国外计算机科学教材系列

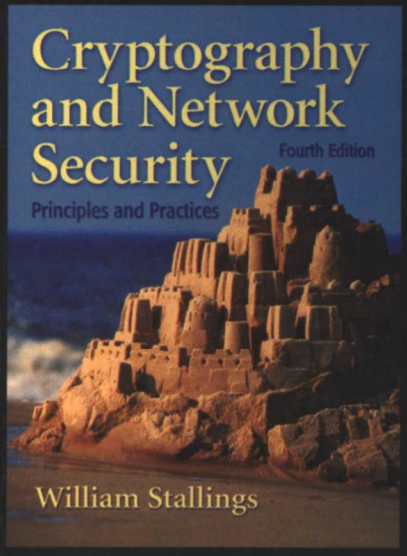
PEARSON Prentice Hall

密码编码学与网络安全

——原理与实践（第四版）

Cryptography and Network Security

Principles and Practices, Fourth Edition



英文版

[美] William Stallings 著

電子工業出版社
Publishing House of Electronics Industry
http://www.phei.com.cn

国外计算机科学教材系列

密码编码学与网络安全

——原理与实践（第四版）

（英文版）

Cryptography and Network Security
Principles and Practices
Fourth Edition

[美] William Stallings 著

電子工業出版社
Publishing House of Electronics Industry
北京 · BEIJING

内容简介

本书系统地介绍了密码编码学与网络安全的基本原理和应用技术。全书主要包括下列四个部分：对称密码部分讨论了对称密码的算法和设计原理；公钥加密和散列函数部分讨论了公钥密码的算法和设计原理、报文鉴别码和散列函数的应用等；网络安全应用部分讨论了系统层的安全问题，包括电子邮件安全、IP安全以及Web安全等；系统安全部分讨论了入侵者和病毒造成的威胁及相应的对策、防火墙和可信系统的应用等。第四版与第三版相比，新增了Whirlpool、CMAC、DDoS以及CCITSE等内容，并对简化的AES、PKI等内容做了扩充。此外，对于基本内容的讲述方法也有许多变化和更新，并新加了100多道习题。

本书可作为信息类专业高年级本科生与低年级研究生的教材，也可供从事信息安全、计算机、通信、电子工程等领域的科技人员参考。

版权贸易合同登记号　图字：01-2006-0891

图书在版编目（CIP）数据

密码编码学与网络安全：原理与实践：第4版 = Cryptography and Network Security: Principles and Practices, Fourth Edition /（美）斯托林斯（Stallings, W.）著. -北京：电子工业出版社，2006.7

（国外计算机科学教材系列）

ISBN 7-121-02767-4

Ⅰ.密… Ⅱ.①斯… Ⅲ.①电子计算机-密码-理论-教材-英文

②计算机网络-安全技术-教材-英文 Ⅳ.①TP309.7 ②TP393.08

中国版本图书馆CIP数据核字（2006）第063362号

责任编辑：谭海平

印　　刷：北京市天竺颖华印刷厂

出版发行：电子工业出版社

北京市海淀区万寿路173信箱　邮编：100036

经　　销：各地新华书店

开　　本：787 × 980　1/16　　印张：43.75　　字数：1120千字

印　　次：2006年7月第1次印刷

定　　价：69.00元

凡购买电子工业出版社的图书，如有缺损问题，请向购买书店调换；若书店售缺，请与本社发行部联系。联系电话：（010）68279077。质量投诉请发邮件至zlts@phei.com.cn，盗版侵权举报请发邮件至dbqq@phei.com.cn。

出 版 说 明

21世纪初的5至10年是我国国民经济和社会发展的重要时期，也是信息产业快速发展的关键时期。在我国加入WTO后的今天，培养一支适应国际化竞争的一流IT人才队伍是我国高等教育的重要任务之一。信息科学和技术方面人才的优劣与多寡，是我国面对国际竞争时成败的关键因素。

当前，正值我国高等教育特别是信息科学领域的教育调整、变革的重大时期，为使我国教育体制与国际化接轨，有条件的高等院校正在为某些信息学科和技术课程使用国外优秀教材和优秀原版教材，以使我国在计算机教学上尽快赶上国际先进水平。

电子工业出版社秉承多年来引进国外优秀图书的经验，翻译出版了“国外计算机科学教材系列”丛书，这套教材覆盖学科范围广、领域宽、层次多，既有本科专业课程教材，也有研究生课程教材，以适应不同院系、不同专业、不同层次的师生对教材的需求，广大师生可自由选择和自由组合使用。这些教材涉及的学科方向包括网络与通信、操作系统、计算机组织与结构、算法与数据结构、数据库与信息处理、编程语言、图形图像与多媒体、软件工程等。同时，我们也适当引进了一些优秀英文原版教材，本着翻译版本和英文原版并重的原则，对重点图书既提供英文原版又提供相应的翻译版本。

在图书选题上，我们大都选择国外著名出版公司出版的高校教材，如Pearson Education培生教育出版集团、麦格劳－希尔教育出版集团、麻省理工学院出版社、剑桥大学出版社等。撰写教材的许多作者都是蜚声世界的教授、学者，如道格拉斯·科默（Douglas E. Comer）、威廉·斯托林斯（William Stallings）、哈维·戴特尔（Harvey M. Deitel）、尤利斯·布莱克（Uyless Black）等。

为确保教材的选题质量和翻译质量，我们约请了清华大学、北京大学、北京航空航天大学、复旦大学、上海交通大学、南京大学、浙江大学、哈尔滨工业大学、华中科技大学、西安交通大学、国防科学技术大学、解放军理工大学等著名高校的教授和骨干教师参与了本系列教材的选题、翻译和审校工作。他们中既有讲授同类教材的骨干教师、博士，也有积累了几十年教学经验的老教授和博士生导师。

在该系列教材的选题、翻译和编辑加工过程中，为提高教材质量，我们做了大量细致的工作，包括对所选教材进行全面论证；选择编辑时力求达到专业对口；对排版、印制质量进行严格把关。对于英文教材中出现的错误，我们通过与作者联络和网上下载勘误表等方式，逐一进行了修订。

此外，我们还将与国外著名出版公司合作，提供一些教材的教学支持资料，希望能为授课老师提供帮助。今后，我们将继续加强与各高校教师的密切联系，为广大师生引进更多的国外优秀教材和参考书，为我国计算机科学教学体系与国际教学体系的接轨做出努力。

电子工业出版社

教材出版委员会

To Antigone
never dull
never boring
always a Sage

NOTATION

Even the natives have difficulty mastering this peculiar vocabulary.

—*The Golden Bough,* Sir James George Frazer

Symbol	Expression	Meaning
D, K	D(K, Y)	Symmetric decryption of ciphertext Y using secret key K.
D, PR_a	D(PR_a, Y)	Asymmetric decryption of ciphertext Y using A's private key PR_a
D, PU_a	D(PU_a, Y)	Asymmetric decryption of ciphertext Y using A's public key PU_a
E, K	E(K, X)	Symmetric encryption of plaintext X using secret key K.
E, PR_a	E(PR_a, X)	Asymmetric encryption of plaintext X using A's private key PR_a
E, PU_a	E(PU_a, X)	Asymmetric encryption of plaintext X using A's public key PU_a
K		Secret key
PR_a		Private key of user A
PU_a		Public key of user A
C, K	C(K, X)	Message authentication code of message X using secret key K.
GF(p)		The finite field of order p, where p is prime. The field is defined as the set Z_p together with the arithmetic operations modulo p.
GF(2^n)		The finite field of order 2^n.
Z_n		Set of nonnegative integers less than n
gcd	gcd(i, j)	Greatest common divisor; the largest positive integer that divides both i and j with no remainder on division.
mod	$a \bmod m$	Remainder after division of a by m.
mod, $\equiv$	$a \equiv b \pmod m$	$a \bmod m = b \bmod m$
mod, $\not\equiv$	$a \not\equiv b \pmod m$	$a \bmod m \neq b \bmod m$
dlog	$\text{dlog}_{a,p}(b)$	Discrete logarithm of the number b for the base a (mod p)
ϕ	$\phi(n)$	The number of positive integers less than n and relatively prime to n. This is Euler's totient function.
Σ	$\sum_{i=1}^{n} a_i$	$a_1 + a_2 + \cdots + a_n$
Π	$\prod_{i=1}^{n} a_i$	$a_1 \times a_2 \times \cdots \times a_n$
$\mid$	$i \mid j$	i divides j, which means that there is no remainder when j is divided by i
$\mid, \mid$	$\mid a \mid$	Absolute value of a
$\parallel$	$x \parallel y$	x concatenated with y
$\approx$	$x \approx y$	x is approximately equal to y
$\oplus$	$x \oplus y$	Exclusive-OR of x and y for single-bit variables; Bitwise exclusive-OR of x and y for multiple-bit variables
$\lfloor, \rfloor$	$\lfloor x \rfloor$	The largest integer less than or equal to x
$\in$	$x \in S$	The element x is contained in the set S.
$\leftrightarrow$	$A \leftrightarrow (a_1, a_2, \ldots, a_k)$	The integer A corresponds to the sequence of integers $(a_1, a_2, \ldots, a_k)$

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 both the principles and practice of cryptography and network security. In the first two parts of the book, the basic issues to be addressed by a network security capability are explored by providing a tutorial and survey of cryptography and network security technology. The latter part of the book deals with the practice of network security: practical applications that have been implemented and are in use to provide network security.

The subject, and therefore this book, draws on a variety of disciplines. In particular, it is impossible to appreciate the significance of some of the techniques discussed in this book without a basic understanding of number theory and some results from probability theory. Nevertheless, an attempt has been made to make the book self-contained. The book presents not only the basic mathematical results that are needed but provides the reader with an intuitive understanding of those results. Such background material is introduced as needed. This approach helps to motivate the material that is introduced, and the author considers this preferable to simply presenting all of the mathematical material in a lump at the beginning of the book.

INTENDED AUDIENCE

The book is intended for both an academic and a professional audience. As a textbook, it is intended as a one-semester undergraduate course in cryptography and 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; NET4 Security, another core area in the Information Technology body of knowledge; and IT311, Cryptography, an advanced course; 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 four parts:

Part One. **Conventional Encryption:** A detailed examination of conventional encryption algorithms and design principles, including a discussion of the use of conventional encryption for confidentiality.

Part Two. **Public-Key Encryption and Hash Functions:** A detailed examination of public-key encryption algorithms and design principles. This part also examines the use of message authentication codes and hash functions, as well as digital signatures and public-key certificates.

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

Part Four. **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, the 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.

A more detailed, chapter-by-chapter summary of each part appears at the beginning of that part.

INTERNET SERVICES FOR INSTRUCTORS AND STUDENTS

There is a Web site for this book that provides support for students and instructors. The site 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/Crypto/Crypto4e.html. 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 CRYPTOGRAPHY AND NETWORK SECURITY

For many instructors, an important component of a cryptography or 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 instructor's manual 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
- **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
- **Writing assignments:** A set of suggested writing assignments, 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

In the three years since the third edition of this book was published, the field has seen continued innovations and improvements. In this new 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 the following:

- **Simplified AES:** This is an educational, simplified version of AES (Advanced Encryption Standard), which enables students to grasp the essentials of AES more easily.
- **Whirlpool:** This is an important new secure hash algorithm based on the use of a symmetric block cipher.
- **CMAC:** This is a new block cipher mode of operation. CMAC (cipher-based message authentication code) provides message authentication based on the use of a symmetric block cipher.
- **Public-key infrastructure (PKI):** This important topic is treated in this new edition.
- **Distributed denial of service (DDoS) attacks:** DDoS attacks have assumed increasing significance in recent years.
- **Common Criteria for Information Technology Security Evaluation:** The Common Criteria have become the international framework for expressing security requirements and evaluating products and implementations.
- **Online appendices:** Six appendices available at this book's Web site supplement the material in the text.

In addition, much of the other material in the book has been updated and revised.

ACKNOWLEDGMENTS

This new edition has benefited from review by a number of people, who gave generously of their time and expertise. The following people reviewed all or a large part of the manuscript: Danny Krizanc (Wesleyan University), Breno de Medeiros (Florida State University), Roger H. Brown (Rensselaer at Hartford), Cristina Nita-Rotarul (Purdue University), and Jimmy McGibney (Waterford Institute of Technology).

Thanks also to the many people who provided detailed technical reviews of a single chapter: Richard Outerbridge, Jorge Nakahara, Jeroen van de Graaf, Philip Moseley, Andre Correa, Brian Bowling, James Muir, Andrew Holt, Décio Luiz Gazzoni Filho, Lucas Ferreira, Dr. Kemal Bicakci, Routo Terada, Anton Stiglic, Valery Pryamikov, and Yongge Wang.

Joan Daemen kindly reviewed the chapter on AES. Vincent Rijmen reviewed the material on Whirlpool. And Edward F. Schaefer reviewed the material on simplified AES.

The following people contributed homework problems for the new edition: Joshua Brandon Holden (Rose-Hulman Institute if Technology), Kris Gaj (George Mason University), and James Muir (University of Waterloo).

Sanjay Rao and Ruben Torres of Purdue developed the laboratory exercises that appear in the instructor's supplement. 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).

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 the staff at Prentice Hall, particularly production manager Rose Kernan; my supplements manager Sarah Parker; and my new editor Tracy Dunkelberger. Also, Patricia M. Daly did the copy editing.

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.

Contents