

CONTENTS IN DETAIL

FOREWORD by Rodrigo Rubira Branco	xix
--	------------

ACKNOWLEDGMENTS	xxiii
------------------------	--------------

ABBREVIATIONS	xxv
----------------------	------------

INTRODUCTION	xxix
---------------------	-------------

Why Read This Book?	xxx
What's in the Book?	xxx
Part 1: Rootkits	xxxi
Part 2: Bootkits	xxxi
Part 3: Defense and Forensic Techniques	xxxiii
How to Read This Book.	xxxiii

PART I: ROOTKITS

1	WHAT'S IN A ROOTKIT: THE TDL3 CASE STUDY	3
----------	---	----------

History of TDL3 Distribution in the Wild.	4
Infection Routine	5
Controlling the Flow of Data	7
Bring Your Own Linker	7
How TDL3's Kernel-Mode Hooks Work	8
The Hidden Filesystem	10
Conclusion: TDL3 Meets Its Nemesis.	12

2	FESTI ROOTKIT: THE MOST ADVANCED SPAM AND DDOS BOT	13
----------	---	-----------

The Case of Festi Botnet	14
Dissecting the Rootkit Driver	15
Festi Configuration Information for C&C Communication	16
Festi's Object-Oriented Framework	17
Plug-in Management	17
Built-in Plug-ins	19
Anti-Virtual Machine Techniques	20
Antidebugging Techniques.	22
The Method for Hiding the Malicious Driver on Disk	22
The Method for Protecting the Festi Registry Key	25
The Festi Network Communication Protocol	26
Initialization Phase	26
Work Phase	26

Bypassing Security and Forensics Software	27
The Domain Generation Algorithm for C&C Failure	30
Malicious Functionality	31
The Spam Module	31
The DDoS Engine	32
Festi Proxy Plug-in	33
Conclusion	34

3 OBSERVING ROOTKIT INFECTIONS 35

Methods of Interception	36
Intercepting System Events	36
Intercepting System Calls	37
Intercepting the File Operations	40
Intercepting the Object Dispatcher	41
Restoring the System Kernel	43
The Great Rootkits Arms Race: A Nostalgic Note	44
Conclusion	46

PART II: BOOTKITS

4 EVOLUTION OF THE BOOTKIT 49

The First Bootkits	50
Boot Sector Infectors	50
Elk Cloner and Load Runner	50
The Brain Virus	51
The Evolution of Bootkits	51
The End of the BSI Era	51
The Kernel-Mode Code Signing Policy	52
The Rise of Secure Boot	53
Modern Bootkits	53
Conclusion	55

5 OPERATING SYSTEM BOOT PROCESS ESSENTIALS 57

High-Level Overview of the Windows Boot Process	58
The Legacy Boot Process	59
The Windows Boot Process	60
BIOS and the Preboot Environment	60
The Master Boot Record	60
The Volume Boot Record and Initial Program Loader	62
The bootmgr Module and Boot Configuration Data	64
Conclusion	68

6	BOOT PROCESS SECURITY	69
The Early Launch Anti-Malware Module	70	
API Callback Routines	70	
How Bootkits Bypass ELAM	72	
Microsoft Kernel-Mode Code Signing Policy	73	
Kernel-Mode Drivers Subject to Integrity Checks	73	
Location of Driver Signatures	73	
The Legacy Code Integrity Weakness	74	
The ci.dll Module	76	
Defensive Changes in Windows 8	77	
Secure Boot Technology	78	
Virtualization-Based Security in Windows 10.	79	
Second Level Address Translation	80	
Virtual Secure Mode and Device Guard.	80	
Device Guard Limitations on Driver Development	81	
Conclusion	82	
7	BOOTKIT INFECTION TECHNIQUES	83
MBR Infection Techniques	84	
MBR Code Modification: The TDL4 Infection Technique	84	
MBR Partition Table Modification	90	
VBR/IPL Infection Techniques	91	
IPL Modifications: Rovnix	91	
VBR Infection: Gapz	92	
Conclusion	93	
8	STATIC ANALYSIS OF A BOOTKIT USING IDA PRO	95
Analyzing the Bootkit MBR	96	
Loading and Decrypting the MBR	96	
Analyzing the BIOS Disk Service.	101	
Analyzing the Infected MBR's Partition Table	104	
VBR Analysis Techniques.	106	
Analyzing the IPL	106	
Evaluating Other Bootkit Components	107	
Advanced IDA Pro Usage: Writing a Custom MBR Loader	108	
Understanding loader.hpp	109	
Implementing accept_file	109	
Implementing load_file.	110	
Creating the Partition Table Structure.	111	
Conclusion	113	
Exercises.	113	

9**BOOTKIT DYNAMIC ANALYSIS:
EMULATION AND VIRTUALIZATION****115**

Emulation with Bochs	116
Installing Bochs	117
Creating a Bochs Environment	117
Infecting the Disk Image	119
Using the Bochs Internal Debugger	121
Combining Bochs with IDA	123
Virtualization with VMware Workstation	124
Configuring the VMware Workstation	125
Combining VMware GDB with IDA	126
Microsoft Hyper-V and Oracle VirtualBox	130
Conclusion	130
Exercises	130

10**AN EVOLUTION OF MBR AND VBR INFECTION TECHNIQUES:
OLMASCO****133**

The Dropper	134
Dropper Resources	134
Tracing Functionality for Future Development	136
Antidebugging and Antiemulation Tricks	137
The Bootkit Functionality	138
Bootkit Infection Technique	138
Boot Process of the Infected System	140
The Rootkit Functionality	141
Hooking the Hard Drive Device Object and Injecting the Payload	141
Maintaining the Hidden Filesystem	141
Implementing the Transport Driver Interface to Redirect Network Communication	144
Conclusion	145

11**IPL BOOTKITS: ROVNIX AND CARBERP****147**

Rovnix's Evolution	148
The Bootkit Architecture	149
Infecting the System	150
Post-Infection Boot Process and IPL	152
Implementing the Polymorphic Decryptor	152
Decrypting the Rovnix Bootloader with VMware and IDA Pro	153
Taking Control by Patching the Windows Bootloader	159
Loading the Malicious Kernel-Mode Driver	163
Kernel-Mode Driver Functionality	164
Injecting the Payload Module	164
Stealth Self-Defense Mechanisms	166

The Hidden Filesystem	167
Formatting the Partition as a Virtual FAT System	168
Encrypting the Hidden Filesystem	168
Accessing the Hidden Filesystem.	168
The Hidden Communication Channel	169
Case History: The Carberp Connection.	171
Development of Carberp	171
Dropper Enhancements	173
Leaked Source Code.	174
Conclusion	175

12 GAPZ: ADVANCED VBR INFECTION 177

The Gapz Dropper	178
Dropper Algorithm	180
Dropper Analysis	180
Bypassing HIPS.	181
Infecting the System with the Gapz Bootkit	186
Reviewing the BIOS Parameter Block.	186
Infecting the VBR	188
Loading the Malicious Kernel-Mode Driver	189
Gapz Rootkit Functionality.	191
Hidden Storage	193
Self-Defense Against Antimalware Software	194
Payload Injection	196
Payload Communication Interface.	201
Custom Network Protocol Stack	204
Conclusion	206

13 THE RISE OF MBR RANSOMWARE 207

A Brief History of Modern Ransomware	208
Ransomware with Bootkit Functionality	209
The Ransomware Modus Operandi	210
Analyzing the Petya Ransomware	212
Acquiring Administrator Privileges	212
Infecting the Hard Drive (Step 1)	213
Encrypting with the Malicious Bootloader Configuration Data.	215
Crashing the System	219
Encrypting the MFT (Step 2)	220
Wrapping Up: Final Thoughts on Petya	224
Analyzing the Satana Ransomware	225
The Satana Dropper	225
The MBR Infection	226
Dropper Debug Information	227
The Satana Malicious MBR	228
Wrapping Up: Final Thoughts on Satana	230
Conclusion	231

14	UEFI BOOT VS. THE MBR/VBR BOOT PROCESS	233
The Unified Extensible Firmware Interface	234	
Differences Between the Legacy BIOS and UEFI Boot Processes	235	
The Boot Process Flow	235	
Disk Partitioning: MBR vs. GPT	235	
Other Differences	237	
GUID Partition Table Specifics	238	
How UEFI Firmware Works	242	
The UEFI Specification	243	
Inside the Operating System Loader	245	
The Windows Boot Loader	250	
Security Benefits of UEFI Firmware	253	
Conclusion	253	
15	CONTEMPORARY UEFI BOOTKITS	255
Overview of Historical BIOS Threats	256	
WinCIH, the First Malware to Target BIOS	256	
Mebromi	257	
An Overview of Other Threats and Counters	258	
All Hardware Has Firmware	261	
UEFI Firmware Vulnerabilities	263	
(In)Effectiveness of Memory Protection Bits	263	
Checks for Protection Bits	264	
Ways to Infect the BIOS	265	
Modifying an Unsigned UEFI Option ROM	267	
Adding or Modifying a DXE Driver	269	
Understanding Rootkit Injection	269	
UEFI Rootkits in the Wild	275	
Hacking Team's Vector-EDK Rootkit	275	
Conclusion	283	
16	UEFI FIRMWARE VULNERABILITIES	285
What Makes Firmware Vulnerable?	286	
Classifying UEFI Firmware Vulnerabilities	289	
Post-Exploitation Vulnerabilities	290	
Compromised Supply Chain Vulnerabilities	291	
Supply Chain Vulnerability Mitigation	292	
A History of UEFI Firmware Protections	293	
How BIOS Protections Work	294	
SPI Flash Protections and Their Vulnerabilities	294	
Risks Posed by an Unauthenticated BIOS Update	297	
BIOS Protection with Secure Boot	297	
Intel Boot Guard	299	
Intel Boot Guard Technology	299	
Vulnerabilities in Boot Guard	300	

Vulnerabilities in the SMM Modules	302
Understanding SMM	302
Exploiting SMI Handlers	302
Vulnerabilities in the S3 Boot Script	306
Understanding the S3 Boot Script	306
Targeting Weaknesses of the S3 Boot Script	307
Exploiting the S3 Boot Script Vulnerability	308
Fixing the S3 Boot Script Vulnerability	311
Vulnerabilities in the Intel Management Engine	311
A History of ME Vulnerabilities	311
ME Code Attacks	312
Case Studies: Attacks on Intel AMT and BMC	312
Conclusion	315

PART III: DEFENSE AND FORENSIC TECHNIQUES

17		319
HOW UEFI SECURE BOOT WORKS		
What Is Secure Boot?	320	
UEFI Secure Boot Implementation Details	320	
The Boot Sequence	321	
Executable Authentication with Digital Signatures	322	
The db Database	323	
The dbx Database	326	
Time-Based Authentication	328	
Secure Boot Keys	328	
UEFI Secure Boot: The Complete Picture	330	
Secure Boot Policy	332	
Protection Against Bootkits Using Secure Boot	334	
Attacking Secure Boot	335	
Patching PI Firmware to Disable Secure Boot	335	
Modifying the UEFI Variables to Bypass Security Checks	337	
Protecting Secure Boot with Verified and Measured Boot	338	
Verified Boot	339	
Measured Boot	339	
Intel BootGuard	339	
Finding the ACM	340	
Exploring FIT	342	
Configuring Intel BootGuard	343	
ARM Trusted Boot Board	346	
ARM Trust Zone	346	
ARM Boot Loaders	347	
Trusted Boot Flow	348	
Verified Boot vs. Firmware Rootkits	350	
Conclusion	350	

18	APPROACHES TO ANALYZING HIDDEN FILESYSTEMS	351
Overview of Hidden Filesystems	352	
Retrieving Bootkit Data from a Hidden Filesystem	353	
Retrieving Data from an Offline System	353	
Reading Data on a Live System	353	
Hooking the Miniport Storage Driver	354	
Parsing the Hidden Filesystem Image	360	
The HiddenFsReader Tool	360	
Conclusion	362	
19	BIOS/UEFI FORENSICS: FIRMWARE ACQUISITION AND ANALYSIS APPROACHES	363
Limitations of Our Forensic Techniques	364	
Why Firmware Forensics Matter	364	
Attacking the Supply Chain	364	
Compromising BIOS Through Firmware Vulnerability	365	
Understanding Firmware Acquisition	365	
The Software Approach to Firmware Acquisition	367	
Locating PCI Configuration Space Registers	368	
Calculating SPI Configuration Register Addresses	369	
Using the SPI Registers	369	
Reading Data from the SPI Flash	372	
Considering the Drawbacks of the Software Approach	373	
The Hardware Approach to Firmware Acquisition	374	
Reviewing a Lenovo ThinkPad T540p Case Study	375	
Locating the SPI Flash Memory Chip	376	
Reading the SPI Flash with the FT2232 Mini Module	377	
Analyzing the Firmware Image with UEFITool	380	
Getting to Know the SPI Flash Regions	380	
Viewing SPI Flash Regions with UEFITool	381	
Analyzing the BIOS Region	383	
Analyzing the Firmware Image with Chipsec	386	
Getting to Know the Chipsec Architecture	387	
Analyzing Firmware with Chipsec Util	388	
Conclusion	390	
INDEX		391