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Network Security

Chapter 9

Attack prevention, detection and response

Part I: Attack Prevention

- ❑ Part I: Attack Prevention
- ❑ Part II: Attack Detection
- ❑ Part III: Response Mechanisms

Attack Prevention

- ❑ *Prevention:*
  - All measures taken in order to avert that an attacker succeeds in realizing a threat
  - Examples:
    - Cryptographic measures: encryption, computation of modification detection codes, running authentication protocols, etc.
    - Firewall techniques: packet filtering, service proxying, etc.
  - Preventive measures are by definition taken *before an attack takes place*

➡ Attention: it is generally impossible to prevent every potential attack!

Prevention: Defense Techniques Against DoS Attacks (1)

- ❑ Defenses against disabling services:
  - Hacking defenses:
    - Good system administration
    - Firewalls, logging & intrusion detection systems
  - Implementation weakness defenses:
    - Code reviews, stress testing, etc.
  - Protocol deviation defenses:
    - Fault tolerant protocol design
    - Error logging & intrusion detection systems
    - “DoS-aware protocol design”:
      - Be aware of possible DoS attacks when reassembling packets
      - Do not perform expensive operations, reserve memory, etc., before authentication

Prevention: Defense Techniques Against DoS Attacks (2)

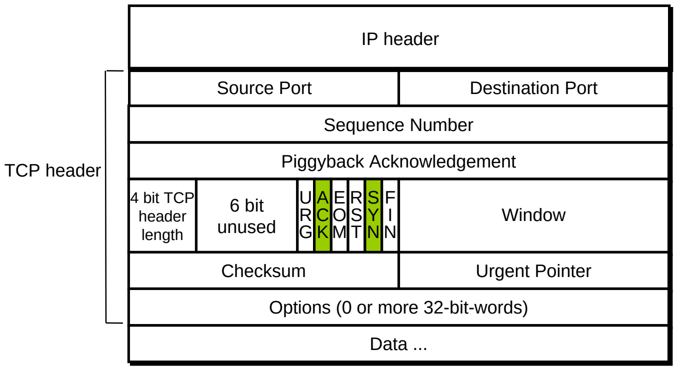
- Defenses against resource depletion:
  - Generally:
    - Rate Control (ensures availability of other functions on same system) i.e. a potential reason to implement QoS mechanisms
    - Accounting & Billing ("if it is for free, why not use it excessively?")
    - Identification and punishment of attackers
  - Authentication of clients plays an important role for the above measures
  - Memory exhaustion: stateless protocol operation
- Concerning origin of malicious traffic:
  - Defenses against single source attacks:
    - Disabling of address ranges (helps if addresses are valid)
  - Defenses against forged source addresses:
    - Ingress Filtering at ISPs (if the world was an ideal one...)
    - "Verify" source of traffic (e.g. with exchange of "cookies")
  - Widely distributed DoS: ???

Ingress/ Egress Filtering

- Goal:
  - Reduce the address space that can be used by the attacker by filtering the packets at the edge of the network
- Ingress filtering:
  - Incoming packets with a source address belonging to the network are blocked
  - Incoming packets from the public Internet with a private source address are blocked
- Egress filtering:
  - Outgoing packets that carry a source IP address that does not belong to the network are blocked

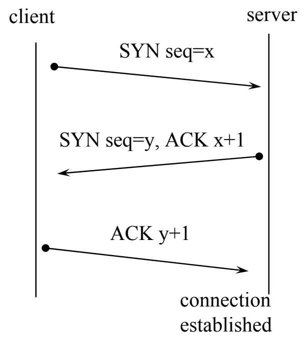
Example: TCP SYN Flood Attack (1)

- The TCP protocol Header:



Example: TCP SYN Flood Attack (2)

- TCP 3-Way Handshake:
  - The client sends a 'TCP SYN' message
    - seq number = *x (*chosen by the client)
    - ACK flag = 0
    - SYN flag = 1
  - The server sends a 'TCP SYN ACK'
    - seq number = *y* (chosen by the server)
    - ack number = *x + 1*
    - ACK flag = 1
    - SYN flag = 1
  - The client sends a 'CONNECT ACK'
    - seq number = *x + 1*
    - ack number = *y + 1*
    - ACK flag = 1
    - SYN flag = 0
  - The handshake ensures that both sides are ready to transmit data.



Example: TCP SYN Flood Attack (3)

- ❑ The attacker floods the victim with SYN packets with spoofed IP addresses.
- ❑ The victim answers with SYN/ACK packets and waits for a responding ACK packet.
- ❑ The server stores half-opened connections in a backlog queue.
- ❑ No response comes back.

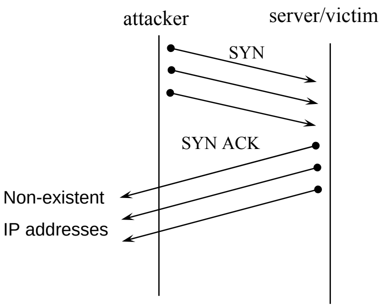
⇒ Too many half-opened connections.

⇒ The backlog queue (connection table) fills up.

⇒ Legitimate users can not establish a TCP connection with the server.

- ❑ Mostly, victims are faced with multiple attackers

⇒ Distributed Denial of Service (DDoS) attack.



Example: TCP SYN Flood Protection

- ❑ Load Balancing and replication of resources:
  - The attack will pass unnoticed.
  - With a sufficient number of attackers the server can still be saturated.
- ❑ TCP stack tweaking
  - Increase backlog size
    - limited by the kernel memory of the server (each entry ~600 Bytes)
  - Decrease waiting time for the third packet of the TCP handshake
    - helps but has drawback that slower clients cannot connect
- ❑ TCP proxies:
  - TCP connections are intercepted by the TCP proxy.
  - When the 3-way handshake is complete, the connection is forwarded to the server.

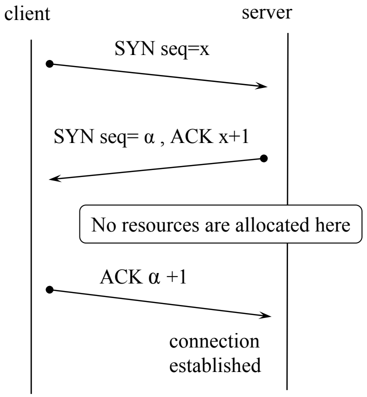
    ⇒ TCP connections are slower.

    ⇒ Use only when an attack is assumed.
  - The sever remains safe. However, in case of an attack, legitimate users still can not connect.

    ⇒ Only a “fuse”. Does not solve the real problem.
- ❑ SYN cookies (see subsequently)
- ❑ Anti-spoofing features

Example: SYN Flood Protection with TCP SYN cookies (1)

- ❑ SYN cookies are a particular choice of the initial *seq number* by the server.
- ❑ The server generates the initial sequence number α such as:
  - α = h(K , S_{SYN})
  - K: a secret key
  - S_{SYN}: source addr of the SYN packet
  - h is a cryptographic hash function.
- ❑ At arrival of the ACK message, the server calculates α again.
- ❑ Then, it verifies if the *ack number* is correct.
- ❑ If yes, it assumes that the client has sent a SYN message recently and it is considered as normal behavior.



Example: SYN Flood Protection with TCP SYN cookies (2)

- ❑ Advantages:
  - The server does not need to allocate resources after the first SYN packet.
  - The client does not need to be aware that the server is using SYN cookies.

    ⇒ SYN cookies don’t requires changes in the specification of the TCP protocol.
- ❑ Disadvantages:
  - Calculating α is CPU power consuming.

    ⇒ Moved the vulnerability from memory overload to CPU overload.
  - TCP options can not be negotiated (e.g. large window option)

    ⇒ Use only when an attack is assumed.
  - Is vulnerable to cryptoanalysis: even if h is a secure function the sequence numbers generated by the server may be predicted after receiving/ hijacking a sufficient number of cookies.

    ⇒ The secret code need to be changed regularly, e.g. by including a timestamp.
- ❑ N.B. SYN cookies are integrated in the Linux Kernel with MD5 as hash function.
  - top 5 bits: t mod 32, where t is a 32-bit time counter that increases every 64 seconds;
  - next 3 bits: an encoding of an MSS selected by the server in response to the client's MSS;
  - bottom 24 bits: a server-selected secret function of the client IP address and port number, the server IP address and port number, and t.

Attack Prevention, Detection and Response

- Part I: Attack Prevention
- Part II: Attack Detection
- Part III: Response Mechanisms

Part II: Attack Detection

- Introduction
- Host IDS vs. Network IDS
- Knowledge-based Detection
- Anomaly Detection

Introduction

- Prevention is not sufficient in practice:
  - Because it is too expensive to prevent all potential attack techniques
  - Because legitimate users get annoyed by too many preventive measures and may even start to circumvent them (introducing new vulnerabilities)
  - Because preventive measures may fail:
    - Incomplete or erroneous specification / implementation / configuration
    - Inadequate deployment by users (just think of passwords...)
- What can be attained with intrusion detection?
  - Detection of attacks and attackers
  - Detection of system misuse (includes misuse by legitimate users)
  - Limitation of damage (if response mechanisms exist)
  - Gain of experience in order to improve preventive measures
  - Deterrence of potential attackers

Introduction (2)

- *Intrusion*
  - Definition 1
    - “An Intrusion is unauthorized access to and/or activity in an information system.”
  - Definition 2 (more general)
    - “…Any set of actions that attempt to compromise the integrity, confidentiality or availability of a resource.” [HLM91]
- As seen in Definition 2, the term “Intrusion” is often used in the literature to characterize any kind of attacks.
- *Intrusion Detection*
  - All measures taken to recognize an attack *while or after it occurred*
  - Examples:
    - Recording and analysis of audit trails
    - On-the-fly traffic monitoring and intrusion detection.

Attack Detection: Classification

- Classification by the scope of the detection:
  - Host-based Intrusion Detection Systems (HIDS)
  - Network- based Intrusion Detection Systems (NIDS)
- Classification by detection strategy:
  - Knowledge-based detection
  - Anomaly detection
  - Hybrid attack detection

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Host Intrusion Detection Systems (HIDS)

- Use information available on a system, e.g. OS-Logs, application-logs, timestamps
- Can easily detect attacks by insiders, as modification of files, illegal access to files, installation of Trojans or root kits
- Drawbacks:
  - Has to be installed on every system.
  - The attack packets can not be detected before they reach the victim

    ⇒ Host-based IDS are helpless against bandwidth saturation attacks.

Network Intrusion Detection Systems (NIDS)

- Use information provided by the network, mainly packets sniffed from the network layer.
- Often used at the edges of the (sub-)networks (ingress/egress points)
- Can detect known attack signatures, port scans, invalid packets, attacks on application layer, DDoS, spoofing attacks
- Uses signature detection (stateful), protocol decoding, statistical anomaly analysis, heuristical analysis

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Knowledge-based Attack Detection (1)

- Store the signatures of attacks in a database
- Each communication is monitored and compared with database entries to discover occurrence of attacks.
- The database is occasionally updated with new signatures.
- Advantage:
  - Known attacks can be reliably detected. No “false positives” (see below for the definition of “false positives”)
  - Drawbacks:
    - Only known attacks can be detected.
    - Slight variations of known attacks are not detected.
- Different appellations for “Knowledge-based” attack detection in the literature
  - “pattern-based”
  - “signature-based”
  - “misuse-based”.

Knowledge-based Attack Detection (2)

- Patterns can be specified at each protocol level
  - Network protocol (e.g. IP, ICMP)
  - Transport protocol (e.g. TCP, UDP)
  - Application protocol (e.g. HTTP, SMTP)

- Example of a rule in the IDS Snort (http://www.snort.org/)

```
alert tcp $HOME_NET any -> any 9996 \
(msg:"Sasser ftp script to transfer up.exe"; \
content:"|5F75702E657865|"; depth:250; flags:A+; classtype: misc-
activity; \ sid:1000000; rev:3)
```

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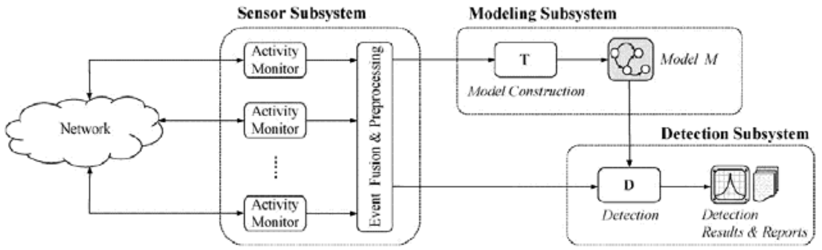
Anomaly Detection (1)

- Anomaly detection systems include a model of “normal system behavior” such as:
  - normal traffic dynamics
  - expected system performance
- The current state of the network is compared with the models to detect anomalies.
- If the current state differs from the normal behavior by a threshold then an alarm is raised.
- Anomalies can be detected in
  - Traffic behavior
  - Protocol behavior
  - Application behavior

Anomaly Detection (2)

- A formal definition: [Tapidor04]
  - An anomaly detection system is a pair $\delta = (M, D)$, where:
    - *M* is the model of normal behavior.
    - *D* is similarity measure that allows obtaining, giving an activity record, the degree of deviation (or likeness) that such activities have with regard to the model *M*.



Source: [Tapiador04]

Anomaly Detection (2)

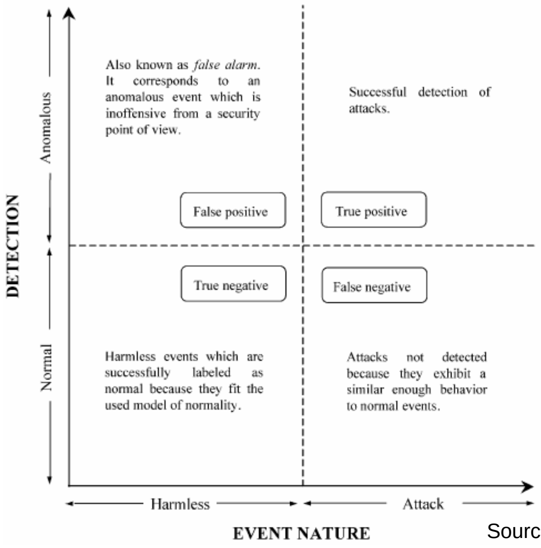
- Pros
  - Might recognize some unknown attacks as well
- Cons
  - False-positive (see definition below) rate might be high

- Definitions:
  - A *false positive* means the attack detection system raises an alarm while the behavior is legitimate.
  - A *false negative* means that an attack happens while it is classified by the attack detection system as normal behavior.

⇒ If the threshold for raising an alarm is set too low, the false positive rate is too high.

If the threshold is set too high, the attack detection system is insensitive.

Detection Quality



Also known as *false alarm*. It corresponds to an anomalous event which is inoffensive from a security point of view.

Successful detection of attacks.

Harmless events which are successfully labeled as normal because they fit the used model of normality.

Attacks not detected because they exhibit a similar enough behavior to normal events.

Source: [Tapiador04]

Anomaly Detection (3)

- Challenges
  - Modeling Internet traffic is not easy
    - Mostly no periodic behavior
    - Applications are very diverse
  - Data collection issues
    - Collection is expensive, collecting the right information is important
  - Anomalies can have different reasons
- *Network Operation Anomalies*
  - caused, e.g. by a link failure or a configuration change
- *Flash Crowd Anomalies*
  - rapid rise in traffic flows due to a sudden interest in a specific services (for instance, a new software path in a repository server or a highly interesting content in a Web site)
- *Network Abuse Anomalies*
  - such as DoS flood attacks and port scans

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Response Strategies

- Packet Filtering
- Kill Connections
- Rate Limiting
  - Congestion control
  - Pushback
- Tracking
  - Traceback techniques
  - Re-configuration of the monitoring environment
- Redirection

Response Strategies: Packet Filtering

- Attack packets are filtered out and dropped.
- Challenges
  - How to distinguish between legitimate packets (the „good“ packets) and illegitimate packets (the „bad“ packets).
  - Attacker’s packet might have spoofed source addresses
- Filterable attacks
  - If the flood packets are not critical for the service offered by the victim, they can be filtered.
  - Example: UDP flood or ICMP request flood on a web server.
- Non-filterable attacks
  - The flood packets request legitimate services from the victim.
  - Examples include
    - HTTP request flood targeting a Web server
    - CGI request flood
    - DNS request flood targeting a name server
  - Filtering all the packets would be an immediate DoS to both attackers and legitimate users.

Response Strategies: Kill Connection

- Kill Connection
  - TCP connections can be killed using RST packets that are sent to both connection end points
  - The RST packet requires correct sequence/ acknowledgement numbers. Otherwise it is ignored.
  - Limitation: this response is possible only for connection-oriented protocols

References

[HLM91] Heberlein, Levitt und Mukherjeeh. A method to detect intrusive activity in a networked environment. In Proceedings of the 14th National Computer Security Conference, 1991.

[Mirkovic2004] J. Mirkovic and P. Reiher, "A Taxonomy of DDoS Attack and DDoS Defense Mechanisms," *ACM SIGCOMM Computer Communication Review*, vol. 34, April 2004, pp. 39-53.

[Tapidor2004] J. M. Estevez-Tapiador, P. Garcia-Teodoro, and J. E. Diaz-Verdejo, "Anomaly detection methods in wired networks: a survey and taxonomy," Computer Communications, vol. 27, July 2004, pp. 1569-1584.