Proceedings

2022

Network and Distributed System Security Symposium

Proceedings

2022

Network and Distributed System Security Symposium

April 24-28, 2022

San Diego, CA, USA

Hosted by the
Internet Society

Internet Society
11710 Plaza America Drive
Suite 400
Reston, VA 20190

Address your correspondence to: NDSS Program Manager, Internet Society, 11710 Plaza America Drive, Suite 400, Reston, VA 20190 USA, tel. +1 703 439 2120, fax +1 703 326 9881, ndss@elists.isoc.org.

ISBN Number (Digital Format) : 1-891562-74-6

Additional copies may be ordered from:

Internet Society
11710 Plaza America Drive
Suite 400
Reston, VA 20190
tel +1 703 439 2120
fax +1 703 326 9881
http://www.internetsociety.org

Table of Contents

Session 4A: Wireless

Session 4B: Secure Computing

Session 7C: Human Factors

Message from the General Chair

Welcome to the 2022 Network and Distributed System Security (NDSS) Symposium!

This year marks our first year trying a hybrid event. We are excited to have an in-person symposium again, while still including those who are unable to travel, and we hope to provide an exceptional experience to both sets of participants! This year, we have an amazing program featuring a stellar line-up of research papers, six workshops, two poster sessions (one in person and one virtual), and two exciting keynote speakers.

NDSS 2022 has continued the tradition of having two submission phases. The Program Committee Co-Chairs Farinaz Koushanfar and Wenyuan Xu have done a wonderful job putting together the program, and I'd like to thank them for their tireless efforts. I would also like to thank the program committee members and the external reviewers for their work in creating an exciting program, and our publications chair, David Balenson, for pulling the papers together to be published.

Thanks also to Yasemin Acar and Ben Stock for bringing together a great set of associated workshops and symposium. This year, we have five workshops - three on Sunday, April 24, and two on Thursday, April 28 – and our first ever symposium on Thursday. The associated events this year are:

1) Automotive and Autonomous Vehicle Security (AutoSec) Workshop;
2) Fuzzing Workshop;
3) Binary Analysis Research (BAR) Workshop;
4) Learning from Authoritative Security Experiment Results (LASER) Workshop;
5) Measurements, Attacks, and Defenses for the Web (MADWeb) Workshop; and
6) Usable Security and Privacy (USEC) Symposium.

Four of the workshops continue from last year, one is entirely new, and we're thrilled to welcome USEC back to NDSS as a symposium rather than a workshop.

I'm also excited that we have a poster session again this year and would like to thank Xiaojing Liao and Alexandra Dmitrienko for putting it together. Thank you especially for the effort to have not one, but two, poster sessions, so that both our in-person and virtual attendees and poster presenters can participate.

There are many other people who have contributed to making NDSS 2022 a success. I would like to thank Stefanie Roos and her team for reviewing the student grant applications, Brendan Saltaformaggio and Ramjita Pai Kasturi for publicity, Lujo Bauer and his team for reviewing papers for the Test of Time award, Robert Broberg as sponsorship chair, and Tom Hutton as local arrangements chair. I would also like to thank the Steering Group for providing sage recommendations and feedback throughout the year.

NDSS is possible in large part thanks to our generous sponsors. I'd like to thank (in alphabetical order) sponsorship from the following companies: Baidu, ByteDance, Check Point, Futurewei Technologies, Google, Homelight, IBM, Intel Security, Microsoft Research, National Science Foundation, Netflix, Novi, Palo Alto Networks, Qualcomm, Resecurity, Team Cymru, and Technology Innovation Institute (TII).

An especially huge thank you to Karen O'Donoghue and her team for all the work performed behind the scenes, especially during the challenges of Covid and our first ever hybrid event! Thank you to the Internet Society for their ongoing support of NDSS, and to the Association Management Solutions (AMS) staff.

And lastly, thank you to everyone who is participating in the symposium for your patience as we changed dates due to Covid, and work to make a hybrid event a success. I hope that you all enjoy NDSS 2022!

Carrie Gates
General Chair, NDSS 2022

Message from the Program Committee Co-Chairs

It is our great pleasure to present to you the technical program of the Annual Network and Distributed System Security (NDSS) Symposium 2022, held as a hybrid event on April 24-28, 2022. For the past 29 years NDSS has established itself as one of the top conferences in systems and network security. Papers published at NDSS have made significant impact on research and practice, as exemplified by the awardees of the NDSS Test-of-Time Award. Our goal continues to be “impact”, especially in the form of novel and practical solutions and techniques in cyber security. We hope that the papers in this year’s program reflect the same strong potential in securing real-world networks and systems.

This year we received a total of 513 complete submissions (i.e., not counting papers that clearly violated the submission guidelines). Submissions were evaluated on the basis of their technical quality, novelty, and significance. Multiple rounds of reviewing culminated in a one-day online program committee meeting on October 21, 2021. At the end of the review process, 83 papers (16.2% acceptance rate) were selected to appear in the program. We strove to make the review process a competitive but constructive one. Program Committee (PC) members were regularly reminded to identify positive points in a submission and provide concrete suggestions to improve each paper. As we did last year, we took the approach of having three reviews per paper in the first review round to guarantee higher assurance of early decisions. Later for each author rebuttal, which was solicited after all reviews were in, we required the corresponding reviews be updated to respond to the rebuttal, to help improve the quality, timeliness, and responsiveness of the review process.

Organizing a conference as large as NDSS is a substantial endeavor, and we would like to extend our sincere thanks to everyone who contributed her or his time and effort. We would like to specifically thank a few individuals who made particular contributions to NDSS 2022. General Chair Carrie Gates oversaw the conference and worked closely with us for Keynote Speaker. Karen O'Donoghue served as a critical interface between the Program Co-Chairs, the Organizing Committee and ISOC. Publicity Chair Brendan Saltaformaggio worked seamlessly with us to solicit submissions and promote the conference. Publications Chair David Balenson took excellent care of the proceedings production matters. Due to the pandemic the PC meeting was conducted online, this year we switched to a one-day single-track schedule with success. Our special thanks also go to Chen Yan from Zhejiang University for continuous effort in maintaining the submission system, supporting the PC Co-Chairs during the reviewing process, and planning the event schedule.

Last but not least, we would like to thank our PC members and the external reviewers. The PC members have contributed significant time and effort to the creation of the technical program. It has been our privilege working with them. Finally, we thank all authors who submitted to NDSS 2022 and all attendees who are virtually joining us at NDSS 2022, without whom NDSS would not be possible. Enjoy the conference!

Farinaz Koushanfar and Wenyuan Xu
Program Co-Chairs, NDSS 2022

Message from the Internet Society

The Internet Society is proud, once again, to host the Network and Distributed System Security (NDSS) Symposium, one of the world's premier academic research conferences on network and distributed system security. Our involvement with the NDSS Symposium spans 29 years, a true testament to the importance, global support, and longevity of this annual event.

A key focus of the Internet Society is improving the security and trustworthiness of the global open Internet. In order to promote this trust, we need new ideas and quality research on the security and privacy of our connected devices, as well as the Internet that brings them together. NDSS 2022 will highlight the latest innovations and research on security and privacy and will give researchers a platform to collaborate further on their work. The symposium, with its focus on student participation, will also help to foster the next generation of leaders in the fields of security and privacy.

After two years of a global pandemic, NDSS 2022 will be the first ever hybrid NDSS symposium. We are excited that some of you will be able to meet face-to-face again in 2022 while those who are virtual will have full access to the program. The program committee and event organization team have put together an exceptional agenda for the online symposium. This agenda is a full five days including five co-located workshops (AutoSec, BAR, FUZZING, MADWeb, and LASER), a co-located symposium (USEC), 83 paper presentations, two exciting keynotes, and 34 posters. The two keynotes this year are particularly important and timely topics. Alex Gantman will open the symposium discussing Measuring Security Outcomes. On Wednesday, Srini Devadas will explore the question: "Will Cryptographically-secure Anonymous Communication Ever be Practical?"

NDSS 2022 is a valuable gathering of security researchers and professionals from around the globe. We are extremely grateful for the hard work and countless hours that the General Chair Carrie Gates, Program Committee Co-chairs Farinaz Koushanfar and Wenyuan Xu, and other members of the Organizing Committee have invested putting together the event. We also thank the reviewers and volunteers who helped prepare the many aspects of the event. Finally, we thank all our sponsors without whom this conference would not be possible. This includes our Platinum sponsor the National Science Foundation; our Gold sponsors Baidu, Google, and Technology Innovation Institute; our T-shirt sponsor IBM; our Silver sponsors ByteDance, Checkpoint, FutureWei Technologies, Intel Security, Microsoft Research, Netflix, Novi, Palo Alto Networks, Qualcomm, Resecurity, and Team Cymru; and our Supporting sponsor Homelight.

On behalf of the Internet Society, I welcome you to NDSS 2022. I hope you have an enjoyable and productive week.

Andrew Sullivan
CEO, Internet Society

Program Committee

Farinaz Koushanfar, *University of California, San Diego* (Program Co-Chair)
Wenyaun Xu, *Zhejiang University* (Program Co-Chair)

Adam Doupe, *Arizona State University*
Adwait Nadkarni, *William & Mary*
Ahmad-Reza Sadeghi, *Technical University of Darmstadt*
Alexandra Dmitrienko, *University of Wuerzburg*
Alvaro Cardenas, *UC Santa Cruz*
Antonio Bianchi, *Purdue University*
Arthur Gervais, *Imperial College London*
Avesta Sasan, *University of California Davis*
Aysajan Abidin, *imec-COSIC, KU Leuven*
Ben Stock, *CISPA Helmholtz Center for Information Security*
Benjamin Andow, *Google*
Berkay Celik, *Purdue University*
Bita Rouhani, *Microsoft*
Brendan Saltaformaggio, *Georgia Institute of Technology*
Brent ByungHoon Kang, *KAIST*
Chao Shen, *Xi'an Jiaotong University*
Christopher Liebchen, *Google*
Cornelius Aschermann, *Ruhr-Universität Bochum*
Dan Wallach, *Rice*
Daniel Holcomb, *University of Massachusetts Amherst*
Dongyan Xu, *Purdue University*
Emiliano De Cristofaro, *University College London*
Gang Qu, *University of Maryland*
Gang Wang, *University of Illinois at Urbana-Champaign*
Guofei Gu, *Texas A&M*
Haixin Duan, *Tsinghua University*
Hamed Okhravi, *MIT Lincoln Laboratory*
Haojin Zhu, *Shanghai Jiao Tong University*
Hong Hu, *Pennsylvania State University*
Houman Homayoun, *UC Davis*
Ivan De Oliveira Nunes, *Rochester Institute of Technology*
Jeyavijayan Rajendran, *Texas A&M University*
Joel Frank, *Ruhr-Universität Bochum*
Johanna Sepulveda, *Airbus Defence and Space*
Kangjie Lu, *University of Minnesota*
Kapil Singh, *IBM T.J. Watson Research Center*
Katharina Kohls, *Radboud University*
Kun Sun, *George Mason University*

Lannan Luo, *University of South Carolina*
Lejla Batina, *Radboud University*
Limin Jia, *CMU*
Lucas Davi, *University of Duisburg-Essen*
Maliheh Shirvanian, *Visa Research*
Manuel Egele, *Boston University*
Marcus Peinado, *Microsoft Research*
Markus Miettinen, *Technical University of Darmstadt*
Mathias Payer, *EPFL*
Mauro Conti, *University of Padua*
Michael Franz, *University of California, Irvine*
Minhui, Jason Xue, *The University of Adelaide*
Neil Gong, *Duke University*
Nele Mentens, *Leiden University and KU Leuven*
Ning Zhang, *Washington University in St. Louis*
Norrathep Rattanavipanon, *Prince of Songkla University, Phuket Campus*
Pedro Moreno-Sanchez, *IMDEA Software Institute*
Qi Alfred Chen, *UC Irvine*
Qi Li, *Tsinghua University*
Qian Wang, *Wuhan University*
Qiang Zeng, *University of South Carolina*
Ren Zhang, *Nervos*
Ryan Gerdes, *Virginia Tech*
Saman Zonouz, *Rutgers University*
Samuel Jero, *MIT Lincoln Laboratory*
Samuel Marchal, *Aalto University and F-Secure Corporation*
Sazzadur Rahaman, *University of Arizona*
Selcuk Uluagac, *Florida International University*
Shouling Ji, *Zhejiang University*
Sooel Son, *KAIST*
Srdjan Capkun, *ETH Zurich*
Srinath Setty, *Microsoft Research*
Stefanie Roos, *TU Delft*
Stjepan Picek, *TU Delft*
Syed Rafiul Hussain, *Pennsylvania State University*
Tiffany Bao, *Arizona State University*
Ting Chen, *University of Electronic Science and Technology of China*
Trent Jaeger, *Penn State University*
Xiaojing Liao, *Indiana University Bloomington*
Xiaoyu Ji, *Zhejiang University*
Xiapu Luo, *The Hong Kong Polytechnic University*
Xinyang Ge, *Microsoft Research*
Yanjiao Chen, *Zhejiang University*

Yier Jin, *University of Florida*
Yiorgos Makris, *UT Dallas*
Yongdae Kim, *KAIST*
Yuan Tian, *University of Virginia*
Zahra Ghodsi, *UC San Diego*
Zhenkai Liang, *National University of Singapore*
Zhou Li, *University of California, Irvine*

External Reviewers

Abbas Acar, *Florida International University*
Aditya Basu, *Pennsylvania State University*
Adrian Dabrowski, *UC Irvine*
Ahmet Aris, *Florida International University*
Alessandro Brighente, *University of Padua*
Amit Seal Ami, *William & Mary*
Anis Yusof, *National University of Singapore*
Arish Sateesan, *KU Leuven*
Baojun Liu, *Tsinghua University*
Changhun Song, *KAIST*
Chaoyi Lu, *Tsinghua University*
Christian Niesler, *University of Duisburg-Essen*
Christopher Orsini, *North Carolina State University*
Chuqi Zhang, *National University of Singapore*
Darion Cassel, *Carnegie Mellon University*
David Gens, *UC Irvine*
David Paaßen, *University of Duisburg-Essen*
David Reinoso, *Pennsylvania State University*
Deliang Chang, *Tsinghua University*
Dimitrios Vasilopoulos, *IMDEA Software Institute*
Dipanjan Das, *UC Santa Barbara*
Dohyun Kim, *KAIST*
Dongkwan Kim, *KAIST*
Erik Pohle, *imec-COSIC KU Leuven*
Eunsoo Kim, *KAIST*
Frank Capobianco, *Pennsylvania State University*
Gaurav Somani, *Central University of Rajasthan*
Han Zhang, *Carnegie Mellon University*
Ignacio Cascudo, *IMDEA Software Institute*
Jaehoon Kim, *KAIST*
Jens-Rene Giesen, *University of Duisburg-Essen*
Jiacen Xu, *UC Irvine*
Jiahao Liu, *National University of Singapore*
Jianwei Huang, *Texas A&M University*
Jo Vliegen, *KU Leuven*
Joann Qiongna Chen, *UC Irvine*
Joonha Jang, *KAIST*
Jun Zeng, *National University of Singapore*
Kaihang Ji, *National University of Singapore*
Kaiming Huang, *Pennsylvania State University*
Kaiwen Shen, *Tsinghua University*
Kaushal Kafle, *William & Mary*

Kevin Hong, *Texas A&M University*
Laurens Le Jeune, *KU Leuven*
Leila Delshadtehrani, *Boston University*
Mangi Cho, *KAIST*
Mariusz Jakubowski, *Microsoft Research*
Matteo Cardaioli, *University of Padua*
Maverick Woo, *Carnegie Mellon University*
Md Masoom Rabbani, *KU Leuven*
Michael Rodler, *University of Duisburg-Esse*
Mincheol Son, *KAIST*
Mingming Zhang, *Tsinghua University*
Mingxuan Liu, *Tsinghua University*
Muoi Tran, *National University of Singapore*
Ning Zhang, *Washington University in St. Louis*
Phakpoom Chinprutthiwong, *Texas A&M University*
Prashast Srivastava, *Purdue University*
Qifan Zhang, *UC Irvine*
Qixiao Lin, *Beihang University*
Rahul George, *Pennsylvania State University*
Riccardo Lazzeretti, *Sapienza University of Rome*
Sangwook Bae, *KAIST*
Sashidhar Jakkamsetti, *UC Irvine*
Satwik Prabhu Kumble, *TU Delft*
Sebastian Surminski, *University of Duisburg-Essen*
Seoyeon Hwang, *UC Irvine*
Shichen Wu, *Shandong University*
Shu Wang, *George Mason University*
Sunil Manandhar, *William & Mary*
Tao Wan, *Carleton University*
Tobias Cloosters, *University of Duisburg-Essen*
Tommy Chen, *George Mason University*
Varun Madathil, *North Carolina State University*
Xiao Sui, *Shandong University*
Xiaorui Pan, *Google*
Xinda Wang, *George Mason University*
Xu He, *George Mason University*
Yangyong Zhang, *Texas A&M University*
Yanmao Man, *University of Arizona*
Yoshimichi Nakatsuka, *UC Irvine*
Yuncong Zhang, *Shanghai Jiao Tong University*
Yu-Tsung Lee, *Pennsylvania State University*
Yiming Zhang, *Tsinghua University*
Zhe Zhou, *Fudan University*
Zhijie Ren, *Shanghai Shanda Networking Development Co. Ltd.*

Organizing Committee

General Chair

Carrie Gates
Bank of America

Program Committee Co-Chairs

Farinaz Koushanfar
University of California, San Diego

Wenyuan Xu
Zhejiang University

Workshop Co-Chairs

Yasemin Acar
Leibniz University Hannover

Ben Stock
CISPA Helmholtz Center for Information Security

Poster Session Co-Chairs

Alexandra Dmitrienko
University of Würzburg

Xiaojing Liao
Indiana University

Student Support Committee

Stefanie Roos (Chair)
TU Delft

Arthur Gervais
Imperial College London

Sazzadur Rahaman
University of Arizona

Pedro Moreno-Sanchez
IMDEA Software Institute

Jason Xue
University of Adelaide

Yanjiao Chen
Zhejiang University

Test of Time Award Committee

Lujo Bauer (Chair)
Carnegie Mellon University

Trent Jaeger
Pennsylvania State University

Yongdae Kim
KAIST

Engin Kirda
Northeastern University

Alina Oprea
Northeastern University

Michael K. Reiter
U. North Carolina at Chapel Hill

Deborah Shands
SRI International

Publicity Co-Chairs

Historian and Publications Chair

Sponsorship Chair

Past General Chair

Local Arrangements Chair

Event Manager

Steering Group

Co-Chairs

Carrie Gates
Bank of America

Karen O'Donoghue
Internet Society

Steering Group Members

David Balenson
SRI International

Gabriela Ciocarlie
University of Texas San Antonio

Tom Hutton
San Diego Supercomputer Center

Trent Jaeger
Pennsylvania State University

Farinaz Koushanfar
University of California, San Diego

Chris Kruegel
University of California, Santa Barbara

Zhenkai Liang
National University of Singapore

Sarah Meiklejohn
University College London

Alina Oprea
Northeastern University

Deborah Shands
SRI International

Dongyan Xu
Purdue University