

Network Security

Chapter 11

Attack prevention,
detection and response



Acknowledgments

This course is based to a significant extend on slides provided by Günter Schäfer, author of the **book "Netzicherheit - Algorithmische Grundlagen und Protokolle"**, available in German from **dpunkt Verlag**. The English version of the book is entitled "Security in Fixed and Wireless Networks: An Introduction to Securing Data Communications" and is published by Wiley is also available. We gratefully acknowledge his support.

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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

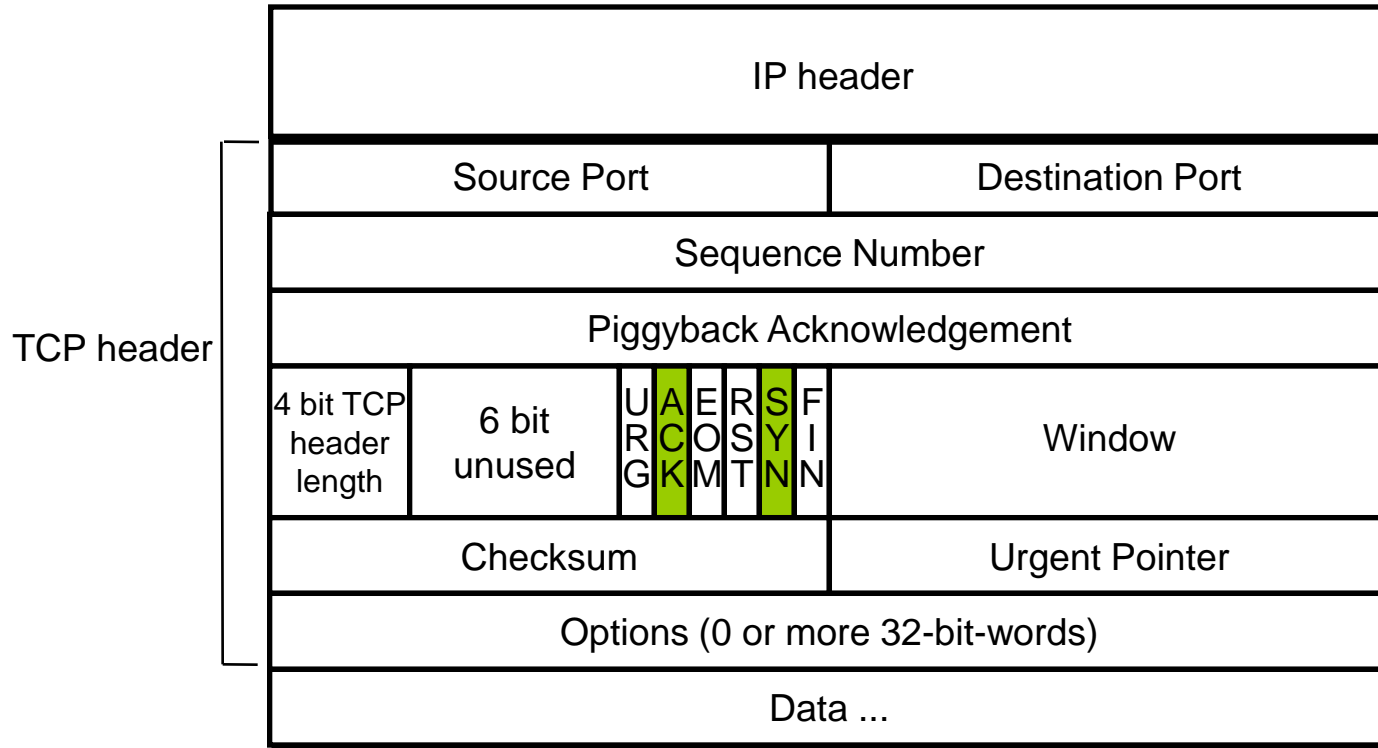
- ❑ Ingress filtering:
 - Incoming packets with a source address belonging to the network are blocked
 - Incoming packets from the public Internet with a private source address are blocked

- ❑ 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)

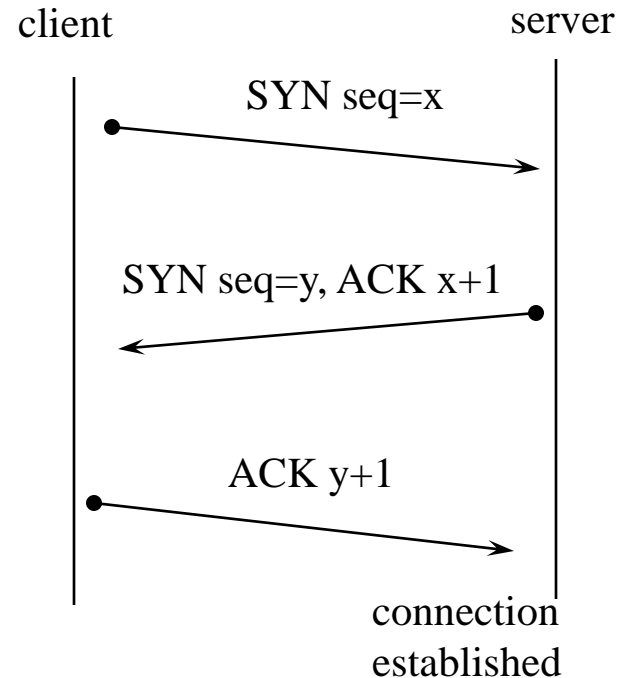
- The TCP protocol Header:





Example: TCP SYN Flood Attack (2)

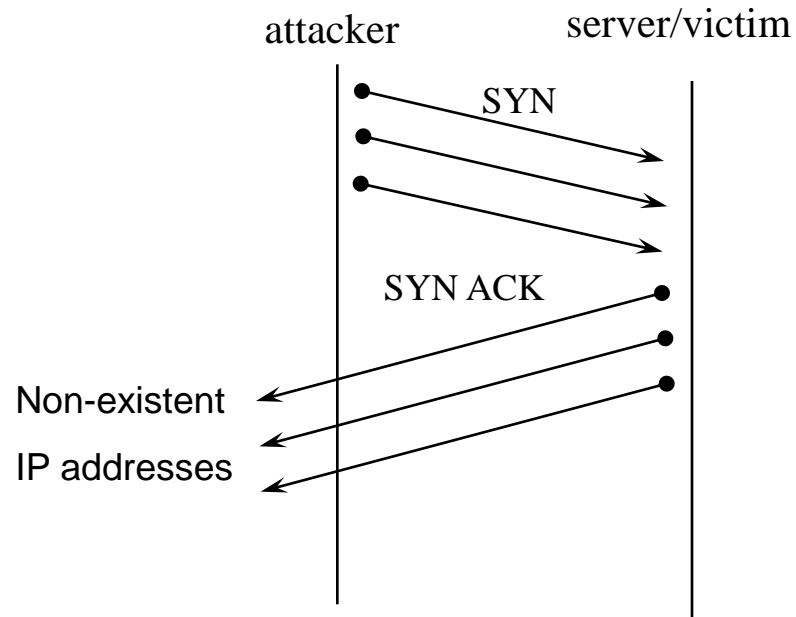
- TCP 3-Way Handshake:
 - The client sends a 'TCP SYN' message
 - seq number = x (chosen by the client)
 - ACK flag = 0
 - SYN flag = 1
 - The server sends a 'TCP SYN ACK'
 - seq number = y (chosen by the server)
 - ack number = $x + 1$
 - ACK flag = 1
 - SYN flag = 1
 - The client sends a 'CONNECT ACK'
 - 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.





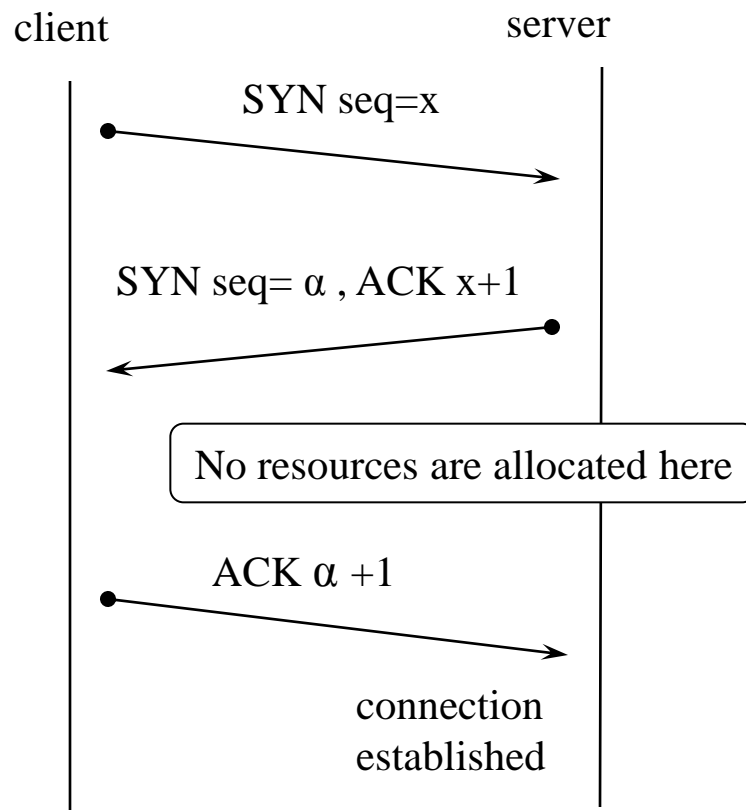
Example: TCP SYN Flood Protection

- ❑ 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:
 - $\alpha = h(K, S_{SYN})$
 - 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 require 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: $t \bmod 32$, 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



- ❑ 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



Part II: Attack Detection

- ❑ Introduction
- ❑ Host IDS vs. Network IDS
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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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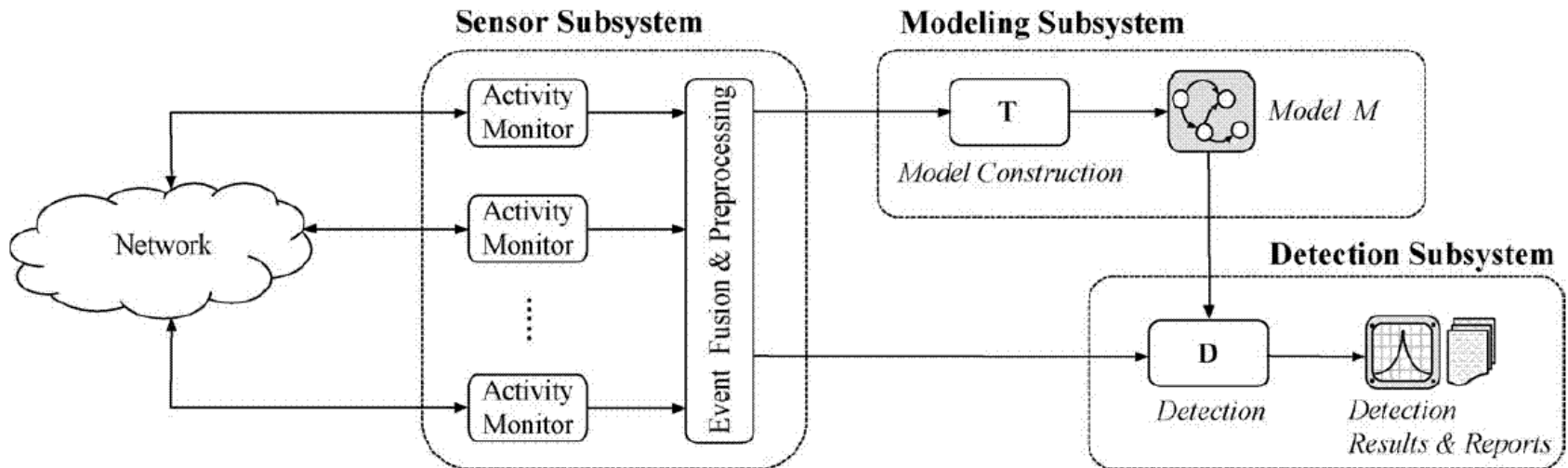
Anomaly Detection (1)

- ❑ 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]

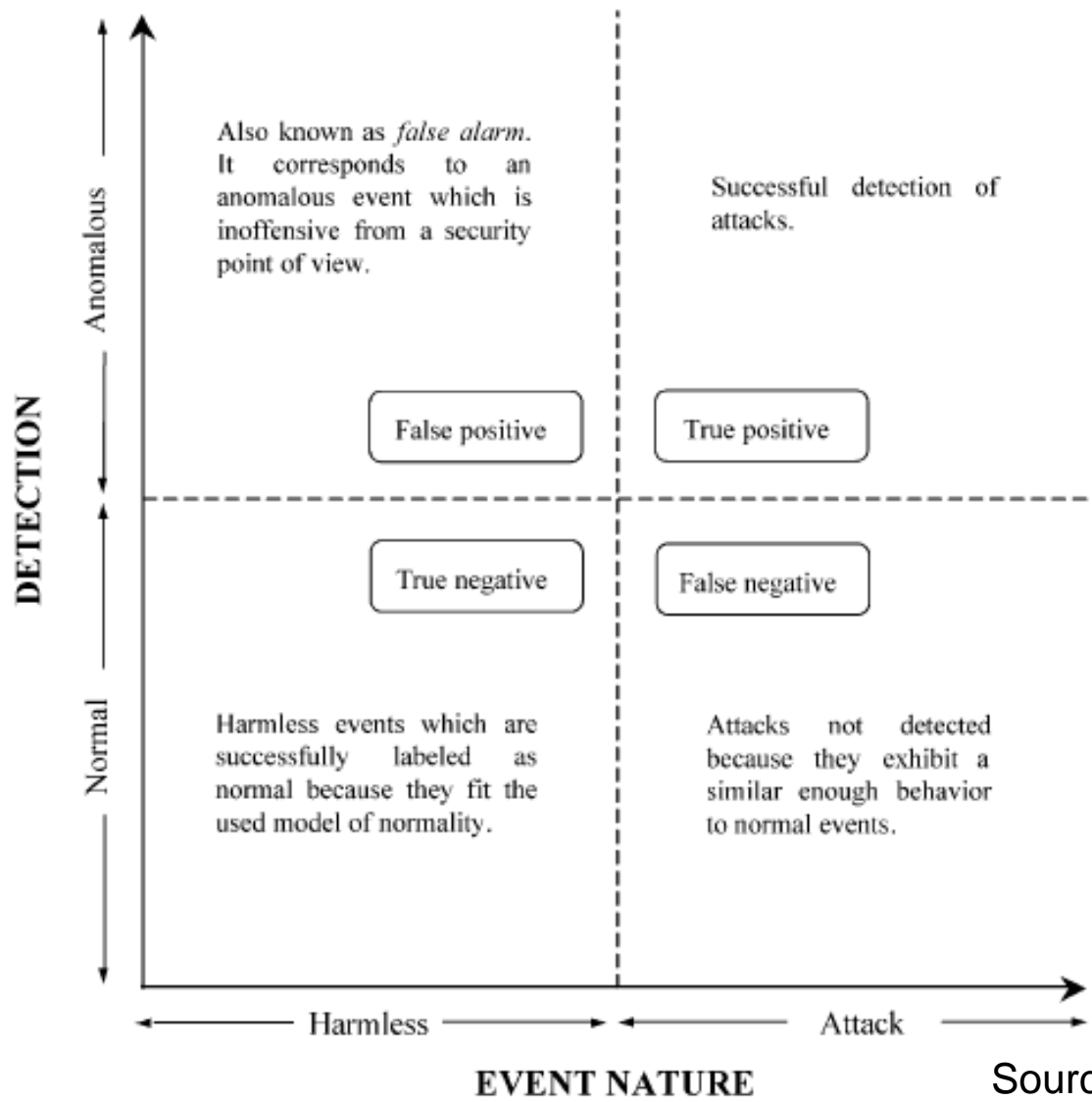


Anomaly Detection (2)

- ❑ 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



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



Attack Prevention, Detection and Response

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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.