Outline

- Firewalls
  - Filtering firewalls
  - Proxy firewalls
- Intrusion Detection System (IDS)
  - Rule-based IDS
  - Anomaly detection IDS
  - Host-based vs. network-based IDS

Internet Security Mechanisms

- Goal: prevent if possible; detect quickly otherwise; and confine the damage

Basic Terms

- **Vulnerabilities**
- **Intrusions** (attacks) and Intrusion Detection Systems (IDS)
- **Alert or alarm**: message generated by IDS

Example Attacks

- Disclosure, modification, and destruction of data
- Compromise host and then attack other systems
- Monitoring and capture of user passwords, then masquerade as authorized user
Firewalls

- Provides secure connectivity between networks
- Implements and enforces a security policy for communication between networks

Firewalls (Cont’d)

- Many organizations have distinct needs
  - access by anyone to public data concerning the company
  - access only by employees to internal data
- Solution: inner and outer (DMZ) networks

Firewall Capabilities

- Controlled access
  - restrict incoming and outgoing traffic according to security policy
- Other functions
  - log traffic, for later analysis
  - network address translation
  - encryption / decryption
  - application (payload) transformations

Limitations of Firewalls

- Cannot protect against traffic that does not cross it
  - i.e., there may be other ingress points to the network, such as modems or wireless access points, that bypass the firewall
  - doesn’t protect against “inside” attacks
- Configuration of firewalls to accomplish a desired high-level security policy is non-trivial

Filtering and Proxy Firewalls

Filtering

- Compare traffic to patterns, then process traffic according to rules if matched
- Two styles
  - packet filtering
  - session filtering
Packet Filtering

- Patterns specify values in the header of a single packet, e.g.,
  - source IP address and port number
  - destination IP address and port number
  - transport protocol type

Packet Filtering (cont’d)

- Decisions made on a per-packet basis
  - no state information (about previous packets) is maintained or used
- Assessment
  - easy to implement
  - but limited capabilities
- May be subject to tiny-fragment attack
  - first fragment has only a few bytes
  - rest of TCP header in a second fragment, not examined by firewall

Session Filtering

- Packet decisions are made in the context of a connection or flow of packets
- If packet is the start of a new connection…
  - check against rules for new connections
- If packet is part of an existing connection…
  - check against state-based rules for existing connections
  - update state of this connection

Session Filtering (cont’d)

- Assessment
  - more powerful than packet filtering, can recognize more sophisticated threats or implement more complex policies
  - also more expensive to implement

Example: Firewall Access for Telnet

Format:

access-list <rule number> <permit|deny> <protocol> <SOURCE host with IP address|any|IP address and mask> [gt|eq <port number>] <DEST host with IP address|any|IP address and mask> [gt|eq <port number>]

Note: any packets not explicitly permitted in an access list assumed to be denied or dropped.

The following allows user to telnet from an IP address (172.168.10.11) to any destination, but not vice-versa:
access-list 100 permit tcp host 172.168.10.11 eq 23
access-list 101 permit tcp host 172.168.10.11 established

Interface Ethernet 0
access-list 100 out ! Apply the first rule to outbound traffic
access-list 101 in ! Apply the second rule to inbound traffic
Application: FTP

FTP Server

- Client opens command channel to server; tells server second port number.
- Server acknowledges.
- Server opens data channel to client’s second port.
- Client acknowledges.

FTP Client

- “USE PORT 5151”
- “OK”
- DATA CHANNEL
- TCP ACK

1. Client opens command channel to server; tells server second port number.
2. Server acknowledges.
3. Server opens data channel to client’s second port.
4. Client acknowledges.

Example: Firewall Access for FTP

- Allow a user to FTP (not passive FTP) from any IP address to the FTP server (172.168.10.12):

  access-list 100 permit tcp any gt 1023 host 172.168.10.12 eq 21
  access-list 100 permit tcp any gt 1023 host 172.168.10.12 eq 20
  ! Allows packets from any client to the FTP control and data ports
  access-list 101 permit tcp host 172.168.10.12 eq 21 any gt 1023
  access-list 101 permit tcp host 172.168.10.12 eq 20 any gt 1023
  ! Allows FTP server to send packets back to any IP address with TCP ports > 1023

Interface Ethernet 0
- access-list 100 in ! Apply the first rule to inbound traffic
- access-list 101 out ! Apply the second rule to outbound traffic

Proxy Firewalls

- Serve as relays for connections
- Two flavors
  1. application level
  2. circuit level

Application Proxies

- Understand specific application protocols, e.g., HTTP, SMTP, Telnet
  - proxy ‘impersonates’ both one side of connection to the other
- Can do arbitrary processing / inspection of application payloads
  - ex.: check mail for viruses before forwarding
- Computationally expensive
- Must write a new proxy application to support new protocols

Application Proxies (Cont’d)

- May require hosts inside the organization to be configured to use the proxy

Circuit-Level Proxies

- Sets up two connections, one to inside user, one to outside server
  - i.e., proxy at the TCP level, rather than the application level
  - client programs must be aware they are using a circuit-level proxy, by linking to modified libraries
- Users must authenticate to proxy before connection to outside will be established
- Example protocol: SOCKS
Overview of IDS

IDS
• Detect if attacks are being attempted, or if system has been compromised
• Desirable features
  – Accuracy
  – Fast
  – Flexible, general
  – Results easy to understand

Measuring Accuracy
• **Events** are actions occurring in the system (file accesses, login attempts, etc.)
  – an **intrusion** (I) is an event that is part of an attack
  – an **alarm** (A) is generated if an event is diagnosed as being an intrusion

<table>
<thead>
<tr>
<th>Intrusion Generated</th>
<th>Intrusion Not Generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>True positive</td>
<td>False positive</td>
</tr>
<tr>
<td>False negative</td>
<td>True negative</td>
</tr>
</tbody>
</table>

Which Ones Count
• It’s trivial to have 100% TPR, and trivial to have 0% FPR
  – how?
• Needed: both

Measuring (Cont’d)
• True positive rate: fraction of intrusions correctly diagnosed (detected)
• False negative rate: fraction of intrusions incorrectly diagnosed (not detected)
  – $\text{FNR} = 1 - \text{TPR}$
• True negative rate: fraction of non-intrusions correctly diagnosed
• False positive rate: fraction of non-intrusions incorrectly diagnosed
  – $\text{FPR} = 1 - \text{TNR}$

Attack Stages
• Intelligence gathering: attacker probes the system to determine vulnerabilities
• Planning: deciding what resource to attack and how
• Attack execution
• Hiding: covering traces of the attack
• Preparation for future attacks: install “back doors” for unhindered access
Example

- 70,000 events, 300 intrusions, 2800 alarms (of which 298 are correct diagnoses, 2502 are incorrect)
- TPR: 298 / 300 = 99.3%
- FNR: 0.7%
- TNR: (70000 - 300 - 2502) / (70000 - 300) = 96.4%
- FPR: 3.6%

“Base-Rate Fallacy” Illustrated

- IDS often suffers from base-rate fallacy
  - intrusions are rare events
  - non-intrusions are common
  - correctly detected intrusions are swamped by incorrectly detected non-intrusions!
- Previous example: only 298 out of 2800 alarms (10.6%) are correct
  - in reality, often less than 1% of alarms are real intrusions

Components of IDS

Audit Data → Audit Records → Audit Data Preprocessor → Activity Data → Detection Engine → Alarms → Decision Table → Notifier → Action/Report

Signature-Based IDS

Basic IDS Techniques

1. Misuse detection
   - use attack signatures (characteristics of real attacks, e.g., illegal sequences of system calls, invalid packets, etc.)
   - can only detect already-known attacks
   - false positive rate is low, but false negative rate is high

Detection (Cont’d)

2. Anomaly detection
   - uses a model of “normal” system behavior
   - tries to detect deviations from this behavior, e.g., raises an alarm when a statistically rare event occurs
   - can potentially detect new (not previously-encountered) attacks
   - low false negative rate, high false positive rate
- Which is better?
Ex.: Misuse vs. Anomaly Detection

<table>
<thead>
<tr>
<th>Event Description</th>
<th>Detection Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Password file modified</td>
<td>?</td>
</tr>
<tr>
<td>Four failed login attempts</td>
<td>?</td>
</tr>
<tr>
<td>Failed connection attempts on 50 sequentially-numbered ports</td>
<td>?</td>
</tr>
<tr>
<td>User who usually logs in around 10am from dorm logs in at 4:30am from an IP address in Lower Slobovia</td>
<td>?</td>
</tr>
<tr>
<td>UDP packet to port 1434 (Slammer Worm)</td>
<td>?</td>
</tr>
</tbody>
</table>

Example Signatures

- A sequence of connection attempts to a large number of ports
- A privileged program spawning a shell
- A network packet that has lots of NOOP instruction bytes in it
- Program input containing a very long string (parameter value)
- A large number of TCP SYN packets sent, with no ACKs coming back

Signature Generation

- Research challenge: fast, automatic extraction of signatures for *new attacks*
  - *Honeypots* are useful for attracting attacks to generate signatures
- Attack signatures are usually very specific
  - automated engines now generate unlimited *variants* of a single attack
  - program obfuscation, self-decrypting code
- Possible response: find attack characteristics that are *difficult to conceal / obfuscate*

Anomaly-Based IDS

Examples of Metrics

- **Count** of the number of occurrences of an event per unit time
  - if count exceeded, raise an alarm
- **Time** elapsed between events
  - if time too small, raise an alarm
- **Resource utilization**
  - if utilization too high, raise an alarm
- **Statistical measures**
  - mean, standard deviation, etc.
Examples (Cont’d)

- Markov process: use expected likelihood of transition from one system state to another, or from one output to another
- Short sequences of events
  - ex. suppose the normal sequences of system calls during execution of two programs has been measured
  - any serious deviation from such sequences will be flagged as possible signs of an attack

Building Profiles

- Profiles are updated regularly, and older data must be "aged" out
  - ex.: \( m_t = \alpha \times m_{t-1} + (1-\alpha) \times m_t \)
  - where \( m_t \) is expected value for time period \( t \), \( \alpha \) is an experimentally-derived weighting factor between .5 and 1.0
- Risk: attacker trains IDS to accept his activity as normal
  - i.e., training data should be free of intrusions, or intrusions must be properly classified in the training data!

Examples of Data Mining Techniques

- Association rule learning (find interesting relations between variables)
- Principal components analysis (isolate and focus on the high variance variables)
- Cluster analysis (group data into categories based on similarities)
- ...

Conventional View

- Anomaly-based IDS by itself generates too many false positives
- Combination of anomaly-based and signature-based is best

Where Is the IDS Deployed?

- Host-based intrusion detection
  - monitor activity on a single host
- Network-based intrusion detection (NIDS)
  - monitor traffic, examine packet headers and payloads
Host-Based IDS

- Use OS auditing and monitoring mechanisms to find applications taken over by an attacker.
  Ex.:
  - log all system events (e.g., file accesses)
  - monitor shell commands and system calls executed
- Advantage: better visibility into behavior of individual applications running on the host
- Example application: detecting rootkits

Rootkit

- Rootkit is a set of “Trojan” system binaries
- Break into a host, download rootkit by FTP, unpack, compile and install
- Possibly turn off anti-virus / IDS
- Hides its own presence!
  - installs hacked binaries for common system monitoring commands, e.g., `netstat`, `ps`, `ls`, `du`, `login`
- “Sniff” user passwords

File Integrity Checking

- Tripwire
  - Records hashes of critical files and binaries
  - System periodically checks that files have not been modified by re-computing and comparing hash
- Ways to bypass?

Network-Based IDS

- Inspects network traffic
  - passive (unlike packet-filtering firewalls)
  - often handled by a router or firewall
- Monitors user activities
  - e.g., protocol violations, unusual connection patterns, attack strings in packet payloads
- Advantage: single NIDS can protect many hosts and look for widespread patterns of activity

Network-Based … (cont’d)

- Drawbacks / limitations
  - may be easily defeated by encryption (data portions and some header information can be encrypted)
  - not all attacks arrive from the network
  - must monitor, record and process huge amount of traffic on high-speed links
- Attack: overload NIDS with huge data streams, then attempt the intrusion
Popular NIDS: Snort

- Popular open-source tool
- Large (> 4000) ruleset for vulnerabilities; Ex:

  "Date: 2005-04-05
  Synopsis: the Sourcefire Vulnerability Research Team (VRT) has learned of serious vulnerabilities affecting various implementations of Telnet [...] Programming errors in the telnet client code from various vendors may present an attacker with the opportunity to overflow a fixed length buffer [...] Rules to detect attacks against this vulnerability are included in this rule pack"

Some Snort Rule Categories

- Backdoors
- Multimedia
- POP
- Telnet
- Chat
- MySQL
- RPC
- TFTP
- DDoS
- NETBIOS
- Scan
- Virus
- Finger
- NNTP
- Shellcode
- Web...
- FTP
- Oracle
- SMTP
- X11
- ICMP
- P2P
- SNMP
- IMAP
- SQL

Snort Rule Syntax

- Each snort rule has two logical sections: rule header and rule options
  - rule header contains action, protocol, source (IP address/port), direction, destination (IP address/port)
  - rule option contains alert messages, info on which parts of packet to be inspected

Snort Rule Examples

- alert icmp $EXTERNAL_NET any $HOME_NET any
  (msg:"DDOS Stacheldraht agent->handler (skillz)"; content:"skillz"; itype:0; icmp_id:6666; reference:url,staff.washington.edu/dittrich/misc/stacheldraht.analysis; classtype:attempted-dos; sid:1855; rev:2;)
- alert any any $EXTERNAL_NET any $HTTP_SERVERS
  (flags:A; ack:0; msg:"NMAP TCP ping";)
- alert tcp $HTTP_SERVERS $HTTP_PORTS
  (msg:"WEB-IIS cmd.exe access"; flow:to_server,established; content:"cmd.exe"; nocase; classtype:web-application-attack; sid:1052; rev:5;)

Detecting Attack Strings

- Scanning for a signature in each packet is not enough
  - attacker can split attack string into several packets; will defeat stateless NIDS
- Recording just previous packet's text is not enough
  - attacker can send packets out of order
- Attacker can use TCP tricks so that certain packets are seen by NIDS but dropped by the receiving application

Summary

1. Firewalls widely used, packet filters most common
   - one valuable technique among many
2. IDS (both host-based and network-based) widely used
3. Attacks are constantly evolving; the "arms race"
4. False alarm volume, and providing clear feedback to administrators, is a problem