Lecture Notes in Computer Science

11505

Founding Editors

Gerhard Goos

Karlsruhe Institute of Technology, Karlsruhe, Germany

Juris Hartmanis

Cornell University, Ithaca, NY, USA

Editorial Board Members

Elisa Bertino

Purdue University, West Lafayette, IN, USA

Wen Gao

Peking University, Beijing, China

Bernhard Steffen

TU Dortmund University, Dortmund, Germany

Gerhard Woeginger

RWTH Aachen, Aachen, Germany

Moti Yung

Columbia University, New York, NY, USA

More information about this series at http://www.springer.com/series/7410

Jintai Ding · Rainer Steinwandt (Eds.)

Post-Quantum Cryptography

10th International Conference, PQCrypto 2019 Chongqing, China, May 8–10, 2019 Revised Selected Papers



Editors
Jintai Ding
University of Cincinnati
Cincinnati, OH, USA

Rainer Steinwandt Department of Mathematical Sciences Florida Atlantic University Boca Raton, FL, USA

ISSN 0302-9743 ISSN 1611-3349 (electronic) Lecture Notes in Computer Science ISBN 978-3-030-25509-1 ISBN 978-3-030-25510-7 (eBook) https://doi.org/10.1007/978-3-030-25510-7

LNCS Sublibrary: SL4 – Security and Cryptology

© Springer Nature Switzerland AG 2019

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

PQCrypto 2019, the 10th International Workshop on Post-Quantum Cryptography, was held in Chongqing, China, during May 8–10, 2019.

The aim of the PQCrypto conference series is to serve as a forum for researchers to present and discuss their work on cryptography in an era with large-scale quantum computers.

Following the same model as its predecessor, PQCrypto 2019 adopted a two-stage submission process in which authors registered their paper(s) one week before the final submission deadline.

The conference received 76 submissions with authors from about 30 countries. Each paper (that had not been withdrawn by the authors) was reviewed in private by at least three Program Committee members. The private review phase was followed by an intensive discussion phase, conducted online. At the end of this process, the Program Committee selected 22 papers for inclusion in the technical program and publication in these proceedings. In some cases, a shepherding phase was imposed to ensure that necessary changes were incorporated by the submitting authors, before the paper was accepted for inclusion in the program and these proceedings. The accepted papers cover a broad spectrum of research within the conference's scope, including both the design and the analysis of cryptographic systems.

In addition to the 22 contributed technical presentations, the program featured outstanding invited talks and a presentation on NIST's ongoing post-quantum cryptography standardization process.

Organizing and running this year's edition of the PQCrypto conference series was a team effort, and we are indebted to everyone who helped make PQCrypto 2019 a success. In particular, we would like to thank all members of the Program Committee and the external reviewers who were a vital part of compiling the technical program. Evaluating and discussing the submissions was a labor-intense task, and we truly appreciate the work that went into this. We also owe a big thank you to Professor Hong Xiang from Chongqing University, who made sure that all local arrangements fell into place as needed.

May 2019 Jintai Ding
Rainer Steinwandt

PQCrypto 2019

The 10th International Conference on Post-Quantum Cryptography

Chongqing, China May 8–10, 2019

Program Chairs

Jintai Ding University of Cincinnati, USA Rainer Steinwandt Florida Atlantic University, USA

Steering Committee

Daniel J. Bernstein University of Illinois at Chicago, USA Johannes Buchmann Technische Universität Darmstadt, Germany

Claude Crépeau McGill University, Canada Jintai Ding University of Cincinnati, USA Philippe Gaborit University of Limoges, France

Tanja Lange Technische Universiteit Eindhoven, The Netherlands

Daniele Micciancio University of California at San Diego, USA

Michele Mosca University of Waterloo, Canada

Nicolas Sendrier Inria, France

Rainer Steinwandt Florida Atlantic University, USA

Tsuyoshi Takagi Kyushu University and University of Tokyo, Japan

Bo-Yin Yang Academia Sinica, Taiwan

Program Committee

Gorjan Alagic University of Maryland, USA Martin R. Albrecht University of London, UK

Yoshinori Aono National Institute of Communication Technology,

Japan

John B. Baena University Nacional de Colombia, Colombia

Shi Bai Florida Atlantic University, USA
Lejla Batina Radboud University, The Netherlands
Daniel J. Bernstein University of Illinois at Chicago, USA
Johannes Buchmann Technische Universität Darmstadt, Germany

Chen-Mou Cheng Osaka University, Japan

Jung Hee Cheon Seoul National University, Republic of Korea

Thomas Eisenbarth Universität zu Lübeck, Germany, and Worcester

Polytechnic Institute, USA

Ali El Kaafarani University of Oxford, UK
Scott Fluhrer Cisco Systems, USA
Philippe Gaborit Université Limoges, France
Tommaso Gagliardoni IBM Research, Switzerland
Kris Gaj George Mason University, USA

María I. González Vasco University Rey Juan Carlos, Spain

Tim Güneysu Ruhr-Universität Bochum, DFKI, Germany Sean Hallgren Pennsylvania State University, USA

David Jao University of Waterloo, evolutionQ Inc., Canada

Jiwu Jing Chinese Academy of Sciences, China

Thomas Johansson Lund University, Sweden

Antoine Joux Institut de Mathematique de Jussieu, France

Kwangjo Kim KAIST, Republic of Korea

Stefan Kölbl Technical University of Denmark, Denmark

Brad Lackey University of Maryland, USA
Kristin Lauter Microsoft Research, USA

Yi-Kai Liu NIST, USA

Vadim Lubachevsky IBM Research, USA

Michele Mosca University of Waterloo, Perimeter Inst., Canada

María Naya-Plasencia Inria, France

Ruben Niederhagen Fraunhofer SIT, Germany

Ray Perlner NIST, USA

Ludovic Perret Post-Quantum Advanced Technologies,

Sorbonne University, France

Edoardo Persichetti Florida Atlantic University, USA
Albrecht Petzoldt University of Versailles, France
Thomas Pöppelmann Infineon Technologies, Germany
Martin Roetteler Microsoft Research, USA
Alexander Russell University of Connecticut, USA

Nicolas Sendrier Inria, France

Junji Shikata Yokohama National University, Japan Daniel Smith-Tone NIST, University of Louisville, USA Fang Song Portland State University, USA

Jakub Szefer Yale University, USA Damien Stehlé ENS de Lyon, France

Tsuyoshi Takagi Kyushu University and University of Tokyo, Japan

Katsuyuki Takashima Mitsubishi Electric, Japan

Jean-Pierre Tillich Inria, France Keita Xagawa NTT, Japan

Bo-Yin Yang Academia Sinica, Taiwan

Shengyu Zhang Tencent, The Chinese University of Hong Kong,

SAR China

Zhang Zhenfeng Chinese Academy of Sciences, China

External Reviewers

Roberto Araujo

Edward Eaton

Markus Krausz

Florian Bache Pedro Maat Massolino

Aaron Lye

Thomas Prest

Ward Beullens Khoa Nguyen Nina Bindel Tobias Oder

Denis Butin Angel L. Perez Del Pozo

Daniel Cabarcas Federico Pintore Ryann Cartor Rachel Player

Crystal Clough Eamonn Postlethwaite

Daniel Escudero Youming Qiao Thomas Espitau Joost Renes Tim Fritzmann Angela Robinson Oian Guo Peter Schwabe Javier Herranz Alan Szepieniec James Howe Rotem Tsabary Lei Hu Javier Verbel Shih-Han Hung Weigiang Wen Shuichi Katsumata Yang Yu Natasha Kharchenko Pavol Zajac

Contents

Lattice-Based Cryptography	
Finding Closest Lattice Vectors Using Approximate Voronoi Cells Emmanouil Doulgerakis, Thijs Laarhoven, and Benne de Weger	3
Evaluating the Potential for Hardware Acceleration of Four NTRU-Based Key Encapsulation Mechanisms Using Software/Hardware Codesign Farnoud Farahmand, Viet B. Dang, Duc Tri Nguyen, and Kris Gaj	23
Forward-Secure Group Signatures from Lattices	44
Towards Practical Microcontroller Implementation of the Signature Scheme Falcon	65
Learning with Errors	
Round5: Compact and Fast Post-quantum Public-Key Encryption	83
The Impact of Error Dependencies on Ring/Mod-LWE/LWR	100
Based Schemes Jan-Pieter D'Anvers, Frederik Vercauteren, and Ingrid Verbauwhede	103
Direct CCA-Secure KEM and Deterministic PKE from Plain LWE Xavier Boyen and Qinyi Li	116
Cryptanalysis	
Recovering Short Secret Keys of RLCE in Polynomial Time	133
Cryptanalysis of an NTRU-Based Proxy Encryption Scheme from ASIACCS'15	153
On the Complexity of "Superdetermined" Minrank Instances	167

Key Establishment

Constant-Round Group Key Exchange from the Ring-LWE Assumption Daniel Apon, Dana Dachman-Soled, Huijing Gong, and Jonathan Katz	189
Hybrid Key Encapsulation Mechanisms and Authenticated Key Exchange Nina Bindel, Jacqueline Brendel, Marc Fischlin, Brian Goncalves, and Douglas Stebila	206
Tighter Security Proofs for Generic Key Encapsulation Mechanism in the Quantum Random Oracle Model	227
(Tightly) QCCA-Secure Key-Encapsulation Mechanism in the Quantum Random Oracle Model	249
Isogeny-Based Cryptography	
Faster SeaSign Signatures Through Improved Rejection Sampling	271
Genus Two Isogeny Cryptography	286
On Lions and Elligators: An Efficient Constant-Time Implementation of CSIDH	307
Hash-Based Cryptography	
Quantum Security of Hash Functions and Property-Preservation of Iterated Hashing	329
Improved Quantum Multicollision-Finding Algorithm	350
Code-Based Cryptography	
Preventing Timing Attacks Against RQC Using Constant Time Decoding of Gabidulin Codes	371
A Traceable Ring Signature Scheme Based on Coding Theory	387

	Contents	Xiii
On the Decoding Failure Rate of QC-MDPC Bit-Flipping Decod Nicolas Sendrier and Valentin Vasseur	ers	404
Author Index		417