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Network Security Essentials
Applications and Standards
Fourth Edition

网络安全基础
应用与标准（第4版）

William Stallings 著

PEARSON Education

清华大学出版社

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出版说明

进入21世纪，世界各国的经济、科技以及综合国力的竞争将更加激烈。竞争的中心无疑是对人才的竞争。谁拥有大量高素质的人才，谁就能在竞争中取得优势。高等教育，作为培养高素质人才的事业，必然受到高度重视。目前我国高等教育的教材更新较慢，为了加快教材的更新频率，教育部正在大力促进我国高校采用国外原版教材。

清华大学出版社从1996年开始，与国外著名出版公司合作，影印出版了“大学计算机教育丛书（影印版）”等一系列引进图书，受到国内读者的欢迎和支持。跨入21世纪，我们本着为我国高等教育教材建设服务的初衷，在已有的基础上，进一步扩大选题内容，改变图书开本尺寸，一如既往地请有关专家挑选适用于我国高校本科及研究生计算机教育的国外经典教材或著名教材，组成本套“大学计算机教育国外著名教材系列（影印版）”，以飨读者。深切期盼读者及时将使用本系列教材的效果和意见反馈给我们。更希望国内专家、教授积极向我们推荐国外计算机教育的优秀教材，以利我们把“大学计算机教育国外著名教材系列（影印版）”做得更好，更适合高校师生的需要。

清华大学出版社

PREFACE

"The tie, if I might suggest it, sir, a shade more tightly knotted. One aims at the perfect butterfly effect. If you will permit me _"

"What does it matter, Jeeves, at a time like this? Do you realize that Mr. Little's domestic happiness is hanging in the scale?"

"There is no time, sir, at which ties do not matter."

—*Very Good, Jeeves!* P. G. Wodehouse

In this age of universal electronic connectivity, of viruses and hackers, of electronic eavesdropping and electronic fraud, there is indeed no time at which security does not matter. Two trends have come together to make the topic of this book of vital interest. First, the explosive growth in computer systems and their interconnections via networks has increased the dependence of both organizations and individuals on the information stored and communicated using these systems. This, in turn, has led to a heightened awareness of the need to protect data and resources from disclosure, to guarantee the authenticity of data and messages, and to protect systems from network-based attacks. Second, the disciplines of cryptography and network security have matured, leading to the development of practical, readily available applications to enforce network security.

OBJECTIVES

It is the purpose of this book to provide a practical survey of network security applications and standards. The emphasis is on applications that are widely used on the Internet and for corporate networks, and on standards (especially Internet standards) that have been widely deployed.

INTENDED AUDIENCE

This book is intended for both an academic and a professional audience. As a textbook, it is intended as a one-semester undergraduate course on network security for computer science, computer engineering, and electrical engineering majors. It covers the material in IAS2 Security Mechanisms, a core area in the Information Technology body of knowledge; and NET4 Security, another core area in the Information Technology body of knowledge. These subject areas are part of the Draft ACM/IEEE Computer Society Computing Curricula 2005.

The book also serves as a basic reference volume and is suitable for self-study.

PLAN OF THE BOOK

The book is organized in three parts:

Part One. Cryptography: A concise survey of the cryptographic algorithms and protocols underlying network security applications, including encryption, hash functions, digital signatures, and key exchange.

Part Two. Network Security Applications: Covers important network security tools and applications, including Kerberos, X.509v3 certificates, PGP, S/MIME, IP Security, SSL/TLS, SET, and SNMPv3.

Part Three. System Security: Looks at system-level security issues, including the threat of and countermeasures for intruders and viruses and the use of firewalls and trusted systems.

In addition, this book includes an extensive glossary, a list of frequently used acronyms, and a bibliography. Each chapter includes homework problems, review questions, a list of key words, suggestions for further reading, and recommended Web sites. In addition, a test bank is available to instructors.

ONLINE DOCUMENTS FOR STUDENTS

For this new edition, a tremendous amount of original supporting material has been made available online in the following categories.

- **Online chapters:** To limit the size and cost of the book, two chapters of the book are provided in PDF format. This includes a chapter on SNMP security and one on legal and ethical issues. The chapters are listed in this book's table of contents.
- **Online appendices:** There are numerous interesting topics that support material found in the text but whose inclusion is not warranted in the printed text. Seven online appendices cover these topics for the interested student. The appendices are listed in this book's table of contents.
- **Homework problems and solutions:** To aid the student in understanding the material, a separate set of homework problems with solutions are provided. These enable the students to test their understanding of the text.
- **Supporting documents:** A variety of other useful documents are referenced in the text and provided online.
- **Key papers:** Twenty-Four papers from the professional literature, many hard to find, are provided for further reading.

Purchasing this textbook new grants the reader six months of access to this online material.

INSTRUCTIONAL SUPPORT MATERIALS

To support instructors, the following materials are provided.

- **Solutions Manual:** Solutions to end-of-chapter Review Questions and Problems.
- **Projects Manual:** Suggested project assignments for all of the project categories listed subsequently in this Preface.
- **PowerPoint Slides:** A set of slides covering all chapters, suitable for use in lecturing.
- **PDF Files:** Reproductions of all figures and tables from the book.
- **Test Bank:** A chapter-by-chapter set of questions.

All of these support materials are available at the Instructor Resource Center (IRC) for this textbook, which can be reached via pearsonhighered.com/stallings or by clicking on the button labeled "Book Info and More Instructor Resources" at this book's Web site WilliamStallings.com/Crypto/Crypto5e.html. To gain access to the IRC, please contact your local Prentice Hall sales representative via pearsonhighered.com/educator/replocator/requestSalesRep.page or call Prentice Hall Faculty Services at 1-800-526-0485.

INTERNET SERVICES FOR INSTRUCTORS AND STUDENTS

There is a Web page for this book that provides support for students and instructors. The page includes links to other relevant sites, transparency masters of figures and tables in the book in PDF (Adobe Acrobat) format, and PowerPoint slides. The Web page is at **WilliamStallings.com/NetSec/NetSec4e.html.**

An Internet mailing list has been set up so that instructors using this book can exchange information, suggestions, and questions with each other and with the author. As soon as typos or other errors are discovered, an errata list for this book will be available at WilliamStallings.com. In addition, the Computer Science Student Resource site, at **WilliamStallings.com/StudentSupport.html**, provides documents, information, and useful links for computer science students and professionals.

PROJECTS FOR TEACHING NETWORK SECURITY

For many instructors, an important component of a network security course is a project or set of projects by which the student gets hands-on experience to reinforce concepts from the text. This book provides an unparalleled degree of support for including a projects component in the course. The IRC not only includes guidance on how to assign and structure the projects, but also includes a set of suggested projects that covers a broad range of topics from the text:

- **Research projects:** A series of research assignments that instruct the student to research a particular topic on the Internet and write a report.
- **Hacking project:** This exercise is designed to illuminate the key issues in intrusion detection and prevention.
- **Programming projects:** A series of programming projects that cover a broad range of topics and that can be implemented in any suitable language on any platform.
- **Lab exercises:** A series of projects that involve programming and experimenting with concepts from the book.
- **Practical security assessments:** A set of exercises to examine current infrastructure and practices of an existing organization.
- **Writing assignments:** A set of suggested writing assignments organized by chapter.
- **Reading/report assignments:** A list of papers in the literature, one for each chapter, that can be assigned for the student to read and then write a short report.

See Appendix B for details.

WHAT'S NEW IN THE FOURTH EDITION

The changes for this new edition of *Network Security Essentials* are more substantial and comprehensive than those for any previous revision.

In the four years since the third edition of this book was published, the field has seen continued innovations and improvements. In this fourth edition, I try to capture these changes while maintaining a broad and comprehensive coverage of the entire field. To begin this process of revision, the third edition was extensively reviewed by a number of professors who teach the subject. In addition, a number of professionals working in the field reviewed individual chapters. The result is that, in many places, the narrative has been clarified and tightened, and illustrations have been improved. Also, a large number of new "field-tested" problems have been added.

Beyond these refinements to improve pedagogy and user friendliness, there have been major substantive changes throughout the book. Highlights include:

- **Pseudorandom number generation and pseudorandom functions (revised):** The treatment of this important topic has been expanded, with the addition of new material in Chapter 2 and a new appendix on the subject.
- **Cryptographic hash functions and message authentication codes (revised):** The material on hash functions and MAC has been revised and reorganized to provide a clearer and more systematic treatment.
- **Key distribution and remote user authentication (revised):** In the third edition, these topics were scattered across three chapters. In the fourth edition, the material is revised and consolidated into a single chapter to provide a unified, systematic treatment.
- **Federated identity (new):** A new section covers this common identity management scheme across multiple enterprises and numerous applications and supporting many thousands, even millions, of users.
- **HTTPS (new):** A new section covers this protocol for providing secure communication between Web browser and Web server.
- **Secure Shell (new):** SSH, one of the most pervasive applications of encryption technology, is covered in a new section.
- **DomainKeys Identified Mail (new):** A new section covers DKIM, which has become the standard means of authenticating e-mail to counter spam.
- **Wireless network security (new):** A new chapter covers this important area of network security. The chapter deals with the IEEE 802.11 (WiFi) security standard for wireless local area networks and the Wireless Application Protocol (WAP) security standard for communication between a mobile Web browser and a Web server.
- **IPsec (revised):** The chapter on IPsec has been almost completely rewritten. It now covers IPsecv3 and IKEv2. In addition, the presentation has been revised to improve clarity and breadth.
- **Legal and ethical issues (new):** A new online chapter covers these important topics.
- **Online appendices (new):** Six online appendices provide addition breadth and depth for the interested student on a variety of topics.
- **Homework problems with solutions:** A separate set of homework problems (with solutions) is provided online for students.
- **Test bank:** A test bank of review questions is available to instructors. This can be used for quizzes or to enable the students to check their understanding of the material.
- **Firewalls (revised):** The chapter on firewalls has been significantly expanded.

With each new edition, it is a struggle to maintain a reasonable page count while adding new material. In part, this objective is realized by eliminating obsolete material and tightening the narrative. For this edition, chapters and appendices that are of less general interest have been moved online as individual PDF files. This has allowed an expansion of material without the corresponding increase in size and price.

RELATIONSHIP TO CRYPTOGRAPHY AND NETWORK SECURITY

This book is adapted from *Cryptography and Network Security, Fifth Edition* (CNS5e). CNS5e provides a substantial treatment of cryptography, including detailed analysis of algorithms and a significant mathematical component, all of which covers 400 pages. *Network Security Essentials: Applications and Standards, Fourth Edition* (NSE4e) provides instead a concise overview of these topics in Chapters 2 and 3. NSE4e includes all of the remaining material of CNS5e. NSE4e also covers SNMP security, which is not covered in CNS5e. Thus, NSE4e is intended for college courses and professional readers where the interest is primarily in the application of network security and without the need or desire to delve deeply into cryptographic theory and principles.

ACKNOWLEDGEMENTS

This new edition has benefited from review by a number of people who gave generously their time and expertise. The following people reviewed all or a large part of the manuscript: Marius Zimand (Towson State University), Shambhu Upadhyaya (University of Buffalo), Nan Zhang (George Washington University), Dongwan Shin (New Mexico Tech), Michael Kain (Drexel University), William Bard (University of Texas), David Arnold (Baylor University), Edward Allen (Wake Forest University), Michael Goodrich (UC-Irvine), Xunhua Wang (James Madison University), Xianyang Li (Illinois Institute of Technology), and Paul Jenkins (Brigham Young University).

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Nikhil Bhargava (IIT Delhi) developed the set of online homework problems and solutions. Professor Sreekanth Malladi of Dakota State University developed the hacking exercises. Sanjay Rao and Ruben Torres of Purdue developed the laboratory exercises that appear in the IRC.

The following people contributed project assignments that appear in the instructor's supplement: Henning Schulzrinne (Columbia University), Cetin Kaya Koc (Oregon State University), and David Balenson (Trusted Information Systems and George Washington University). Kim McLaughlin developed the test bank.

Finally, I would like to thank the many people responsible for the publication of the book, all of whom did their usual excellent job. This includes my editor Tracy Dunkelberger and her assistants Melinda Hagerty and Allison Michael. Also, Jake Warde of Warde Publishers managed the reviews.

With all this assistance, little remains for which I can take full credit. However, I am proud to say that, with no help whatsoever, I selected all of the quotations.

About the Author

William Stallings has made a unique contribution to understanding the broad sweep of technical developments in computer security, computer networking, and computer architecture. He has authored 17 titles and, counting revised editions, a total of 42 books on various aspects of these subjects. His writings have appeared in numerous ACM and IEEE publications, including the *Proceedings of the IEEE* and *ACM Computing Reviews*.

He has 11 times received the award for the best Computer Science textbook of the year from the Text and Academic Authors Association.

In over 30 years in the field, he has been a technical contributor, technical manager, and an executive with several high-technology firms. He has designed and implemented both TCP/IP-based and OSI-based protocol suites on a variety of computers and operating systems, ranging from microcomputers to mainframes. As a consultant, he has advised government agencies, computer and software vendors, and major users on the design, selection, and use of networking software and products.

He created and maintains the **Computer Science Student Resource Site** at WilliamStallings.com/StudentSupport.html. This site provides documents and links on a variety of subjects of general interest to computer science students (and professionals). He is a member of the editorial board of *Cryptologia*, a scholarly journal devoted to all aspects of cryptology.

Dr. Stallings holds a PhD from M.I.T. in Computer Science and a B.S. from Notre Dame in electrical engineering.

CONTENTS

ONLINE CHAPTERS

CHAPTER 1

INTRODUCTION

The combination of space, time, and strength that must be considered as the basic elements of this theory of defense makes this a fairly complicated matter. Consequently, it is not easy to find a fixed point of departure.

—*On War*, Carl Von Clausewitz

The art of war teaches us to rely not on the likelihood of the enemy's not coming, but on our own readiness to receive him; not on the chance of his not attacking, but rather on the fact that we have made our position unassailable.

—*The Art of War*, Sun Tzu

The requirements of **information security** within an organization have undergone two major changes in the last several decades. Before the widespread use of data processing equipment, the security of information felt to be valuable to an organization was provided primarily by physical and administrative means. An example of the former is the use of rugged filing cabinets with a combination lock for storing sensitive documents. An example of the latter is personnel screening procedures used during the hiring process.

With the introduction of the computer, the need for automated tools for protecting files and other information stored on the computer became evident. This is especially the case for a shared system, such as a time-sharing system, and the need is even more acute for systems that can be accessed over a public telephone network, data network, or the Internet. The generic name for the collection of tools designed to protect data and to thwart hackers is **computer security**.

The second major change that affected security is the introduction of distributed systems and the use of networks and communications facilities for carrying data between terminal user and computer and between computer and computer. Network security measures are needed to protect data during their transmission. In fact, the term **network security** is somewhat misleading, because virtually all business, government, and academic organizations interconnect their data processing equipment with a collection of interconnected networks. Such a collection is often referred to as an internet,[1] and the term **internet security** is used.

There are no clear boundaries between these two forms of security. For example, one of the most publicized types of attack on information systems is the computer virus. A virus may be introduced into a system physically when it arrives on an optical disk and is subsequently loaded onto a computer. Viruses may also arrive over an internet. In either case, once the virus is resident on a computer system, internal computer security tools are needed to detect and recover from the virus.

This book focuses on internet security, which consists of measures to deter, prevent, detect, and correct security violations that involve the transmission of information. That is a broad statement that covers a host of possibilities. To give you a feel for the areas covered in this book, consider the following examples of security violations:

[1] We use the term *internet* with a lowercase "i" to refer to any interconnected collection of network. A corporate intranet is an example of an internet. The Internet with a capital "I" may be one of the facilities used by an organization to construct its internet.

1. User A transmits a file to user B. The file contains sensitive information (e.g., payroll records) that is to be protected from disclosure. User C, who is not authorized to read the file, is able to monitor the transmission and capture a copy of the file during its transmission.
2. A network manager, D, transmits a message to a computer, E, under its management. The message instructs computer E to update an authorization file to include the identities of a number of new users who are to be given access to that computer. User F intercepts the message, alters its contents to add or delete entries, and then forwards the message to E, which accepts the message as coming from manager D and updates its authorization file accordingly.
3. Rather than intercept a message, user F constructs its own message with the desired entries and transmits that message to E as if it had come from manager D. Computer E accepts the message as coming from manager D and updates its authorization file accordingly.
4. An employee is fired without warning. The personnel manager sends a message to a server system to invalidate the employee's account. When the invalidation is accomplished, the server is to post a notice to the employee's file as confirmation of the action. The employee is able to intercept the message and delay it long enough to make a final access to the server to retrieve sensitive information. The message is then forwarded, the action taken, and the confirmation posted. The employee's action may go unnoticed for some considerable time.
5. A message is sent from a customer to a stockbroker with instructions for various transactions. Subsequently, the investments lose value and the customer denies sending the message.

Although this list by no means exhausts the possible types of security violations, it illustrates the range of concerns of network security.

This chapter provides a general overview of the subject matter that structures the material in the remainder of the book. We begin with a general discussion of network security services and mechanisms and of the types of attacks they are designed for. Then we develop a general overall model within which the security services and mechanisms can be viewed.

1.1 COMPUTER SECURITY CONCEPTS

A Definition of Computer Security

The NIST *Computer Security Handbook* [NIST95] defines the term *computer security* as

COMPUTER SECURITY

The protection afforded to an automated information system in order to attain the applicable objectives of preserving the integrity, availability, and confidentiality of information system resources (includes hardware, software, firmware, information/data, and telecommunications).