

# SpringerBriefs in Computer Science

## Series Editors

Stan Zdonik, Brown University, Providence, RI, USA

Shashi Shekhar, University of Minnesota, Minneapolis, MN, USA

Xindong Wu, University of Vermont, Burlington, VT, USA

Lakhmi C. Jain, University of South Australia, Adelaide, SA, Australia

David Padua, University of Illinois Urbana-Champaign, Urbana, IL, USA

Xuemin Sherman Shen, University of Waterloo, Waterloo, ON, Canada

Borko Furht, Florida Atlantic University, Boca Raton, FL, USA

V. S. Subrahmanian, University of Maryland, College Park, MD, USA

Martial Hebert, Carnegie Mellon University, Pittsburgh, PA, USA

Katsushi Ikeuchi, University of Tokyo, Tokyo, Japan

Bruno Siciliano, Università di Napoli Federico II, Napoli, Italy

Sushil Jajodia, George Mason University, Fairfax, VA, USA

Newton Lee, Institute for Education, Research and Scholarships, Los Angeles, CA, USA

SpringerBriefs present concise summaries of cutting-edge research and practical applications across a wide spectrum of fields. Featuring compact volumes of 50 to 125 pages, the series covers a range of content from professional to academic.

Typical topics might include:

- A timely report of state-of-the art analytical techniques
- A bridge between new research results, as published in journal articles, and a contextual literature review
- A snapshot of a hot or emerging topic
- An in-depth case study or clinical example
- A presentation of core concepts that students must understand in order to make independent contributions

Briefs allow authors to present their ideas and readers to absorb them with minimal time investment. Briefs will be published as part of Springer's eBook collection, with millions of users worldwide. In addition, Briefs will be available for individual print and electronic purchase. Briefs are characterized by fast, global electronic dissemination, standard publishing contracts, easy-to-use manuscript preparation and formatting guidelines, and expedited production schedules. We aim for publication 8–12 weeks after acceptance. Both solicited and unsolicited manuscripts are considered for publication in this series.

**\*\*Indexing:** This series is indexed in Scopus, Ei-Compendex, and zbMATH **\*\***

More information about this series at <http://www.springer.com/series/10028>

Ahmed Imteaj • M. Hadi Amini  
Panos M. Pardalos

# Foundations of Blockchain

Theory and Applications

Ahmed Imteaj  
Florida International University  
Miami, FL, USA

M. Hadi Amini  
Florida International University  
Miami, FL, USA

Panos M. Pardalos  
University of Florida  
Gainesville, FL, USA

ISSN 2191-5768 ISSN 2191-5776 (electronic)  
SpringerBriefs in Computer Science  
ISBN 978-3-030-75024-4 ISBN 978-3-030-75025-1 (eBook)  
<https://doi.org/10.1007/978-3-030-75025-1>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2021

This work is subject to copyright. All rights are solely and exclusively licensed 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

This book provides a comprehensive analysis of fundamental topics related to blockchain. It explores different vital issues and specific application areas that can benefit from blockchain. The authors present the elementary description, visualize the working procedure of the blockchain paradigm, and highlight the areas it can be applied in real life. The main focus of this book is to explain blockchain and its application from a new perspective, that is, distributed Internet of Things (IoT) and interdependent networks.

Miami, FL, USA

Ahmed Imteaj

Miami, FL, USA

M. Hadi Amini

Gainesville, FL, USA

Panos M. Pardalos

# Contents

## Part I Blockchain Theory

- 1 Introduction to Blockchain Technology** ..... 3
  - 1.1 What Is Blockchain Technology? ..... 3
  - 1.2 Blockchain Components ..... 4
    - 1.2.1 Cryptographic Hash Functions ..... 4
    - 1.2.2 Transactions ..... 5
    - 1.2.3 Asymmetric-Key Cryptography ..... 5
    - 1.2.4 Block ..... 6
    - 1.2.5 Chaining Blocks ..... 7
  - 1.3 How Blockchain Works ..... 7
  - 1.4 Key Characteristics of Blockchain ..... 8
    - 1.4.1 Decentralization ..... 8
    - 1.4.2 Immutability ..... 9
    - 1.4.3 Anonymity ..... 9
    - 1.4.4 Auditability ..... 10
    - 1.4.5 Non-repudiation ..... 10
  - 1.5 Taxonomy of Blockchain ..... 10
    - 1.5.1 Public Blockchain ..... 10
    - 1.5.2 Private Blockchain ..... 11
    - 1.5.3 Consortium Blockchain ..... 11
  - 1.6 Examples of Blockchain Applications ..... 12
  - 1.7 Advantage and Limitations of Blockchain ..... 12
  - 1.8 Discussion ..... 13
  - References ..... 13
- 2 Toward Smart Contract and Consensus Mechanisms of Blockchain** ... 15
  - 2.1 Smart Contract ..... 15
    - 2.1.1 Creation of a Smart Contract ..... 16
    - 2.1.2 Deployment of a Smart Contract ..... 18
    - 2.1.3 Execution of a Smart Contract ..... 18
    - 2.1.4 Completion of a Smart Contract ..... 18

2.2	Blockchain Consensus Algorithms .....	19
2.2.1	Proof-of-Work (PoW) Consensus Model .....	19
2.2.2	Proof of Stake (PoS) .....	20
2.2.3	Practical Byzantine Fault Tolerance .....	22
2.2.4	Proof of Elapsed Time .....	23
2.2.5	Proof of Activity .....	23
2.2.6	Proof of Importance .....	24
2.2.7	Proof of Capacity .....	24
2.2.8	Proof of Burn .....	25
2.3	Comparison of Typical Consensus Algorithms .....	26
2.4	Discussion .....	26
	References .....	27
<b>3</b>	<b>Blockchain Interoperability from the Perspective of Interdependent Networks .....</b>	<b>29</b>
3.1	Interoperability Definition .....	29
3.2	An Architecture of Interoperability .....	30
3.2.1	Data Generation in Data Layer .....	31
3.2.2	Cross-Chain Mechanism in Network Layer .....	31
3.2.3	Verification of Transaction in Consensus Layer .....	32
3.2.4	Smart Contract for Cross-Chain Mechanism in Contract Layer .....	32
3.2.5	Application Programming Interface (API) in Application Layer .....	32
3.3	How Blockchain Interoperability Concept Can Be Useful for Interdependent Networks? .....	32
3.4	Interoperability Challenges .....	33
3.4.1	Assurance of Atomicity .....	33
3.4.2	Improvement of Efficiency .....	34
3.4.3	Maintenance of Security .....	34
3.4.4	Handling of Diversification .....	34
3.5	A Comparison of Existing Interoperability Schemes .....	35
3.6	Open Issues and Challenges .....	35
3.7	Research Directions .....	36
3.8	Discussion .....	37
	References .....	37
 <b>Part II Blockchain Applications</b>		
<b>4</b>	<b>Blockchain Applicability in Internet-of-Things (IoT) Environment ....</b>	<b>41</b>
4.1	Importance of Integrating Blockchain with IoT .....	41
4.2	Customized Application of Blockchain in an IoT Environment .....	42
4.3	Blockchain-Based IoT (BIoT) Applications .....	45
4.3.1	Smart Home .....	45
4.3.2	Smart Energy .....	45
4.3.3	Smart Healthcare .....	46
4.3.4	Supply Chain Management .....	46

4.4	Current Challenges of BIoT Application .....	47
4.5	Discussion .....	48
	References .....	48
<b>5</b>	<b>Leveraging Blockchain Technology for Artificial Intelligence .....</b>	<b>51</b>
5.1	Importance of Integrating Blockchain with AI .....	51
5.1.1	Improved and Secured Decision Outcomes .....	52
5.1.2	Collaborative Decision and Decentralized Intelligence .....	52
5.1.3	Reliable and Trustworthy Intelligent Decisions .....	53
5.1.4	Higher Efficiency .....	53
5.2	Goals of Blockchain-Based AI Applications .....	53
5.2.1	Autonomous Computation .....	53
5.2.2	Planning .....	54
5.2.3	Discovering New Knowledge .....	54
5.2.4	Perceive Environment .....	54
5.2.5	Efficient Searching.....	54
5.2.6	Optimization of Decision-Making Process .....	55
5.3	Emerging Challenges and Research Gaps .....	55
5.3.1	Privacy.....	55
5.3.2	Security.....	56
5.3.3	Scalability .....	56
5.3.4	Consensus Protocol Design for AI Applications .....	56
5.3.5	Blockchain Regulations and Interoperability.....	56
5.3.6	Governance.....	57
5.4	Discussion .....	57
	References .....	57
<b>6</b>	<b>Coupling Blockchain with Emerging Real-Life Applications .....</b>	<b>59</b>
6.1	Blockchain in Healthcare .....	59
6.2	Energy Market Trading .....	61
6.3	Banking and Finance.....	62
6.4	Agriculture and Food Supply Chain .....	62
6.5	Smart City .....	63
6.6	Smart Manufacturing .....	65
6.7	Voting .....	66
6.8	Personal Identity Management .....	66
6.9	Discussion .....	67
	References .....	67
	<b>Index.....</b>	<b>71</b>



## About the Authors

**Ahmed Imteaj** is currently a PhD candidate and graduate assistant at the Knight Foundation School of Computing and Information Sciences, Florida International University, under the supervision of Professor M. Hadi Amini. He is also a research lab member of Sustainability, Optimization, and Learning for InterDependent networks laboratory (solid lab) at Florida International University. His research interests span federated learning, machine learning, internet of things (IoT), smart systems, and Blockchain. He holds a B.Sc. degree in Computer Science and Engineering from Chittagong University of Engineering and Technology (CUET), Bangladesh in 2015. From 2015 to 2018, he worked as a Lecturer at International Islamic University Chittagong (IIUC), Chittagong, Bangladesh. Ahmed's work on federated learning for IoT environments is the recipient of the best paper award from "2019 IEEE Conference on Computational Science & Computational Intelligence" and won the second place at 2021 Florida International University Graduate Student Appreciation Week. He has published more than 30 referred journals and conference papers.

**M. Hadi Amini** is an assistant professor in the Knight Foundation School of Computing and Information Sciences at Florida International University. He is the director of Sustainability, Optimization, and Learning for InterDependent networks laboratory ([www.solidlab.network](http://www.solidlab.network)). He received both his Ph.D. in electrical and computer engineering in 2019 and M.Sc. degree in 2015 from Carnegie Mellon University. He also holds a doctoral degree in computer science and technology. Prior to that, he received an M.Sc. degree from Tarbiat Modares University in 2013 and a B.Sc. degree from Sharif University of Technology in 2011. His research interests include distributed optimization and learning algorithms, distributed computing and intelligence, sensor networks, interdependent networks, and cyber-physical-social resilience. Application domains include smart cities, energy systems, transportation electrification, and healthcare.

Hadi is a life member of IEEE-Eta Kappa Nu (IEEE-HKN), the honor society of IEEE. He served as the president of Carnegie Mellon University Energy Science and Innovation Club, as technical program committee of several IEEE and ACM conferences, and as the lead editor for a book series on sustainable interdependent networks since 2017. He also serves as associate editor of SN Operations Research Forum and International Transactions on Electrical Energy Systems. He has published in more than 100 refereed journals and conference papers and book chapters. He edited/authored six books. He is the recipient of the best paper award at the 2019 IEEE Conference on Computational Science & Computational Intelligence, 2020 Excellence in Teaching Award from the School of Computing and Information Sciences at Florida International University, best reviewer award from four IEEE Transactions, the best journal paper award by the Journal of Modern Power Systems and Clean Energy, and the dean's honorary award from the president of Sharif University of Technology. (Homepage: [www.hadiamini.com](http://www.hadiamini.com))

**Panos M. Pardalos** is a distinguished professor and the Paul and Heidi Brown preeminent professor in the Departments of Industrial and Systems Engineering at the University of Florida, and a world-renowned leader in global optimization, mathematical modeling, and data sciences. He is a fellow of AAAS, AIMBE, and INFORMS and was awarded the 2013 Constantin Caratheodory Prize by the International Society of Global Optimization. In addition, Dr. Pardalos has been awarded the 2013 EURO Gold Medal prize bestowed by the Association for European Operational Research Societies. This medal is the preeminent European award given to operations research (OR) professionals for “scientific contributions that stand the test of time.” Dr. Pardalos is also a member of the New York Academy of Sciences, the Lithuanian Academy of Sciences, the Royal Academy of Spain, and the National Academy of Sciences of Ukraine. He is the founding editor of Optimization Letters, Energy Systems, and co-founder of the International Journal of Global Optimization. He has published over 600 papers, edited/authored over 200 books, and organized over 80 conferences. He has about 57,000 citations on his work, an H-index of 95, an *i*10- index of 575 (Google Scholar), and has graduated 62 Ph.D. students so far.