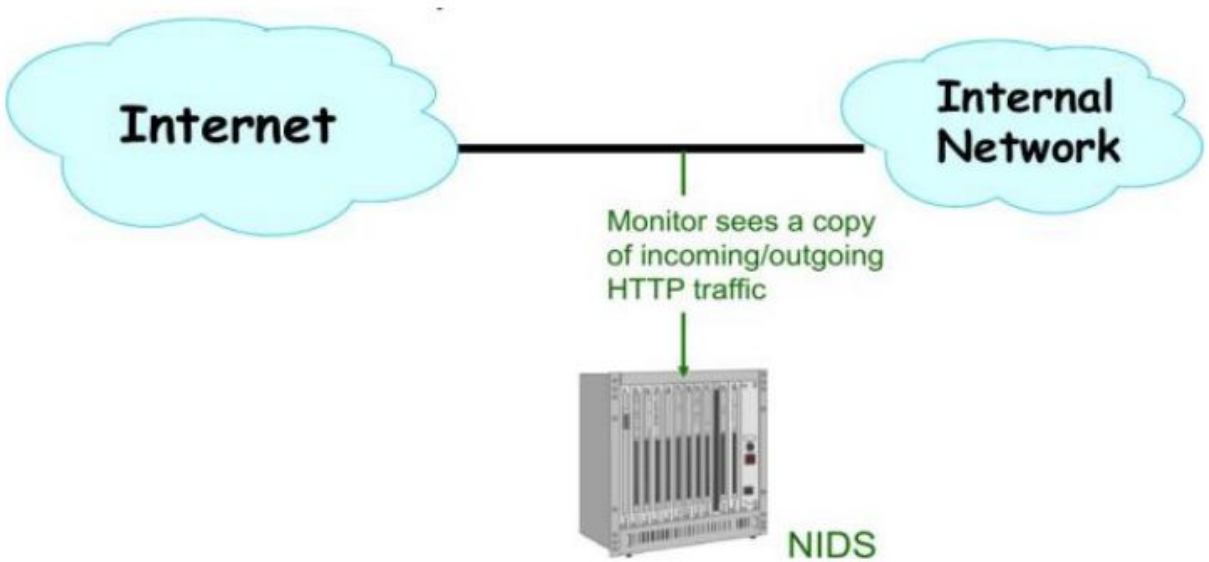


XKCD

Network Intrusion Detection Systems (NIDS)

- Idea: Passively monitor network traffic for signs of attack (e.g., look for /etc/passwd)



Network Intrusion Detection Systems (NIDS)

- NIDS has a table of all active connections, and maintains state for each
  - E.g., has it seen partial match of /etc/passwd
- What do you do when you see a new packet not associated with any known connection?

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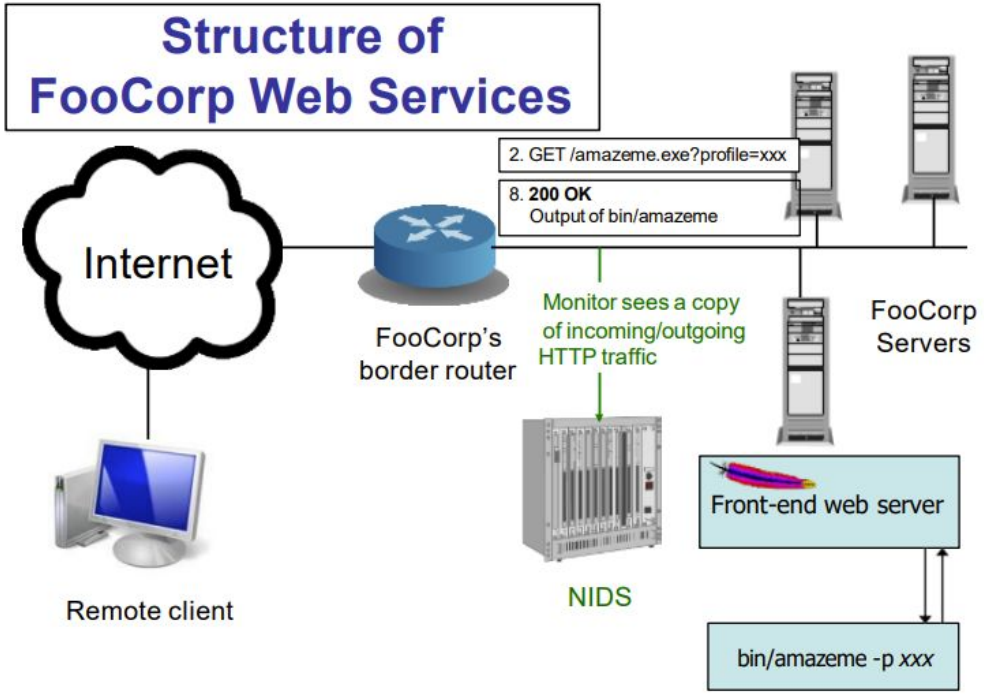
- What do you do when you see a new packet not associated with any known connection?
  - Create a new connection: when NIDS starts, it doesn't know what connections might be existing
- Where should you do the detection?
  - Network, host, or both?

Approach #1: Network-based Detection



- Look at network traffic, scanning HTTP requests
  - E.g., look for /etc/password or ../../

Network-based Detection Pros and Cons

Benefits

- Don't need to *modify* or *trust* end systems
- Cover many systems with single monitor
- Centralized management

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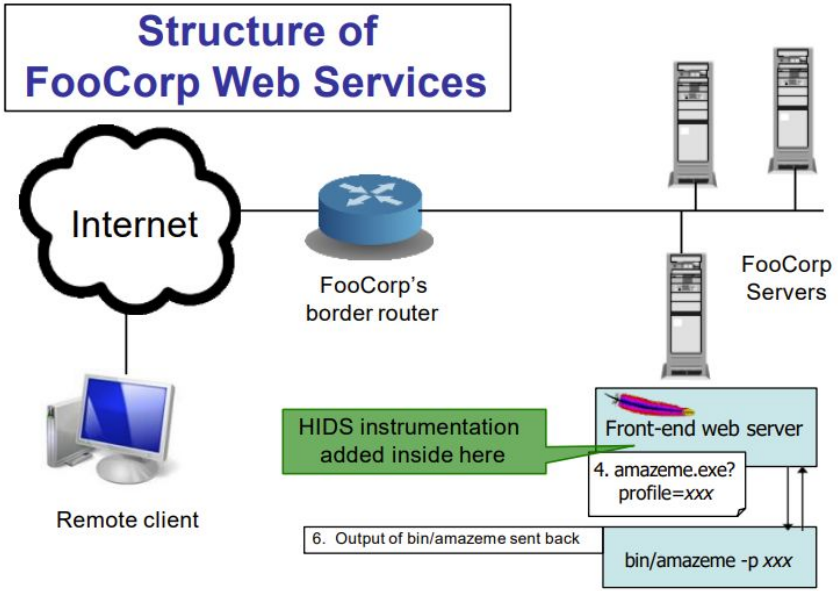
Issues

- Expensive: 10Gbps link ≈ 1M packets/second ≈ ns/packet
- Vulnerable to evasion attacks
  - Some evasions reflect incomplete analysis
    - E.g., hex escape or ../../../..////
    - In principle, can deal with these with implementation care
  - Some are due to imperfect observability
    - E.g., what if what NIDS sees doesn't exactly match what arrives at destination?

Understanding the Downsides

- Does /etc/passwd exist on all systems? Do you include rules for all OSes?
- Are all requests with ../../ *necessarily* bad?
  - False positives: Sometimes seen in legit requests
- Do you handle all encodings and semantic meaning?
  - Evasion: Abusing URL encodings (%2e%2e%2f%2e%2e%2f)
  - Evasion: Abusing UNIX semantics (..///.///../////)
- What if the traffic is encrypted (HTTPS)?
  - Need access to session key or decrypted text
  - Why might you not want to give the NIDS your TLS keys?

Approach #2: Host-based Detection



Instrument web server, scan arguments sent to back-end programs (and outbound requests)

- E.g., look for /etc/password or ../../

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Benefits

- The semantic gap is smaller, have understanding of URLs (and thus %2e%2e%2f%2e%2e%2f)
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- Still have to consider e.g., UNIX filename semantics ../../../..////
- Still have to consider other sensitive files, databases, etc.

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Issues

- Expensive: Add code to each server
- Still have to consider e.g., UNIX filename semantics ../////.////..////
- Still have to consider other sensitive files, databases, etc.
- Only (kind of) helps with web server attacks; what do you do about other end systems?

die.net

Site Search

Library
linux docs
linux man pages
page load time

Toys
world sunlight
moon phase
trace explorer

arpwatch(8) - Linux man page

Name

arpwatch - keep track of ethernet/ip address pairings

Synopsis

arpwatch [**-dN**] [**-f** *datafile*] [**-i** *interface*]

[**-n** *net[/width*]] [**-r** *file*] [**-u** *username*] [**-e** *username*] [**-s** *username*]

Description

Arpwatch keeps track for ethernet/ip address pairings. It syslogs activity and reports certain changes via email. **Arpwatch** uses **pcap**(3) to listen for arp packets on a local ethernet interface.

The **-d** flag is used enable debugging. This also inhibits forking into the background and emailing the reports. Instead, they are sent to *stderr*.

The **-f** flag is used to set the ethernet/ip address database filename. The default is *arp.dat*.

The -i flag is used to override the default interface.

The **-n** flag specifies additional local networks. This can be useful to avoid "bogon" warnings when there is more than one network running on the same wire. If the optional *width* is not specified, the default netmask for the network's class is used.

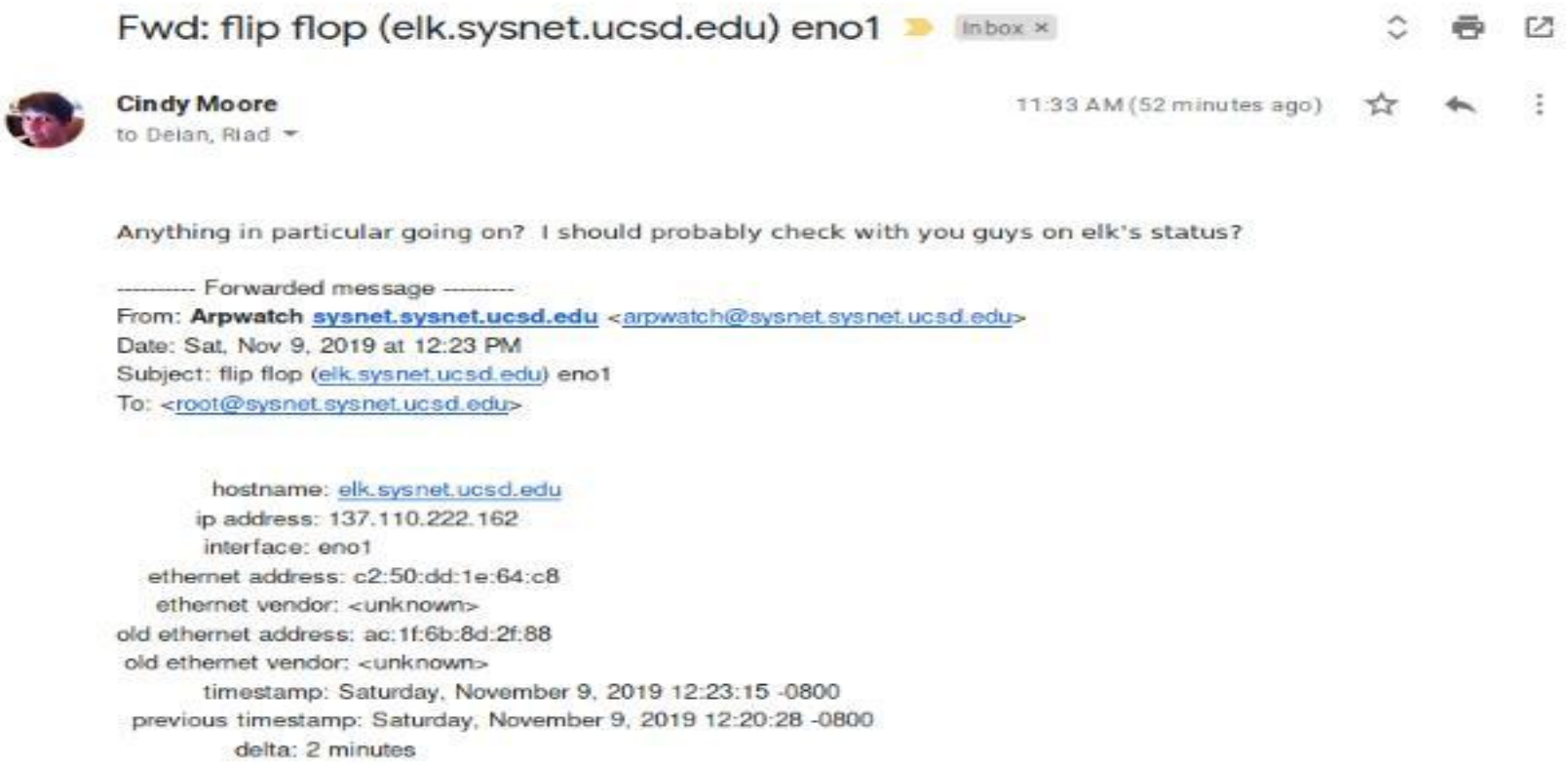
The **-N** flag disables reporting any bogons.

The **-r** flag is used to specify a savefile (perhaps created by **tcpdump**(1) or **pcapture**(1)) to read from instead of reading from the network. In this case, **arpwatch** does not fork.

If **-u** flag is used, **arpwatch** drops root privileges and changes user ID to *username* and group ID to that of the primary group of *username*. This is recommended for security reasons.

If the **-e** flag is used, **arpwatch** sends e-mail messages to *username* rather than the default (root). If a single '-' character is given for the username, sending of e-mail is suppressed, but logging via syslog is still done as usual. (This can be useful during initial runs, to collect data without being flooded with messages about new stations.)

Example: arpwatch



Fwd: flip flop (elk.sysnet.ucsd.edu) eno1 Inbox ×

Cindy Moore
to Delan, Riad

11:33 AM (52 minutes ago)

Anything in particular going on? I should probably check with you guys on elk's status?

---------- Forwarded message ---------
From: **Arpwatch sysnet.sysnet.ucsd.edu** <arpwatch@sysnet.sysnet.ucsd.edu>
Date: Sat, Nov 9, 2019 at 12:23 PM
Subject: flip flop (elk.sysnet.ucsd.edu) eno1
To: <root@sysnet.sysnet.ucsd.edu>

hostname: elk.sysnet.ucsd.edu
ip address: 137.110.222.162
interface: eno1
ethernet address: c2:50:dd:1e:64:c8
ethernet vendor: <unknown>
old ethernet address: ac:1f:6b:8d:2f:88
old ethernet vendor: <unknown>
timestamp: Saturday, November 9, 2019 12:23:15 -0800
previous timestamp: Saturday, November 9, 2019 12:20:28 -0800
delta: 2 minutes

Approach #3: Log analysis

• Log analysis: run scripts to analyze system log files (e.g., every night, hour, etc.)

Benefits

- Cheap: Servers already have logging facilities
- No escaping issues (logging done by server)

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- Reactive: detection delayed, can't block attacks
- Still need to worry about UNIX filename semantics
- Malware may be able to modify logs

Example: fail2ban

Fail2ban *scans log files (e.g.* `/var/log/apache/error_log`*) and bans IPs that show the malicious signs – too many password failures, seeking for exploits, etc. Generally Fail2Ban is then used to update firewall rules to reject the IP addresses for a specified amount of time, although any arbitrary other* ***action*** *(e.g. sending an email) could also be configured. Out of the box Fail2Ban comes with* ***filters*** *for various services (apache, courier, ssh, etc).*

```
# fail2ban-client status sshd
[sudo] password for d:
Status for the jail: sshd
|- Filter
|  |- Currently failed: 20
|  |- Total failed:     27703
|  `- Journal matches:  _SYSTEMD_UNIT=sshd.service + _COMM=sshd
`- Actions
   |- Currently banned: 31
   |- Total banned:     433
   `- Banned IP list:   64.39.111.160 27.64.18.149 83.26.10.131 213.138.194.140
   112.81.80.75 37.179.160.141 115.74.141.4 116.105.211.185 171.238.155.87
   115.73.17.2 64.39.98.116 207.144.245.38 116.110.73.16 171.227.192.81
   116.105.24.194 183.196.172.108 109.91.195.58 189.95.171.105 188.225.140.153
   177.19.178.53 167.99.211.161 49.65.70.208 217.173.9.37 68.183.1.20
   36.110.228.254 116.105.172.23 178.64.168.129 116.105.217.33 171.227.217.229
   201.249.146.101 192.196.164.84
```

But this has its own issues

- Filters are complicated regular expressions
- Can accidentally block self
- Can be tricked into blocking others

```
# !!! WARNING !!!
# Since UDP is connection-less protocol, spoofing of IP and imitation
# of illegal actions is way too simple. Thus enabling of this filter
# might provide an easy way for implementing a DoS against a chosen
# victim. See
# http://nion.modprobe.de/blog/archives/690-fail2ban-+-dns-fail.html
# Please DO NOT USE this jail unless you know what you are doing.
#
# IMPORTANT: see filter.d/named-refused for instructions to enable logging
# This jail blocks UDP traffic for DNS requests.
# [named-refused-udp]
#
# filter = named-refused
# port = domain,953
# protocol = udp
# logpath = /var/log/named/security.log
# IMPORTANT: see filter.d/named-refused for instructions to enable logging
# This jail blocks TCP traffic for DNS requests.
```

Detection Accuracy

- Two types of detector errors:
  - False positives (FPs): alerting about a non-problem
  - False negatives (FNs): failing to alert about a real problem
- Detector accuracy is often addressed in terms of rates:
  - Let I be the event of an instance of intrusive behavior
  - Let A be the event of detector generating an alarm
  - We then define: FP rate = $P[A|\neg I]$ and FN rate = $P[\neg A|I]$
- Can we build a perfect detector?

Detection Tradeoffs

- The art of a good detector is achieving **effective balance** between FP and FN rate.
  - Is low FP rate more better than low FN rate?
  - Is an FP rate of 0.1% and FN rate of 2% good?

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- It depends…
  - on cost of each type of error (e.g., FPs can waste an engineer's time; FN might lead to huge clean up fee)
  - on rate at which attacks occur (e.g., your laptop vs. Google's servers)

Vulnerability Scanning

Idea: Rather than detect attacks, launch them yourself.

- Probe internal systems with a range of attacks
- Patch/fix/block any that succeed.
- Pros:
  - Accurate: If your scanning tool is good, it finds real problems
  - Proactive: Can prevent future misuse
  - Intelligence: Can ignore IDS alarms you know can’t Succeed
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  - Dangerous for disruptive attacks
- In practice, this approach is prudent and widely used.
- Good complement to running an IDS

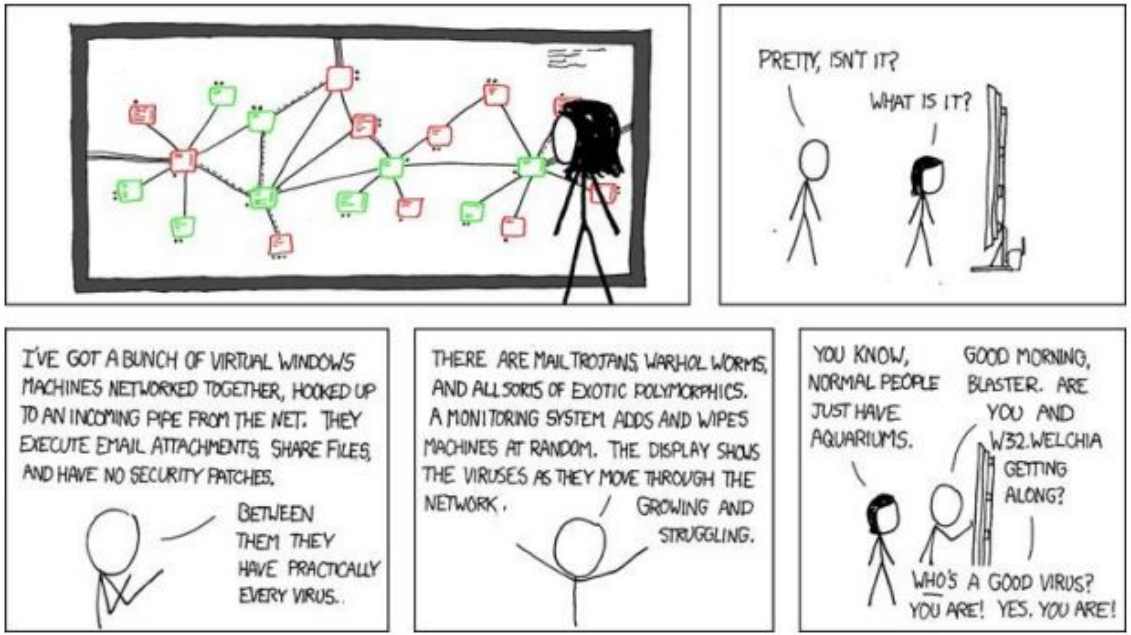
Honeypots

Idea: Deploy a sacrificial system that has no operational purpose

- Designed to lure attackers
- Any access is by definition not authorized, and is either an intruder or a mistake
- Provides opportunity to:
  - Identify intruders
  - Study what they're up to
  - Divert them from legitimate targets

Honeypots

Honeypots for automated attacks easier than building a convincing environment for dedicated attackers.



XKCD