

INTRUSION DETECTION AND CORRELATION

Challenges and Solutions

Advances in Information Security

Sushil Jajodia

Consulting editor

Center for Secure Information Systems

George Mason University

Fairfax, VA 22030-4444

email: jajodia@gmu.edu

The goals of Kluwer International Series on ADVANCES IN INFORMATION SECURITY are, one, to establish the state of the art of, and set the course for future research in information security and, two, to serve as a central reference source for advanced and timely topics in information security research and development. The scope of this series includes all aspects of computer and network security and related areas such as fault tolerance and software assurance.

ADVANCES IN INFORMATION SECURITY aims to publish thorough and cohesive overviews of specific topics in information security, as well as works that are larger in scope or that contain more detailed background information than can be accommodated in shorter survey articles. The series also serves as a forum for topics that may not have reached a level of maturity to warrant a comprehensive textbook treatment.

Researchers as well as developers are encouraged to contact Professor Sushil Jajodia with ideas for books under this series.

Additional titles in the series:

THE AUSTIN PROTOCOL COMPILER by Tommy M. McGuire and Mohamed G. Gouda; ISBN: 0-387-23227-3

ECONOMICS OF INFORMATION SECURITY by L. Jean Camp and Stephen Lewis; ISBN: 1-4020-8089-1

PRIMALITY TESTING AND INTEGER FACTORIZATION IN PUBLIC KEY CRYPTOGRAPHY by Song Y. Yan; ISBN: 1-4020-7649-5

SYNCHRONIZING E-SECURITY by Godfried B. Williams; ISBN: 1-4020-7646-0

INTRUSION DETECTION IN DISTRIBUTED SYSTEMS:

An Abstraction-Based Approach by Peng Ning, Sushil Jajodia and X. Sean Wang; ISBN: 1-4020-7624-X

SECURE ELECTRONIC VOTING edited by Dimitris A. Gritzalis; ISBN: 1-4020-7301-1

DISSEMINATING SECURITY UPDATES AT INTERNET SCALE by Jun Li, Peter Reiher, Gerald J. Popek; ISBN: 1-4020-7305-4

SECURE ELECTRONIC VOTING by Dimitris A. Gritzalis; ISBN: 1-4020-7301-1

APPLICATIONS OF DATA MINING IN COMPUTER SECURITY, edited by Daniel Barbará, Sushil Jajodia; ISBN: 1-4020-7054-3

MOBILE COMPUTATION WITH FUNCTIONS by Zeliha Dilsun Kırılı, ISBN: 1-4020-7024-1

Additional information about this series can be obtained from

<http://www.wkap.nl/prod/s/ADIS>

INTRUSION DETECTION AND CORRELATION

Challenges and Solutions

by

Christopher Kruegel
Fredrik Valeur
Giovanni Vigna

University of California, Santa Barbara, USA

Springer

eBook ISBN: 0-387-23399-7
Print ISBN: 0-387-23398-9

©2005 Springer Science + Business Media, Inc.

Print ©2005 Springer Science + Business Media, Inc.
Boston

All rights reserved

No part of this eBook may be reproduced or transmitted in any form or by any means, electronic, mechanical, recording, or otherwise, without written consent from the Publisher

Created in the United States of America

Visit Springer's eBookstore at: <http://ebooks.kluweronline.com>
and the Springer Global Website Online at: <http://www.springeronline.com>

Contents

List of Figures	ix
List of Tables	xi
Preface	xiii
1. INTRODUCTION	1
1 Motivating Scenario	3
2 Alert Correlation	6
3 Organization	7
2. COMPUTER SECURITY AND INTRUSION DETECTION	9
1 Security Attacks and Security Properties	9
2 Security Mechanisms	11
2.1 Attack Prevention	11
2.2 Attack Avoidance	12
2.3 Attack Detection	17
3 Intrusion Detection	17
3.1 Architecture	19
3.2 Taxonomy	20
3.3 Detection Method	21
3.4 Type of Response	25
3.5 Audit Source Location	25
3.6 Usage Frequency	28
3.7 IDS Cooperation and Alert Correlation	28
3. ALERT CORRELATION	29

4. ALERT COLLECTION	35
1 Alert Normalization	36
2 Alert Preprocessing	37
2.1 Determining the Alert Time	38
2.2 Determining the Alert's Source and Target	42
2.3 Determining the Attack's Name	42
5. ALERT AGGREGATION AND VERIFICATION	43
1 Alert Fusion	43
2 Alert Verification	45
2.1 Passive Approach	48
2.2 Active Approach	48
3 Attack Thread Reconstruction	52
4 Attack Session Reconstruction	53
5 Attack Focus Recognition	56
6. HIGH-LEVEL ALERT STRUCTURES	59
1 Multistep Correlation	59
2 Impact Analysis	63
3 Alert Prioritizing	65
4 Alert Sanitization	66
7. LARGE-SCALE CORRELATION	71
1 Pattern Specification	77
1.1 Definitions	77
1.2 Attack Specification Language	78
1.3 Language Grammar	79
2 Pattern Detection	80
2.1 Basic Data Structures	80
2.2 Constraints	82
2.3 Detection Process	83
2.4 Implementation Issues	90
8. EVALUATION	93
1 Evaluation of Traditional ID Sensors	93
1.1 Evaluation Efforts	94
1.2 Problems	95
2 Evaluation of Alert Correlators	95
2.1 Evaluation Efforts	96

<i>Contents</i>	vii
2.2 Problems	98
2.3 Correlation Evaluation Truth Files	99
2.4 Factors Affecting the Alert Reduction Rate	100
9. OPEN ISSUES	103
1 Intrusion Detection	103
2 Alert Correlation	106
10. CONCLUSIONS	109
References	111
Index	117

List of Figures

1.1	Victim Network Installation	3
2.1	Security Attacks	10
2.2	Encryption and Decryption	13
2.3	CIDF Description of an IDS System	20
2.4	Block Diagram of a Typical Knowledge-Based IDS	21
2.5	Block Diagram of a Typical Behavior-Based IDS	24
3.1	Correlation Process Overview	30
3.2	Alert Merging Process	32
7.1	Centralized Correlation Schema	71
7.2	Hierarchical Correlation Schema	73
7.3	Pattern Graph Transformation	81
7.4	Complete Pattern Graph	85
7.5	Constraint Clustering	86
7.6	Sample Pattern Detection	89
7.7	Message Tuple Calculation	92
8.1	Two Possible Ways of Correlating the Same Data	100

List of Tables

3.1	Attack Scenario Alerts	33
4.1	Alert Normalization	37
4.2	Alert Preprocessing	42
5.1	Alert Fusion	45
5.2	Alert Verification	47
5.3	Attack Thread Reconstruction	54
5.4	Attack Session Reconstruction	56
6.1	Multistep Correlation	62
6.2	Correlated Output with Priorities for Example Attack Scenario	66
7.1	Node Constraints and Message / Bypass Pools	87

Preface

The Internet is omnipresent and companies have increasingly put critical resources online. This has given rise to the activities of cyber criminals, and virtually all organizations face increasing threats to their networks and the services they provide. This book presents intrusion detection systems (IDSs) and addresses the problem of managing and correlating the alerts that are produced. We discuss the role of intrusion detection in the realm of network security and compare it to traditional methods such as firewalls and cryptography. We then analyze the challenges in interpreting and combining (i.e., correlating) alerts produced by these systems. Existing academic and commercial systems are classified and their advantages and shortcomings are presented, especially in the case of deployment in large, real-world sites.

Recently, IDSs have been increasingly pounded for failing to meet the expectations that researchers and IDS vendors were rising. Promises that IDSs are capable of reliably identifying malicious activity in large networks were premature and never turned into reality. While virus scanners and firewalls have visible benefits and remain virtually unnoticed during normal operations, the situation is different with intrusion detection sensors. State-of-the-art IDSs produce hundreds or even thousands of alerts every day. Unfortunately, almost all of these alerts are false positives, that is, they are not related to security-relevant incidents. Although tuning and proper configuration eliminate the most obvious false alerts, the problem of the vast imbalance between important and spurious notifications remains.

Researchers and IDS vendors have reacted and proposed alert correlation, an additional step intended to manage the alert flood and turn the raw sensor output into compact reports on the security status of the network under surveillance. The idea is to aggregate and group individual alerts into attack scenarios that provide a higher-level view of the activities on the network. Unfortunately, current systems fall short in dealing with the immense data volume that is produced by the sensors that are deployed in large network installations. In

addition, dedicated nodes such as centralized processors become vulnerable to faults or targeted denial of service attempts and often represent performance bottlenecks. Another problem stems from the fact that it is often the case that sensor alerts are invalid. This causes the correlation process to deduce attack scenarios from incidents that have never occurred.

We address the aforementioned issues and present solutions that allow intrusion detection systems to be deployed in real-world installations to the benefit of the system administrator. Our proposed alert correlation process is realized by collaborating nodes that correlate and assemble the pieces of evidence, which are scattered over many hosts in the victim's network, into a single and coherent picture of ongoing attacks. The information of emerging threats is then fed back into the system and utilized to selectively adapt to data from suspicious sources. The main focus of our design is the protection of huge enterprise networks against coordinated attacks without being overwhelmed by the produced alert data and without failing because of the loss of a few critical correlation nodes. We also describe an approach to reduce the number of false positives by actively performing alert verification. The idea is to determine whether a potential attack has succeeded by checking for visible traces that this attack has left on the system.

This book introduces solutions to practical problems that intrusion detection systems experience when deployed in large network installations. The reader is familiarized with the basics and concepts of this fast growing and fascinating field in network security and learns about state-of-the-art systems. We focus on current research problems and help the reader understand the limitations and advantages of intrusion detection systems and, in particular, alert correlation and mechanisms to detect false alarms.