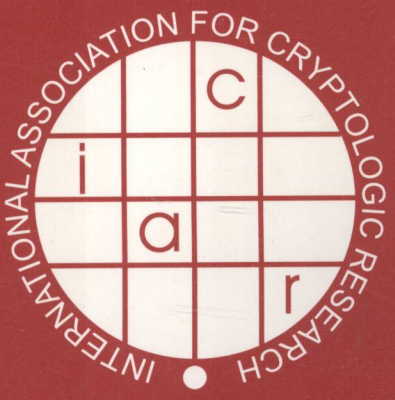
Serge Vaudenay (Ed.)

LNCS 4004

Advances in Cryptology – EUROCRYPT 2006

24th Annual International Conference on the Theory and Applications of Cryptographic Techniques
St. Petersburg, Russia, May/June 2006, Proceedings



Springer

Serge Vaudenay (Ed.)

Advances in Cryptology – EUROCRYPT 2006

24th Annual International Conference on the Theory and Applications of Cryptographic Techniques
St. Petersburg, Russia, May 28 – June 1, 2006
Proceedings

Springer

Volume Editor

Serge Vaudenay
EPFL, I&C, LASEC, Station 14
INF Building, 1015 Lausanne, Switzerland
E-mail: serge.vaudenay@epfl.ch

Library of Congress Control Number: 2006925895

CR Subject Classification (1998): E.3, F.2.1-2, G.2.1, D.4.6, K.6.5, C.2, J.1

LNCS Sublibrary: SL 4 – Security and Cryptology

ISSN 0302-9743
ISBN-10 3-540-34546-9 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-34546-6 Springer Berlin Heidelberg New York

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India
Printed on acid-free paper SPIN: 11761679 06/3142 5 4 3 2 1 0

Lecture Notes in Computer Science 4004

Commenced Publication in 1973
Founding and Former Series Editors:
Gerhard Goos, Juris Hartmanis, and Jan van Leeuwen

Editorial Board

Preface

The 2006 edition of the Eurocrypt conference was held in St. Petersburg, Russia from May 28 to June 1, 2006. It was the 25th Eurocrypt conference. Eurocrypt is sponsored by the International Association for Cryptologic Research (IACR). Eurocrypt 2006 was chaired by Anatoly Lebedev, and I had the privilege to chair the Program Committee.

Eurocrypt collected 198 submissions on November 21, 2005. The Program Committee carried out a thorough review process. In total, 863 review reports were written by renowned experts, Program Committee members as well as external referees. Online discussions led to 1,114 additional discussion messages and about 1,000 emails. The review process was run using e-mail and the iChair software by Thomas Baignères and Matthieu Finiasz. Every submitted paper received at least three review reports. The Program Committee had a meeting in Lausanne on February 4, 2006. We selected 33 papers, notified acceptance or rejection to the authors, and had a cheese fondue. Authors were then invited to revise their submission. The present proceedings include all the revised papers. Due to time constraints the revised versions could not be reviewed again.

We delivered a "Eurocrypt Best Paper Award." The purpose of the award is to formally acknowledge authors of outstanding papers and to recognize excellence in the cryptographic research fields. Committee members were invited to nominate papers for this award. A poll then yielded a clear majority. This year, we were pleased to deliver the Eurocrypt Best Paper Award to Phong Q. Nguyen and Oded Regev for their brilliant paper "Learning a Parallelepiped: Cryptanalysis of GGH and NTRU Signatures."

The Program Committee invited two speakers: David Naccache and Kevin McCurley. The current proceedings include papers about their presentation.

I would like to thank Anatoly Lebedev for organizing the conference. I would like to thank the IACR Board for honoring me by asking me to chair the Program Committee. The Program Committee and external reviewers worked extremely hard. I deeply thank them for this volunteer work. Acknowledgments also go to the authors of submitted papers, the speakers, and the invited speakers. I am grateful to Thomas Baignères and Matthieu Finiasz for their hard work developing the iChair software and constantly adding features. I also thank Shai Halevi and Amr Youssef, who participated in the software testing. Finally, I heartily thank Christine and Emilien, my family, for letting me spend some time on Eurocrypt.

This year, we celebrated the 30th anniversary of the publication of the Diffie-Hellman seminal paper "New Directions in Cryptography." As cryptography was becoming a new academic research area, this pioneer paper invented public-key cryptography. My wish is that research in cryptography will lead us to 30 more years of fun.

March 2006

Serge Vaudenay
Lausanne

Eurocrypt 06

May 28–June 1, 2006, Saint Petersburg, Russia

General Chair

Anatoly Lebedev, LAN Crypto
Moscow, Russia

Program Chair

Serge Vaudenay, EPFL
Lausanne, Switzerland

Program Committee

Feng Bao ..... Institute for Infocomm Research
Eli Biham ..... Technion
Alex Biryukov ..... Katholieke Universiteit Leuven
Alexandra Boldyreva ..... Georgia Institute of Technology
Colin Boyd ..... Queensland University of Technology
Jean-Sébastien Coron ..... University of Luxembourg
Yevgeniy Dodis ..... New York University
Matt Franklin ..... University of California Davis
Eiichiro Fujisaki ..... NTT Laboratories
Juan Garay ..... Bell Labs — Lucent Technologies
Martin Hirt ..... ETH Zurich
Tetsu Iwata ..... Ibaraki University
Pil Joong Lee ..... Pohang University of Science and Technology
Antoine Joux ..... DGA and University of Versailles
Jonathan Katz ..... University of Maryland
Arjen Lenstra ..... Bell Labs – Lucent Technologies and Technische Universiteit Eindhoven
Helger Lipmaa ..... Cybernetica AS and University of Tartu
Javier Lopez ..... University of Malaga
Stefan Lucks ..... University of Mannheim
Philip MacKenzie ..... DoCoMo USA Labs
Mitsuru Matsui ..... Mitsubishi Electric
Alexander May ..... University of Paderborn
Willi Meier ..... FH Aargau
Atsuko Miyaji ..... JAIST
Kaisa Nyberg ..... Helsinki University of Technology and Nokia
Kenny Paterson ..... Royal Holloway University of London
Greg Rose ..... Qualcomm
Berry Schoenmakers ..... Technische Universiteit Eindhoven
Serge Vaudenay (Chair) ..... EPFL
Michael Wiener ..... Cryptographic Clarity
Robert Zuccherato ..... Entrust, Inc.

External Reviewers

Michel Abdalla
Masayuki Abe
Carlisle Adams
Luis von Ahn
Koichiro Akiyama
Elena Andreeva
Kazumaro Aoki
Seigo Arita
Frederik Armknecht
Tomoyuki Asano
Gildas Avoine
Thomas Baignères
Elad Barkan
Don Beaver
Zuzana Beerliová
Mihir Bellare
Vicente Benjumea
Dan Bernstein
John Black
Daniel Bleichenbacher
Johannes Blömer
Jean Christian Boileau
Xavier Boyen
Harry Buhrman
Jan Camenisch
Ran Canetti
Juyoung Cha
Liqun Chen
Rafi Chen
Kookrae Cho
Sherman Chow
Carlos Cid
Scott Contini
Yang Cui
Reza Curtmola
Ivan Damgård
Vanesa Daza
Alex Dent
Claus Diem
Yan Zong Ding
Martin Döring
Orr Dunkelman
Stefan Dziembowski
Daniela Engelbert
Nelly Fazio
Serge Fehr
Matthieu Finiasz
Marc Fischlin
Matthias Fitzi
Pierre-Alain Fouque
Felix Freiling
Jun Furukawa
Soichi Furuya
Martin Gagne
Steven Galbraith
David Galindo
Ran Gelles
Mark Gondree
Daniel Gottesman
Louis Goubin
Ignacio Gracia
Safuat Hamdy
Goichiro Hanaoka
Phil Hawkes
Ryotaro Hayashi
Javier Herranz
Florian Hess
Shoichi Hirose
Dennis Hofheinz
Thomas Holenstein
Nick Howgrave-Graham
Yong Ho Hwang
Yuval Ishai
Stanislaw Jarecki
Jorge Jiménez
Ellen Jochemsz
Pascal Junod
Senny Kamara
Akinori Kawachi
John Kelsey
Aggelos Kiayias
Joe Killian
Mehmet Kiraz
Kazukuni Kobara
Vladimir Kolesnikov
Chiu-Yuen Koo
Matthias Krause
Volker Krummel
Caroline Kudla
Ulrich Kühn
Simon Künzli
Kaoru Kurosawa
Tanja Lange
Joseph Lano
Peeter Laud
Sven Laur
Jung Wook Lee
Reynald Lercier
Christina Lindenberg
Moses Liskov
Yi Lu
Christoph Ludwig
Anna Lysyanskaya
Greg Maitland
John Malone-Lee
Keith Martin
Sebastiá Martín
Natsume Matsuzaki
Lorenz Minder
Serge Mister
Payman Mohassel
Jean Monnerat
Paz Morillo
Tim Moses
Siguna Mueller
Frederic Muller
Sean Murphy
Toru Nakanishi
Deholo Nali
Anderson Nascimento
Gregory Neven
Phong Nguyen
Antonio Nicolosi
Jesper Nielsen
Wakaha Ogata
Kazuo Ohta
Koji Okada
Takeshi Okamoto
Tatsuaki Okamoto
Rafail Ostrovsky
Raphael Overbeck
Michael Paddon

Carles Padro
Adriana Palacio
Saurabh Panjwani
Jung Hyung Park
Sylvain Pasini
Kun Peng
Rene Peralta
Adrian Perrig
Giuseppe Persiano
Krzysztof Pietrzak
Benny Pinkas
Bart Preneel
Bartosz Przydatek
Prashant Puniya
Carla Rafols
Dominik Raub
Omer Reingold
German Saez
Yasuyuki Sakai
Bagus Santoso
Hovav Schaham
Daniel Schepers
Katja Schmidt-Samoa
Jasper Scholten
Jae Woo Seo
Ji Sun Shin
Jong Hoon Shin
Tom Shrimpton
Andrey Sidorenko
Johan Sjödin
Nigel Smart
Adam Smith
Clayton Smith
Miguel Soriano
Masakazu Soshi
Martijn Stam
Heiko Stamer
Dirk Stegemann
Ron Steinfeld
Daisuke Suzuki
Koutarou Suzuki
Mitsuru Tada
Katsuyuki Takashima
Keisuke Tanaka
Lauri Tarkkala
Tamir Tassa
Isamu Teranishi
Stefano Tessaro
Toyohiro Tsurumaru
Pim Tuyls
Shigenori Uchiyama
Maribel Vasco
Frederik Vercauteren
Jorge L. Villar
Ulrich Vollmer
Martin Vuagnoux
Shabsi Walfish
Johan Wallén
Guilin Wang
Yongge Wang
Bogdan Warinschi
Benne de Weger
Ralf-Philipp Weinmann
William Whyte
Christopher Wolf
Stefan Wolf
Yongdong Wu
Jürg Wullschleger
Alex Yampolskiy
Ke Yang
Yeon Hyeong Yang
Yiqun Lisa Yin
Shoko Yonezawa
Dae Hyun Yum
Yunlei Zhao
Huafei Zhu

Lecture Notes in Computer Science

For information about Vols. 1–3899

please contact your bookseller or Springer

Vol. 4004: S. Vaudenay (Ed.), Advances in Cryptology - EUROCRYPT 2006. XIV, 613 pages. 2006.

Vol. 3998: T. Calamoneri, I. Finocchi, G.F. Italiano (Eds.), Algorithms and Complexity. XII, 394 pages. 2006.

Vol. 3994: V.N. Alexandrov, G.D. van Albada, P.M.A. Sloot, J. Dongarra (Eds.), Computational Science – ICCS 2006, Part IV. XXIX, 1094 pages. 2006.

Vol. 3993: V.N. Alexandrov, G.D. van Albada, P.M.A. Sloot, J. Dongarra (Eds.), Computational Science – ICCS 2006, Part III. XXX, 1138 pages. 2006.

Vol. 3992: V.N. Alexandrov, G.D. van Albada, P.M.A. Sloot, J. Dongarra (Eds.), Computational Science – ICCS 2006, Part II. XXIX, 1121 pages. 2006.

Vol. 3991: V.N. Alexandrov, G.D. van Albada, P.M.A. Sloot, J. Dongarra (Eds.), Computational Science – ICCS 2006, Part I. CCXX, 1090 pages. 2006.

Vol. 3990: J. C. Beck, B.M. Smith (Eds.), Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems. X, 301 pages. 2006.

Vol. 3987: M. Hazas, J. Krumm, T. Strang (Eds.), Location- and Context-Awareness. X, 289 pages. 2006.

Vol. 3986: K. Stølen, W.H. Winsborough, F. Martinelli, F. Massacci (Eds.), Trust Management. XIV, 474 pages. 2006.

Vol. 3984: M. Gavrilova, O. Gervasi, V. Kumar, C.J. K. Tan, D. Taniar, A. Laganà, Y. Mun, H. Choo (Eds.), Computational Science and Its Applications - ICCSA 2006, Part V. XXV, 1045 pages. 2006.

Vol. 3983: M. Gavrilova, O. Gervasi, V. Kumar, C.J. K. Tan, D. Taniar, A. Laganà, Y. Mun, H. Choo (Eds.), Computational Science and Its Applications - ICCSA 2006, Part IV. XXVI, 1191 pages. 2006.

Vol. 3982: M. Gavrilova, O. Gervasi, V. Kumar, C.J. K. Tan, D. Taniar, A. Laganà, Y. Mun, H. Choo (Eds.), Computational Science and Its Applications - ICCSA 2006, Part III. XXV, 1243 pages. 2006.

Vol. 3981: M. Gavrilova, O. Gervasi, V. Kumar, C.J. K. Tan, D. Taniar, A. Laganà, Y. Mun, H. Choo (Eds.), Computational Science and Its Applications - ICCSA 2006, Part II. XXVI, 1255 pages. 2006.

Vol. 3980: M. Gavrilova, O. Gervasi, V. Kumar, C.J. K. Tan, D. Taniar, A. Laganà, Y. Mun, H. Choo (Eds.), Computational Science and Its Applications - ICCSA 2006, Part I. LXXV, 1199 pages. 2006.

Vol. 3979: T.S. Huang, N. Sebe, M.S. Lew, V. Pavlović, M. Kölsch, A. Galata, B. Kisačanin (Eds.), Computer Vision in Human-Computer Interaction. XII, 121 pages. 2006.

Vol. 3978: B. Hnich, M. Carlsson, F. Fages, F. Rossi (Eds.), Recent Advances in Constraints. VIII, 179 pages. 2006. (Sublibrary LNAI).

Vol. 3976: F. Boavida, T. Plagemann, B. Stiller, C. Westphal, E. Monteiro (Eds.), Networking 2006. Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications Systems. XXVI, 1276 pages. 2006.

Vol. 3975: S. Mehrotra, D.D. Zeng, H. Chen, B. Thuraisingham, F.Y. Wang (Eds.), Intelligence and Security Informatics. XXII, 772 pages. 2006.

Vol. 3970: T. Braun, G. Carle, S. Fahmy, Y. Koucheryavy (Eds.), Wired/Wireless Internet Communications. XIV, 350 pages. 2006.

Vol. 3968: K.P. Fishkin, B. Schiele, P. Nixon, A. Quigley (Eds.), Pervasive Computing. XV, 402 pages. 2006.

Vol. 3967: D. Grigoriev, J. Harrison, E.A. Hirsch (Eds.), Computer Science – Theory and Applications. XVI, 684 pages. 2006.

Vol. 3966: Q. Wang, D. Pfahl, D.M. Raffo, P. Wernick (Eds.), Software Process Change. XIV, 356 pages. 2006.

Vol. 3965: M. Bernardo, A. Cimatti (Eds.), Formal Methods for Hardware Verification. VII, 243 pages. 2006.

Vol. 3964: M. Ü. Uyar, A.Y. Duale, M.A. Fecko (Eds.), Testing of Communicating Systems. XI, 373 pages. 2006.

Vol. 3962: W. IJsselsteijn, Y. de Kort, C. Midden, B. Eggen, E. van den Hoven (Eds.), Persuasive Technology. XII, 216 pages. 2006.

Vol. 3960: R. Vieira, P. Quaresma, M.d.G.V. Nunes, N.J. Mamede, C. Oliveira, M.C. Dias (Eds.), Computational Processing of the Portuguese Language. XII, 274 pages. 2006. (Sublibrary LNAI).

Vol. 3959: J.-Y. Cai, S. B. Cooper, A. Li (Eds.), Theory and Applications of Models of Computation. XV, 794 pages. 2006.

Vol. 3958: M. Yung, Y. Dodis, A. Kiayias, T. Malkin (Eds.), Public Key Cryptography - PKC 2006. XIV, 543 pages. 2006.

Vol. 3956: G. Barthe, B. Gregoire, M. Huisman, J.-L. Lanet (Eds.), Construction and Analysis of Safe, Secure, and Interoperable Smart Devices. IX, 175 pages. 2006.

Vol. 3955: G. Antoniou, G. Potamias, C. Spyropoulos, D. Plexousakis (Eds.), Advances in Artificial Intelligence. XVII, 611 pages. 2006. (Sublibrary LNAI).

Vol. 3954: A. Leonardis, H. Bischof, A. Pinz (Eds.), Computer Vision – ECCV 2006, Part IV. XVII, 613 pages. 2006.

Vol. 3953: A. Leonardis, H. Bischof, A. Pinz (Eds.), Computer Vision – ECCV 2006, Part III. XVII, 649 pages. 2006.

Vol. 3952: A. Leonardis, H. Bischof, A. Pinz (Eds.), Computer Vision – ECCV 2006, Part II. XVII, 661 pages. 2006.

Vol. 3951: A. Leonardis, H. Bischof, A. Pinz (Eds.), Computer Vision – ECCV 2006, Part I. XXXV, 639 pages. 2006.

Vol. 3950: J.P. Müller, F. Zambonelli (Eds.), Agent-Oriented Software Engineering VI. XVI, 249 pages. 2006.

Vol. 3947: Y.-C. Chung, J.E. Moreira (Eds.), Advances in Grid and Pervasive Computing. XXI, 667 pages. 2006.

Vol. 3946: T.R. Roth-Berghofer, S. Schulz, D.B. Leake (Eds.), Modeling and Retrieval of Context. XI, 149 pages. 2006. (Sublibrary LNAI).

Vol. 3945: M. Hagiya, P. Wadler (Eds.), Functional and Logic Programming. X, 295 pages. 2006.

Vol. 3944: J. Quiñonero-Candela, I. Dagan, B. Magnini, F. d'Alché-Buc (Eds.), Machine Learning Challenges. XIII, 462 pages. 2006. (Sublibrary LNAI).

Vol. 3943: N. Guelfi, A. Savidis (Eds.), Rapid Integration of Software Engineering Techniques. X, 289 pages. 2006.

Vol. 3942: Z. Pan, R. Aylett, H. Diener, X. Jin, S. Göbel, L. Li (Eds.), Technologies for E-Learning and Digital Entertainment. XXV, 1396 pages. 2006.

Vol. 3941: S.W. Gilroy, M.D. Harrison (Eds.), Interactive Systems. XI, 267 pages. 2006.

Vol. 3940: C. Saunders, M. Grobelnik, S. Gunn, J. Shawe-Taylor (Eds.), Subspace, Latent Structure and Feature Selection. X, 209 pages. 2006.

Vol. 3939: C. Priami, L. Cardelli, S. Emmott (Eds.), Transactions on Computational Systems Biology IV. VII, 141 pages. 2006. (Sublibrary LNBI).

Vol. 3936: M. Lalmas, A. MacFarlane, S. Rüger, A. Tombros, T. Tsikrika, A. Yavlinsky (Eds.), Advances in Information Retrieval. XIX, 584 pages. 2006.

Vol. 3935: D. Won, S. Kim (Eds.), Information Security and Cryptology - ICISC 2005. XIV, 458 pages. 2006.

Vol. 3934: J.A. Clark, R.F. Paige, F.A. C. Polack, P.J. Brooke (Eds.), Security in Pervasive Computing. X, 243 pages. 2006.

Vol. 3933: F. Bonchi, J.-F. Boulicaut (Eds.), Knowledge Discovery in Inductive Databases. VIII, 251 pages. 2006.

Vol. 3931: B. Apolloni, M. Marinaro, G. Nicosia, R. Tagliaferri (Eds.), Neural Nets. XIII, 370 pages. 2006.

Vol. 3930: D.S. Yeung, Z.-Q. Liu, X.-Z. Wang, H. Yan (Eds.), Advances in Machine Learning and Cybernetics. XXI, 1110 pages. 2006. (Sublibrary LNAI).

Vol. 3929: W. MacCaull, M. Winter, I. Düntsch (Eds.), Relational Methods in Computer Science. VIII, 263 pages. 2006.

Vol. 3928: J. Domingo-Ferrer, J. Posegga, D. Schreckling (Eds.), Smart Card Research and Advanced Applications. XI, 359 pages. 2006.

Vol. 3927: J. Hespanha, A. Tiwari (Eds.), Hybrid Systems: Computation and Control. XII, 584 pages. 2006.

Vol. 3925: A. Valmari (Ed.), Model Checking Software. X, 307 pages. 2006.

Vol. 3924: P. Sestoft (Ed.), Programming Languages and Systems. XII, 343 pages. 2006.

Vol. 3923: A. Mycroft, A. Zeller (Eds.), Compiler Construction. XIII, 277 pages. 2006.

Vol. 3922: L. Baresi, R. Heckel (Eds.), Fundamental Approaches to Software Engineering. XIII, 427 pages. 2006.

Vol. 3921: L. Aceto, A. Ingólfsdóttir (Eds.), Foundations of Software Science and Computation Structures. XV, 447 pages. 2006.

Vol. 3920: H. Hermanns, J. Palsberg (Eds.), Tools and Algorithms for the Construction and Analysis of Systems. XIV, 506 pages. 2006.

Vol. 3918: W.K. Ng, M. Kitsuregawa, J. Li, K. Chang (Eds.), Advances in Knowledge Discovery and Data Mining. XXIV, 879 pages. 2006. (Sublibrary LNAI).

Vol. 3917: H. Chen, F.Y. Wang, C.C. Yang, D. Zeng, M. Chau, K. Chang (Eds.), Intelligence and Security Informatics. XII, 186 pages. 2006.

Vol. 3916: J. Li, Q. Yang, A.-H. Tan (Eds.), Data Mining for Biomedical Applications. VIII, 155 pages. 2006. (Sublibrary LNBI).

Vol. 3915: R. Nayak, M.J. Zaki (Eds.), Knowledge Discovery from XML Documents. VIII, 105 pages. 2006.

Vol. 3914: A. Garcia, R. Choren, C. Lucena, P. Giorgini, T. Holvoet, A. Romanovsky (Eds.), Software Engineering for Multi-Agent Systems IV. XIV, 255 pages. 2006.

Vol. 3911: R. Wyrzykowski, J. Dongarra, N. Meyer, J. Waśniewski (Eds.), Parallel Processing and Applied Mathematics. XXIII, 1126 pages. 2006.

Vol. 3910: S.A. Brueckner, G.D.M. Serugendo, D. Hales, F. Zambonelli (Eds.), Engineering Self-Organising Systems. XII, 245 pages. 2006. (Sublibrary LNAI).

Vol. 3909: A. Apostolico, C. Guerra, S. Istrail, P. Pevzner, M. Waterman (Eds.), Research in Computational Molecular Biology. XVII, 612 pages. 2006. (Sublibrary LNBI).

Vol. 3908: A. Bui, M. Bui, T. Böhme, H. Unger (Eds.), Innovative Internet Community Systems. VIII, 207 pages. 2006.

Vol. 3907: F. Rothlauf, J. Branke, S. Cagnoni, E. Costa, C. Cotta, R. Drechsler, E. Lutton, P. Machado, J.H. Moore, J. Romero, G.D. Smith, G. Squillero, H. Takagi (Eds.), Applications of Evolutionary Computing. XXIV, 813 pages. 2006.

Vol. 3906: J. Gottlieb, G.R. Raidl (Eds.), Evolutionary Computation in Combinatorial Optimization. XI, 293 pages. 2006.

Vol. 3905: P. Collet, M. Tomassini, M. Ebner, S. Gustafson, A. Ekárt (Eds.), Genetic Programming. XI, 361 pages. 2006.

Vol. 3904: M. Baldoni, U. Endriss, A. Omicini, P. Torroni (Eds.), Declarative Agent Languages and Technologies III. XII, 245 pages. 2006. (Sublibrary LNAI).

Vol. 3903: K. Chen, R. Deng, X. Lai, J. Zhou (Eds.), Information Security Practice and Experience. XIV, 392 pages. 2006.

Vol. 3902: R. Kronland-Martinet, T. Voinier, S. Ystad (Eds.), Computer Music Modeling and Retrieval. XI, 275 pages. 2006.

Vol. 3901: P.M. Hill (Ed.), Logic Based Program Synthesis and Transformation. X, 179 pages. 2006.

Vol. 3900: F. Toni, P. Torroni (Eds.), Computational Logic in Multi-Agent Systems. XVII, 427 pages. 2006. (Sublibrary LNAI).

Author Index

Table of Contents

Hash Functions

Oblivious Transfer

Numbers and Lattices

Foundations

Invited Talk II

Block Ciphers

Cryptography Without Random Oracles

Multiparty Computation

Cryptography for Groups

Security Analysis of the Strong Diffie-Hellman Problem

Jung Hee Cheon

ISaC and Dept. of Mathematics, Seoul National University, Republic of Korea
jhcheon@snu.ac.kr
http://www.math.snu.ac.kr/~jhcheon

Abstract. Let g be an element of prime order p in an abelian group and $\alpha \in \mathbb{Z}_p$. We show that if g, g^{α}, and g^{α^d} are given for a positive divisor d of $p-1$, we can compute the secret α in $O(\log p \cdot (\sqrt{p/d} + \sqrt{d}))$ group operations using $O(\max\{\sqrt{p/d}, \sqrt{d}\})$ memory. If g^{α^i} $(i = 0, 1, 2, \ldots, d)$ are provided for a positive divisor d of $p+1$, α can be computed in $O(\log p \cdot (\sqrt{p/d} + d))$ group operations using $O(\max\{\sqrt{p/d}, \sqrt{d}\})$ memory. This implies that the strong Diffie-Hellman problem and its related problems have computational complexity reduced by $O(\sqrt{d})$ from that of the discrete logarithm problem for such primes.

Further we apply this algorithm to the schemes based on the Diffie-Hellman problem on an abelian group of prime order p. As a result, we reduce the complexity of recovering the secret key from $O(\sqrt{p})$ to $O(\sqrt{p/d})$ for Boldyreva's blind signature and the original ElGamal scheme when $p-1$ (resp. $p+1$) has a divisor $d \leq p^{1/2}$ (resp. $d \leq p^{1/3}$) and d signature or decryption queries are allowed.

Keywords: Discrete logarithm, Diffie-Hellman, strong Diffie-Hellman, ElGamal encryption, blind signature.

1 Introduction

Let g be an element of prime order p in an abelian group and $\alpha \in \mathbb{Z}_p$. The ℓ-Strong Diffie-Hellman (ℓ-SDH) problem asks to find $g^{\alpha^{\ell+1}}$ given $g, g^{\alpha}, \ldots, g^{\alpha^{\ell}}$. Recently, many cryptographic schemes including encryption, signature, and key management schemes are proposed on the basis of the Strong Diffie-Hellman (SDH) problem [MSK02, BB04e, BB04s], or its variants such as the Bilinear Diffie-Hellman problem [BBS04, DY05] and the Bilinear Diffie-Hellman Exponent (BDHE) problem [BBG05, BGW05]. A lower bound on the computational complexity of the SDH problem or its variants for generic groups are known in the sense of Shoup [Sho97], but it does not guarantee the security for specific parameters.

In this paper, we analyze the security of the SDH problem. More precisely, we show that if g, g^{α} and g^{α^d} are given for a positive divisor d of $p-1$, the secret $\alpha \in \mathbb{Z}_p$ can be computed in $O(\log p \cdot (\sqrt{p/d} + \sqrt{d}))$ group operations using $O(\max\{\sqrt{p/d}, \sqrt{d}\})$ memory. If g^{α^i} $(i = 0, 1, 2, \ldots, d)$ are provided for a positive

S. Vaudenay (Ed.): EUROCRYPT 2006, LNCS 4004, pp. 1–11, 2006.

divisor d of $p+1$, it can be computed in $O(\log p \cdot (\sqrt{p/d}+d))$ group operations using the same size of memory. This implies that the strong Diffie-Hellman problem and its related problems have computational complexity reduced by $O(\sqrt{d})$ from that of the discrete logarithm problem for such primes. Hence it is necessary to increase by the size of d the key size of the cryptographic schemes based on the ℓ-SDH problem or its variants if the base group has such a prime as its order.

We investigate some known elliptic curve parameters and find that either $p-1$ or $p+1$ has many small divisors for the largest prime divisor p of its order for each elliptic curve in [NIST, BLS01, KM05, MIRACL]. For example, if we use the curve E^+ over $GF(3^{155})$ [BLS01] for the broadcast encryption [BGW05], the secret key can be computed in $O(2^{59})$ exponentiations (resp. $O(2^{42})$ exponentiations) when the number of users is 2^{32} (resp. 2^{64}), rather than $O(2^{76})$ group operations.

Moreover, we apply this algorithm to the schemes based on the Diffie-Hellman problem on an abelian group of prime order p. As a result, we show the complexity of recovering the secret key is reduced from $O(\sqrt{p})$ to $O(\sqrt{p/d})$ for Boldyreva's blind signatures [Bol03] when d signature or decryption queries are allowed and $p-1$ has a divisor $d \leq p^{1/2}$ or $p+1$ has a divisor $d \leq p^{1/3}$. Similar results hold for the original ElGamal scheme [ElG85] with decryption oracles and the conference keying protocol by Burmester-Desmedt [BD94] with key issuing oracles.

The rest of the paper is organized as follows: In Section 2, we introduce the SDH related problems and some schemes based on them. In Section 3, we present our algorithms. In Section 4, we exploit our algorithms to attack several protocols based on the Diffie-Hellman problem. In Section 5, we investigate some known elliptic curve parameters in order to check if our algorithms are applicable for these parameters. We conclude in Section 6.

2 Strong Diffie-Hellman Problems and Their Variants

Let G be an abelian group of prime order p and g a generator of G. The **Discrete Logarithm (DL) Problem** in G asks to find $a \in \mathbb{Z}_p$ given g and g^a in G. Many cryptosystems are designed on the basis of the DL problem, but most of them have the security equivalent to a weaker variant of the DL problem rather than the DL problem itself. Two most important weaker variants are as follows:

The Computation Diffie-Hellman (CDH) Problem. Given (g, g^a, g^b), compute g^{ab}.
The Decisional Diffie-Hellman (DDH) Problem. Given (g, g^a, g^b, g^c), decide whether $c = ab$ in $\mathbb{Z}_p$.

Recently, some weakened variants of the CDH problem are introduced and being used to construct cryptosystems for various functionalities or security without random oracles. One characteristic of these problems is to disclose $g, g^\alpha, \ldots, g^{\alpha^\ell}$ for the secret α and some integer ℓ.