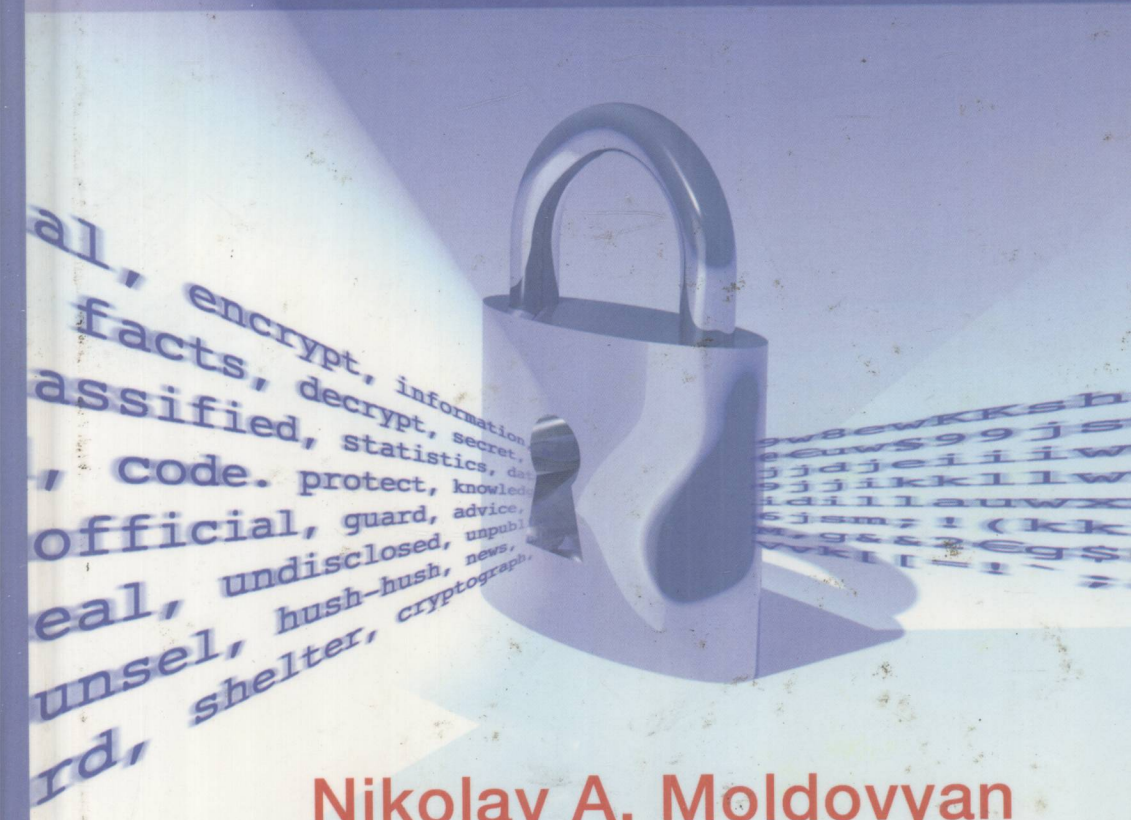
DATA-DRIVEN BLOCK CIPHERS FOR FAST TELECOMMUNICATION SYSTEMS



Nikolay A. Moldovyan
Alexander A. Moldovyan

Auerbach Publications
Taylor & Francis Group

DATA-DRIVEN BLOCK CIPHERS FOR FAST TELECOMMUNICATION SYSTEMS

Nikolay A. Moldovyan
Alexander A. Moldovyan

Auerbach Publications
Taylor & Francis Group
New York London

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Auerbach Publications
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Auerbach is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-13: 978-1-4200-5411-8 (Hardcover)

Library of Congress Cataloging-in-Publication Data

Moldovyan, Nick.
Data-driven block ciphers for fast telecommunication systems / Nikolai Moldovyan, Alexander A. Moldovyan.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-4200-5411-8 (hardback : alk. paper) 1. Computer security. 2. Ciphers. 3. Cryptography. I. Moldovyan, Alex. II. Title.

QA76.9.A25M664 2007
005.8--dc22 2007031200

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the Auerbach Web site at
http://www.auerbach-publications.com

DATA-DRIVEN BLOCK CIPHERS FOR FAST TELECOMMUNICATION SYSTEMS

OTHER TELECOMMUNICATIONS BOOKS FROM AUERBACH

Architecting the Telecommunication Evolution: Toward Converged Network Services
Vijay K. Gurbani and Xian-He Sun
ISBN: 0-8493-9567-4

Business Strategies for the Next-Generation Network
Nigel Seel
ISBN: 0-8493-8035-9

Chaos Applications in Telecommunications
Peter Stavroulakis
ISBN: 0-8493-3832-8

Context-Aware Pervasive Systems: Architectures for a New Breed of Applications
Seng Loke
ISBN: 0-8493-7255-0

Fundamentals of DSL Technology
Philip Golden, Herve Dedieu, Krista S Jacobsen
ISBN: 0-8493-1913-7

Introduction to Mobile Communications: Technology,, Services, Markets
Tony Wakefield, Dave McNally, David Bowler, Alan Mayne
ISBN: 1-4200-4653-5

IP Multimedia Subsystem: Service Infrastructure to Converge NGN, 3G and the Internet
Rebecca Copeland
ISBN: 0-8493-9250-0

MPLS for Metropolitan Area Networks
Nam-Kee Tan
ISBN: 0-8493-2212-X

Performance Modeling and Analysis of Bluetooth Networks: Polling, Scheduling, and Traffic Control
Jelena Misic and Vojislav B Misic
ISBN: 0-8493-3157-9

A Practical Guide to Content Delivery Networks
Gilbert Held
ISBN: 0-8493-3649-X

Resource, Mobility, and Security Management in Wireless Networks and Mobile Communications
Yan Zhang, Honglin Hu, and Masayuki Fujise
ISBN: 0-8493-8036-7

Security in Distributed, Grid, Mobile, and Pervasive Computing
Yang Xiao
ISBN: 0-8493-7921-0

TCP Performance over UMTS-HSDPA Systems
Mohamad Assaad and Djamal Zeghlache
ISBN: 0-8493-6838-3

Testing Integrated QoS of VoIP: Packets to Perceptual Voice Quality
Vlatko Lipovac
ISBN: 0-8493-3521-3

The Handbook of Mobile Middleware
Paolo Bellavista and Antonio Corradi
ISBN: 0-8493-3833-6

Traffic Management in IP-Based Communications
Trinh Anh Tuan
ISBN: 0-8493-9577-1

Understanding Broadband over Power Line
Gilbert Held
ISBN: 0-8493-9846-0

Understanding IPTV
Gilbert Held
ISBN: 0-8493-7415-4

WiMAX: A Wireless Technology Revolution
G.S.V. Radha Krishna Rao, G. Radhamani
ISBN: 0-8493-7059-0

WiMAX: Taking Wireless to the MAX
Deepak Pareek
ISBN: 0-8493-7186-4

Wireless Mesh Networking: Architectures, Protocols and Standards
Yan Zhang, Jijun Luo and Honglin Hu
ISBN: 0-8493-7399-9

Wireless Mesh Networks
Gilbert Held
ISBN: 0-8493-2960-4

AUERBACH PUBLICATIONS

www.auerbach-publications.com
To Order Call: 1-800-272-7737 • Fax: 1-800-374-3401
E-mail: orders@crcpress.com

Dedicated to the memory of our father,
Andrey Alexander Moldovyan(u),
who always supported us in our creative affairs.

Preface

Among different directions of applied cryptography, the cipher design based on the data-driven operations (DDOs) is, by comparison, poorly represented in the published and available literature. The RC5 and RC6 block ciphers based on data-dependent rotations (DDRs) are well known, but many other DDO-based ciphers are known only to a small number of readers. The first application of the DDOs as a main cryptographic primitive relates to RC5 [56] and encryption algorithms based on data-dependent subkey selection [32]. The DDO are implemented with so-called controlled operation boxes (COBs), the most known type of which is represented by permutation networks (PNs). The PNs have been well studied in the field of telephone switching systems and parallel computations (1950–1980), see for example [4, 11, 68]. However, the first application of PNs in cryptalgorithm design relates to 1992 [53], where PNs have been applied to perform key-dependent bit permutations. Only about ten years later were the PNs used to perform data-dependent permutations. Dependence of the bit permutations on input data has imparted a new quality to PNs as a cryptographic primitives and solved some principal problems connected with key-dependent permutations. New applications of PNs have been requested to investigate new properties of PNs. In this area differential and linear characteristics of PNs have been studied and the notions of the PN order and switchable PNs have been introduced.

The next step of the development of the DDO-based cipher design relates to generalization of PNs connected with introducing the controlled substitution–permutation networks (CSPNs) constructed using the minimum size controlled elements. It has been shown that ciphers based on the PNs and CSPNs, implementing DDOs of different types, provide fast encryption and low implementation cost in hardware.

One can currently read papers devoted to different particular items on DDOs as a cryptographic primitive, however there is no published work introducing the DDO-based design as an individual section of the applied cryptography. Because the DDO-based ciphers represent an essential interest for application in the fast telecommunication systems and mobile networks, we have found that summarizing the known results in one book to be both reasonable and important.

In this book we present the most interesting results on the DDO boxes topologies, classification of the controlled elements, DDO-based ciphers, and fast software-oriented encryption algorithms using the data-driven subkey section as a main primitive. Prior to this book a major portion of these results have been available only in Russian literature.

Acknowledgments

We are grateful to the editorial board of *The Computer Science Journal of Moldova* for permission to use the material previously published in our papers. These include: 1994, volume 2, pp. 269–282; 2000, volume 8, pp. 270–283; 2003, volume 11, pp. 292–315; 2005, volume. 13, pp. 84–109; 2005, volume 13, pp. 268–291.

We also thank the co-authors of our papers and the authors of other papers, reports, and books cited for their contributions to the development of data-driven block ciphers, the subject of this book.

Introduction

Block data encryption is the most widely used cryptographic transformation in computer and telecommunication systems. The security of ciphers should be based on the secrecy of a small portion of information called a *key*. All other details of cryptosystems are considered as known elements. Moreover, ciphers should be secure against known and chosen text attacks as well as against different side channel attacks. If we mention encryption algorithm, then first of all we have in mind security requirements. Substitution-permutation and Feistel's networks represent conventional designs of block ciphers. Controlled operations have been unsuccessfully tried over a long term as the main cryptographic primitive in cipher design. Recently, they have been proposed to perform variable transformation, i.e., data-dependent (DD) operations (DDOs). This has given birth to a new direction in fast cryptography oriented to cheap hardware implementation. Such application of the controlled operations lead to designing the data-driven ciphers providing significant reduction of hardware implementation costs to relatively conventional designs. The implementation efficacy estimated using different comparison models increases by a factor up to 10 against AES candidates and other conventional ciphers. The data-driven ciphers are very attractive while embedding security mechanisms in constrained environments. Therefore, the data-driven ciphers are extremely interesting for usage to support the successful solution of security problems while deploying ad hoc and sensor networks.

Histories, different types, and topologies of the DDO boxes are considered in this book. Detailed attention is paid to design, properties, and application of the DD permutations (DDPs). Several DDP-based ciphers are considered concerning security and implementation items. Topologies of the controlled substitution-permutation networks (CSPNs) that are built up using small-size controlled elements (CEs) as standard building block are considered. The notion of the order of the CSPN is explained. The classification of CEs corresponding to different types is described. Reversible CSPNs representing a new cryptographic primitive and their designs are discussed. Application of the CSPNs as DDOs is illustrated by examples of several ciphers with 64- and 128-bit data block. A feature of the ciphers is the use of very simple key scheduling providing high performance in case of frequent change of keys.

About the Authors

Nikolay A. Moldovyan, Ph.D., is an honored inventor of the Russian Federation (2002), Prof. Doctor (2001), a chief researcher with the Specialized Center of Program Systems "SPECTR," and a professor with the Saint Petersburg State Electrotechnical University. His research interests include computer security and cryptography. He has authored or co-authored more than 60 patents and 250 scientific articles, books, and reports. He received his Ph.D. from the Academy of Sciences of Moldova (1981). He can be contacted at: nmold@cobra.ru.

Alexander A. Moldovyan, Ph.D., is a Prof. Doctor (2005), a director with the Specialized Center of Program Systems "SPECTR," and a professor with the State University for Waterway Communications (Saint Petersburg, Russia). His research interests include information assurance, computer security, and applied cryptography. He has authored or co-authored more than 45 patents and 180 scientific articles, books, and reports. He received his Ph.D. from the Saint Petersburg Electrical Engineering University (1996). He can be contacted at: ma@cobra.ru.

Abbreviations

AES	advanced encryption standard
ASIC	application specific integrated circuit
BF	Boolean function
BPI	bit permutation instruction
CBC	cipher block chaining
CE	controlled element
CFB	cipher-feedback
CLB	configurable logic block
COS	controlled operational substitution
CP	controlled permutation
CPB	controlled permutation box
CPI	controlled permutation instruction
CPU	central processing unit (processor)
CSPN	controlled substitution-permutation network
CTPO	controlled two-place operation
DC	differential characteristic
DCA	differential cryptanalysis
DDO	data-dependent operation (data-driven operation)
DDP	data-dependent permutation (data-driven permutation)
DDR	data-dependent rotation
DDSS	data-dependent subkey selection
DFA	differential fault analysis
DFF	D Flip-Flop
DSS	digital signature scheme
ECB	electronic codebook
FG	functional generator
FPGA	field programmable gate array
FT	final transformation
IV	initialization vector
LC	linear characteristic
LCA	linear cryptanalysis

LUA	loop unrolling architecture
MDA	microprocessor design architecture
MDC	manipulation detection code
MAC	message authentication code
NL	nonlinearity
OFB	output-feedback
PA	pipelined architecture
PN	permutation network
RAM	random access memory
RCO	reversible controlled operations
RDDO	reversible data-dependent (data-driven) operations
SCO	switchable controlled operation
SDDO	switchable data-dependent operation (data-driven operation)
SDDP	switchable data-driven permutation
SPN	switchable permutation network
TT	truth table
VBP	variable bit permutation
VLSI	very large scale integration

Notations Used in the Book

- $[x]$ denotes the integer part of x
- $\{0,1\}^g$ denotes the set of all binary vectors $U = (u_1, u_2, \ldots, u_g)$, where $\forall i \in \{1, \ldots, g\}\ u_i \in \{0,1\}$
- (X, Y) denotes concatenation of the vectors X and Y
- $X \oplus Y$ denotes the bitwise XOR (EXCLUSIVE-OR) operation of the two vectors X and Y: $X, Y \in \{0,1\}^s$
- $X >>> k$ or $X^{>>>k}$ (or $X^{>k>}$) denotes to-right rotation of the word X by k bits
- $X <<< k$ or $X^{<<<k}$ (or $X^{<k<}$) denotes to-left cyclic rotation of the word $X = (x_1, \ldots, x_{32})$ by k bits, i.e., $\forall i \in \{1, \ldots, 32 - k\}$ we have $y_i = x_{i+k}$ and $\forall i \in \{33 - k, \ldots, 32\}$ we have $y_i = x_{i+k-32}$.
- $\varphi(U)$ denotes Hamming weight of binary vector U; $\varphi(U)$ is equal to the number of nonzero components of U, i.e., $\varphi(U) \stackrel{def}{=} \sum_{i=1}^{g} u_i$
- $X \otimes Y$ denotes bitwise AND operation of the two vectors X and Y: $X, Y \in \{0,1\}^{(g)}$. For $c \in \{0,1\}$ and $X \in \{0,1\}^g$, we define $Y = c \cdot X$ where $y_i = c \cdot x_i\ \forall\ i \in \{1, \ldots, g\}$
- $\varnothing$ denotes a reserved two-place operation
- $\varphi'(U)$ denotes the parity of $\varphi(U)$, i.e., $\varphi'(U) \stackrel{def}{=} \varphi(U) \bmod 2$
- "$\leftarrow$" or ":=" denotes assign operation
- $\bullet$ denotes the binary scalar product $c = A \bullet X = \varphi'(A \otimes X)$, $c \in \{0,1\}$
- $\mathbf{F}_1 \| \mathbf{F}_2$ denotes the cascade of the $\mathbf{F}_1$ and $\mathbf{F}_2$ transformation boxes, i.e., $\mathbf{F}_1 \| \mathbf{F}_2(X_1, X_2) = (\mathbf{F}_1(X_1), \mathbf{F}_2(X_2))$
- $\mathbf{F} \circ \mathbf{S}$ denotes superposition of $\mathbf{F}$ and $\mathbf{S}$ transformations
- "$+_z$" denotes modulo 2^z addition of words (for example, the expression $j \leftarrow W \bmod 2^{11}$ is equivalent to the expression $j \leftarrow Z +_{11} 0$)
- "$-_z$" denotes modulo 2^z subtraction
- $\langle Z \rangle$ denotes the average value of the variable Z
- $\#\{z_1, z_2, \ldots\}$ denotes the number of elements in the set $\{z_1, z_2, \ldots\}$
- $a | b$ denotes that number a divides number b

Contents