Firewall & Network-based Intrusion Detection

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Network-level Filtering

- **Firewalls & Intrusion Prevention Systems**
  - **Peremiter defense**
  - **Btw internet & intranet**
  - **Block traffic violating security policy**

This Lecture

Network-based Filtering

- **Power**
- **Mechanism**
- **Challenges**

Power of Network-based Filtering

- **Why we do it (as opposed to host-based filtering)?**
  - **Central chokepoint uses single place to easily enforce a security policy on 1,000's of machines**
    - » **Similar to airport security – few entrances**
  - **Firewall operation does not rely on host security**
- **Power**
  - **Broad spectrum**
    - » **Packet filtering: stateless, only-header based**
    - » **Application firewall: stateful, content-based, understanding application semantics**

Packet Filters

- **Simplest kind of firewall is a *packet filter***
  - **Router with list of access control rules**
  - **Router checks each received packet against security rules to decide to forward or drop it**
  - **Each rule specifies which packets it applies to based on a packet's header fields**
    - » **Specify source and destination IP addrs, port numbers, and protocol names, or wild cards**
    - » **Each rule also specifies an action for matching packets: ALLOW or DROP**
    - » **`<ACTION> <PRTCL> <SRC:PT> -> <DEST:PT>`**
  - **List of rules is examined one-by-one**
    - » **First matching rule determines how packet will be handled**

Security Policy based on IP Header

- **A TCP service is specified by machine's IP address and TCP port number on it**
  - **Web server `www.cs.berkeley.edu` at `169.229.60.105`, port `80`**
  - **Mail service at `169.229.60.93`, port `25`**
  - **UDP services similarly identified**
- **Identify each svc with triplet *(m,r,p)*:**
  - ***m* is machine's IP addr (`A.B.C.D/[MASK]`)**
  - ***r* is a TCP/UDP protocol identifier**
  - ***p* is the port number**

Example

- **Want to allow:**
  - Inbound mail connections to our mail server (`1.2.3.4:25`)
  - All outbound connections
  - Nothing else
  - Consider this ruleset:
    - » `allow tcp *:* -> 1.2.3.4:25`
    - » `allow tcp 1.2.3.*:* -> *:*`
    - » `drop   *  *:* -> *:*`
- **This policy doesn't work…**
  - TCP connections are bidirectional
  - 3-way handshake: send SYN, receive SYN|ACK, send ACK, send DATA w/ACK bit

Problem: Outbound Connections Fail

- **Inside host opens TCP connection to port 80 on external machine:**
  - Initial SYN packet passed through by rule 2
  - SYN|ACK packet coming back is dropped
    - » Fails rule 1 (not destined for port 25)
    - » Fails rule 2 (source not inside host)
    - » Matches rule 3 -> DROP
- **Distinguish between 2 kinds of inbound pkts**
  - Allow inbound packets associated with an outbound connection to pass
  - Restrict inbound packets associated with an inbound connection

Inbound versus Outbound Connections

- **Key idea: use a feature of TCP!**
  - ACK bit set on all packets except first one
  - Recipients discard any TCP packet with ACK bit set, if packet is not associated with an existing TCP connection
- **Solution ruleset?**
  - `allow tcp *:* -> 1.2.3.4:25`
  - `allow tcp 1.2.3.*:* -> *:*`
  - `allow tcp *:* -> {`*`int_hosts`*`}:* (if ACK bit set)`
  - `drop   *  *:* -> *:*`
  - Rules 1 and 3 allow inbound connections to port 25 on machine `1.2.3.4`
  - Rules 2 and 3 allow outbound connections to any port

Example Using This Ruleset

- **Outside attacker trying to exploit finger service (TCP port 79) vulnerability**
  - Tries to open an inbound TCP connection to our finger server
- **Attempt #1:Sends SYN pkt to int. machine**
  - Pkt doesn't have ACK bit set, so fw rule drops it
- **Attempt #2: Sends SYN|ACK pkt to internal machine**
  - FW permits pkt, then dropped by TCP stack (ACK bit set but isn't part of existing connection)
- **We can specify policies restricting inbound connections arbitrarily**

IP Spoofing: Another Security Hole

- **IP protocol doesn't prevent attacker from sending pkt with wrong (*spoofed*) src addr**
  - Most routers ignore src addrs
- **Suppose `1.2.3.7` is an internal host**
  - Attacker sends spoofed TCP SYN packet
    - » Src addr `1.2.3.7`, dest addr target internal machine, dest port 79 – rule 2 allows
  - Target replies with SYN|ACK pkt to `1.2.3.7` and waits for ACK (to finish 3-way handshake)
  - Attacker sends spoofed TCP ACK packet
  - Attacker then sends data packet

Attack Analysis

- **Attack allows connections to internal hosts**
  - Violates of our security policy
  - Allows attacker to exploit any security holes
    - » Ex: finger service vulnerability
  - Caveat:
    - » Attacker has to "guess" Initial Sequence Number set by target in SYN|ACK packet sent to `1.2.3.7` (many ways to guess…)
- **Modified Solution**
  - Packet filter marks each packet with incoming interface ID, and rules match IDs
    - » Recall: Router has 2+ interfaces, forwards packets from one to another

New Solution

- **New ruleset**
  - Int. interface: `in`, ext. interface: `out`
  - `allow tcp *:*/out -> 1.2.3.4:25/in`
  - `allow tcp *:*/in  -> *:*/out`
  - `allow tcp *:*/out -> *:*/in  (if ACK bit set)`
  - `drop   *  *:*     -> *:*`
  - Allows inbound packets only if destined to `1.2.3.4:25` (rule 1), or, if ACK bit set (rule 3)
  - Drops all other inbound packets
- **Clean solution: defeats IP spoofing threat**
  - Simplifies ruleset admin (no hardcode internal hosts list)

Other Kinds of Firewalls

- **Packet filters are quite crude firewalls**
  - Network level using TCP, UDP, and IP headers
- **Alternative: examine data field contents**
  - Application-layer firewalls (application firewalls)
    - » Can enforce more restrictive security policies and transform data on the fly
- **For more information on firewalls, read:**
  - Cheswick, Bellovin, and Rubin: ***Firewalls and Internet Security: Repelling the Wily Hacker***.
- **Packet filtering sw available for many OS's:**
  - Linux `iptables`, OpenBSD/FreeBSD PF, and Windows XP SP2 firewall

Deployment

- **Extremely broad deployment**
- **Many commercial products**
  - High-speed firewalls/IPSes
- **New products on webapp filtering**

Administravia

- **Proj 2:**

Mean: 23.7
Standard deviation: 2.6
9 groups extra credit

Network-based Intrusion Detection/Prevention

- **Often stateful, deep-packet inspection**
  - Full stream re-assembly
  - Content-based analysis
- **Examples**
  - Snort
  - Bro
  - Commercial appliances
- **Detection methods**
  - Misuse detection (signature-based)
    - » E.g., snort rules
  - anomaly detection (specification-based or statistical-based)
    - » E.g., port-scanning detection
- **Often much more complex than packet filters**

Attacks on NIDS

- **Algorithmic complexity attacks**
- **Evasion attacks**
- **Stealthy port scanning**

Algorithmic Complexity Attacks

- DoS attacks not only serious for denying service, but can be more severe by using it as a component of an attack
- DoS attack on IDS enables other attacks to remain undetected
- "Denial of Service via Algorithmic Complexity Attacks" by Crosby and Wallach

Complexity Attack on Hash Table

- On average, a hash table has O(n) overhead to insert n elements
- In the worst case, a hash table may have $O(n^2)$ overhead to insert n elements!
- Attack against Perl hash table:
  - 90K inserts
    - » Random: < 2 sec
    - » Worse case: > 6500 sec

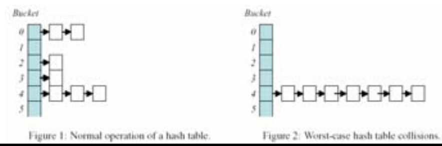


Figure 1: Normal operation of a hash table.

Figure 2: Worst-case hash table collisions.

Complexity Attack Against Bro

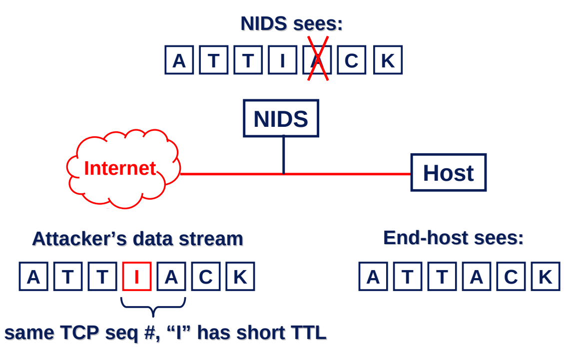
- Bro uses simple xor to "hash" values for hash table
  - Easy to find collisions!
- Example: Bro port scanning detector keeps a hash table
  - Keep the list of internal IP addresses scanned for each <src IP, dst port>
- Using source IP spoofing, can exploit this structure to perform DoS attack!

	Attack	Random
Total CPU time	44.50 min	.86 min
Hash table time	43.78 min	.02 min

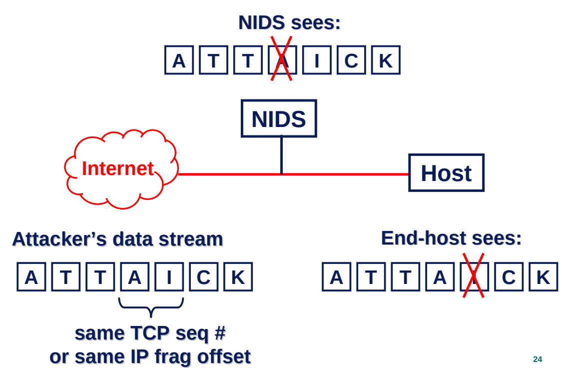
NIDS: Evasion & Normalization

- Problems
  - Complete fragment reassembly necessary to detect certain attacks
  - NIDS only has partial knowledge of what traffic the host sees (e.g., TTL expires, MTU)
  - Ambiguities in TCP/IP (e.g., Overlapping IP & TCP fragments)
    - » Different OS implement standard differently

Small TTL Attack



Fragmentation Overlap Attack



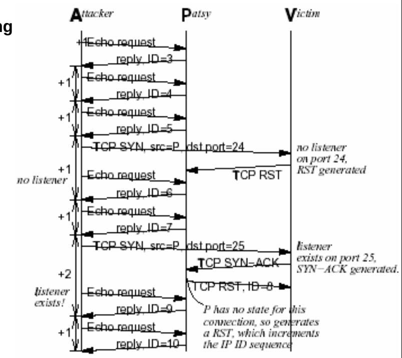
Solution: Traffic Normalizer

- Introduce “bump in the wire”: traffic normalizer to evade protocol ambiguities
  - Drop overlapping IP/TCP fragments
  - Increase TTL in packets with low TTL

- Other approaches
  - Host-based IDS
  - Detailed Intranet map

Stealth Port Scanning

- IP id field used for stealth port scanning



Summary

- **Network-based filters:**
  - Another type of reference monitor