Blockchain and AI for Beyond 5G Networks





Yan Zhang Kun Wang Hassnaa Moustafa Stephen Wang Ke Zhang

Beyond the fifth-generation (B5G) networks, or so-called "6G," is emerging to support a massive number of users' connectivity and multi-gigabits transmission rate. The B5G networks should be intelligent enough to adapt to very dynamic topologies, intensive computation and storage applications, and diverse QoS requirements for ultra-high efficiency and resiliency purposes.

It is envisioned that blockchain and AI will be two very important technologies for the successful development of the future B5G networks. B5G networks encounter fundamental challenges from resource-constrained devices to radio resource management and the underlying heterogeneous networking and computing infrastructures. To tackle the challenges, joining blockchain and AI into B5G networks may achieve an elegant breakthrough in terms of seamless interoperability, low cost, high security and privacy-preservation, and increased efficiency. Since blockchain technologies employ a distributed ledger to offer secure services without a third-party, blockchain has the high potential to offer the underlying secure and transparent networking foundation for B5G. The FCC (Federal Communications Commission, U.S.) also believes that blockchain will be a key technology for dynamic spectrum sharing in 6G. On the other hand, AI approaches, e.g., reinforcement learning and deep learning, can be incorporated in B5G networks to process data and manage radio and computation resources in an intelligent and efficient way. Further, blockchain and AI are not independent from each other. AI approaches are able to determine the optimal parameters for blockchain which may dramatically improve the computation, communications, and storage performance of B5G networks.

Until now, limited research efforts have been made and few papers have been published in blockchain and AI for B5G networks. The scope of this special issue is to present and highlight the advances and the latest implementations and applications in the field of blockchain and AI for B5G networks such that the theoretical and practical frontiers can be moved forward for a deeper understanding from both the academic and industrial viewpoints. In response to the Call for Papers, six outstanding articles have been selected for this SI after a careful review process.

The articles in this SI are classified into three categories:

- Security and privacy in blockchain and AI-enabled Beyond 5G Networks.
- Blockchain and AI-based analytics architectures for Beyond 5G Networks.
- Optimization methods with blockchain and AI for Beyond 5G Networks.

In the first article, "Rethinking Blockchains in the Internet of Things Era from A Wireless Communication Perspective," the authors investigate the security and privacy of a massive number of devices connected to the Internet. First, the authors rethink the roles of communication and computing in blockchains by accounting for communication reliability. Then the authors analyze the tradeoff between communication reliability and computing power in blockchain security, and present a lower bound to the computing power that is needed to conduct an attack with a given communication reliability. The simulation results have shown that adversarial nodes can succeed in tampering a block with less computing power by hindering the propagation of blocks from other nodes.

In the second article, "Blockchain-Based Data Security for Artificial Intelligence Applications in 6G Networks," the authors explore blockchain-enabled data storage security for artificial intelligence (AI) applications in the coming 6G era. A potential architecture of 6G network, i.e., a space-air-ground-underwater integrated four-tier network, is first presented. Then, the authors investigate the AI applications, which is the most significant breakthrough of 6G. In order to solve the main security challenge, i.e., data storage security existing in AI applications, the authors develop the blockchain as the storage platform due to its immutable and unforgeable information. Finally, the case study of an indoor navigation system demonstrates the high level of security for blockchain-based data storage.

Blockchain and AI can efficiently ensure several relevant trust factors such as content credibility, operator fairness, and provider incentive in the coming 6G era to enhance efficiency.

In the third article, "Blockchain and AI Empowered Trust-Information Centric Network for Beyond 5G," the authors investigate blockchain and AI-based content trust in the information-centric network (ICN) for beyond the fifth-generation (B5G). First, a blockchain-enabled trust evaluation and circulation scheme called TrustCoin is proposed to quantify the credibility of B5G nodes in a dynamic and fine-grained way. Then, deep reinforcement learning (DRL) is presented to decide the content credibility according to the content status and history behaviors of B5G nodes. Finally, a smart incentive mechanism is established for the endogenous trust of B5G networks. The experimental results have verified the effectiveness of the proposed blockchain and AI-enhanced trust-ICN architecture and mechanism in B5G.

In the fourth article, "Blockchain Enabled Federated Slicing for 5G Networks with AI Accelerated Optimization," the authors propose a decentralized federated slicing architecture that is trustful and efficient. First, the authors systematically discuss the design principles and key challenges in realizing the blockchain-enabled architecture. With these principles and challenges in mind, the authors then develop a general architecture for multiple operators and cloud providers, with a new Proof of Business (PoB) consensus protocol to ensure incentive and fairness.

Finally, to further enhance its efficiency, the authors utilize reinforcement learning to accelerate optimizations in the resource allocation. The simulation results have demonstrated the benefits of the AI accelerated optimizer.

The remaining articles discuss the technical challenges and recent results related to blockchain and AI optimal methods on Beyond 5G networks.

In the fifth article, "Countermeasure Based on Smart Contracts and AI Against DoS/DDoS Attack in 5G Circumstances," the authors emphasize that the imbalance between high communication and low processing power could introduce a vulnerability for attackers to amplify the destructiveness of DoS/DDoS attacks. To mitigate the impact of DoS/DDoS attacks, increasing the cost of DoS/DDoS attacks by designing a blockchain-based incentive mechanism, which detects DoS/DDoS attacks and punishes such behavior by charging exaggerated communication traffic, is the goal of this work. By hiding protected servers in the blockchain network and designing a novel routing mechanism, the attackers are prevented from attacking protected servers without the audit from the defense mechanism. By embedding the AI module into a smart contract using YODA, a novel, low-cost computationally intensive contract execution mechanism, AI models for detecting DoS/DDoS attacks are allowed to be trained and execute over a trusted infrastructure without producing massive cost. Gaming analysis shows that the cost of DoS/DDoS attacks could theoretically be lifted to infinite.

Finally, in the sixth article, "AI-Chain: A Blockchain Energized Edge Intelligence for Beyond 5G Networks," the authors consider the challenges of sharing learning results among heterogeneous and non-confident network edges. They study a blockchain helped edge intelligence for B5G networks, named AI-Chain. The AI-Chain is designed as a distributed and immutable record of edge learning results. To this end, a novel learning-based consensus protocol is proposed, termed as proof of learning (PoL). Instead of solving a meaningless hashing puzzle, as in the proof of work (PoW) protocol, the PoL protocol replaces the training process as a working puzzle; meanwhile, a block generator turns into a training winner, rather than a hashing solver. Finally, in order to reveal the effectiveness of the proposed scheme, we employ the AI-Chain approach to solve a resource allocation problem in B5G networks. The experimental results show good performances in the current scheme.

In closing, we would like to extend our sincere gratitude to all the authors who submitted their research to this SI. We would like to thank all the experts in this field who reviewed these articles and provided suggestions to help the authors improve their research. Especially, we would express our gratitude to the publishing team and editors for their helpful suggestions and great support for this SI.

Biographies

Yan Zhang [F'20] is currently a full professor with the Department of Informatics, University of Oslo, Norway. He received the Ph.D. degree from the School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore. He received M.S. and B.S. degrees from Beihang University and Nanjing University of Post and Telecommunications, respectively. His research interests include next-generation wireless networks leading to 5G beyond/6G, green and secure cyber-physical systems (e.g., smart grid and transport). He is an editor (or area editor, senior editor, associate editor) for several IEEE transactions/magazines, including *IEEE Communications Magazine*, *IEEE Network*, *IEEE Transactions on Network Science and Engineering*, *IEEE Transactions on Vehicular Technology*, *IEEE Transactions on Industrial Informatics*, *IEEE Transactions on Green Communications and Networking*, *IEEE Communications Survey and Tutorials*, *IEEE Internet of Things Journal*, *IEEE Systems Journal*, *IEEE Vehicular Technology Magazine*, and *IEEE Blockchain Technical Briefs*. He is a symposium/track chair for a number of conferences, including IEEE ICC 2021, IEEE Globecom 2017, IEEE PIMRC 2016, and IEEE SmartGridComm 2015. He is the Chair of the IEEE Communications Society Technical Committee on Green Communications and Computing (TCGCC). He is an IEEE Vehicular Technology Society Distinguished Lecturer (2016-2020). He is a CCF Senior Member, an elected member of the CCF Technical Committee of Blockchain, and 2019 CCF Distinguished Speaker. Since 2018, he was a recipient of the global "Highly Cited Researcher" Award (Web of Science top 1% most cited worldwide). He is a Fellow of IEEE, a Fellow of IET, an elected member of Academia Europaea (MAE), and an elected member of the Norwegian Academy of Technological Sciences (NTVA).

Kun Wang (M'13-SM'17) (wangk@ucla.edu) received two Ph.D. degrees in computer science from Nanjing University of Posts and Telecommunications, Nanjing, China, in 2009, and from the University of Aizu, Aizuwakamatsu, Japan, in 2018. He was a post-doctoral fellow at UCLA, USA from 2013 to 2015, where he is a senior research professor. He was a research fellow at the Hong Kong Polytechnic University, Hong Kong, from 2017 to 2018, and a professor at Nanjing University of Posts and Telecommunications. His current research interests are mainly in the area of Artificial Intelligence and Internet of Things, AI hardware acceleration, and blockchain. He is the recipient of the ACM CHI 2020 Horourable Mention Award, ACM FPGA 2020 Best Paper Award Candidate, ACM MobiSys 2020 Best Paper Award, ACM SenSys 2019 Best Paper Award, IEEE GLOBECOM 2016 Best Paper Award, IEEE ISJ Best Paper Award 2019, IEEE TCGCC Best Paper Award 2018, IEEE TCBD Best Paper Award 2019 and CBD 2019 Best Student Paper Award. He is/was the symposium chair/co-chair of IEEE GLOBECOM 2021, IEEE CNCC 2017, IEEE WCSP 2016, etc. He serves/has served as an associate editor of *IEEE Access*, an editor of the *Journal of Network and Computer Applications*, and a Guest Editor of *IEEE Network*, *Future Generation Computer Systems*, the *Journal of Systems Architecture*, *Peer-to-Peer Networking and Applications*, *IEICE Transactions on Communications*, *IEEE Access*, *Journal of Internet Technology*, and *Future Internet*.

Hassnaa Moustafa is a principal engineer at Intel Corporation currently working on edge AI solutions across IoT segments and network and edge infrastructure. Previously at Intel, Hassnaa led car-to-cloud solutions for connected/autonomous vehicles, and connectivity technologies across IoT segments. Before joining Intel, she was a senior R&D engineer at France Telecom (Orange Labs) in France, where she contributed to low cost wireless network solutions for emerging countries and led engineering efforts on personalization and context-aware video and multimedia services within the NGN effort. She obtained her tenure in computer science from the University of Paris XI, her Ph.D. in computer and networks from Telecom Paris Tech, and her master degree in distributed systems from the University of Paris XI. Her broad experience covers IoT E2E network and services infrastructure, media networks, video delivery optimization, services personalization and content adaptation. She also worked for many years on ad hoc and vehicular network routing and AAA solutions. She contributed to the IETF standardization for 10 years and she is a senior IEEE member. She has over 80 publications in international conferences and journals including IEEE and ACM. She has co-authored books published by the CRC press, and she is a regular guest editor for several journals and an active member in TPCs for IEEE and ACM conferences. She is also a regular co-chair for several IEEE workshops and conference symposiums. She has been involved in several European projects with technical lead role and she served as a consultant for the European Commission (EU) from 2008 until 2012 and contributed in defining the research agenda for Future Internet and Media Networks published in EU white papers.

Stephen Wang [SM] (Stephen.Wang1@huawei.com) received his M.Sc. and Ph.D. degrees from the University of Warwick and the University of Bristol in 2005 and 2009, respectively. He served different roles as engineer, researcher, and team leader at China Telecom, the Chinese Academy of Sciences, Toshiba Research Europe Limited, and Ocado Technology. He oversees digital innovations strategy and steers R&D programs in wearables, 5G/6G, indoor positioning, industrial 4.0 IoT automation, and bioengineering. He served as the Director of Emerging Technologies at Huawei Technologies Research & Development (UK) between 2017-2019 and take more responsibility starting in 2020 as the Director of Corporate Strategy and Partnerships, taking care of the Europe research strategic planning, university collaboration, and start-up investment activities by interacting with external consultants, universities, and start-ups to understand the ecosystem value and recommend technology strategy. He also serves as a member of the Industrial Advisory Board, Imperial College London's Bioengineering Department. He is an inventor/co-inventor of 20+ patents. His research interests include 5G/6G, blockchain-enabled technologies, industrial IoT, energy-efficient NBIC, channel propagation, bioengineering and metamaterial. He is a regular author and reviewer of IEEE journals, guest editor, session chair and general co-chair. He is a UK chartered engineer, a Fellow of IET, and a senior member of IEEE.

Ke Zhang (zhangke@uestc.edu.cn) received the Ph.D. degree from the University of Electronic Science and Technology of China in 2017. He is currently a lecturer with the School of Information and Communication Engineering, University of Electronic Science and Technology of China. His research interests include scheduling of mobile edge computing, design and optimization of next-generation wireless networks, smart grid, and the Internet of Things. He has published 15+ papers leading work in the field of edge computing and blockchain for 5G beyond networks and IoT applications.