



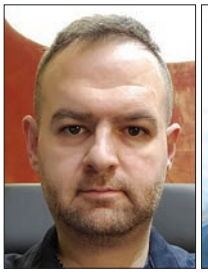


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Blockchain-Enabled Industrial Internet of Things: Advances, Applications, and Challenges

The revolutionary industry digitization coupled with the proliferation of the Internet-of-Things causes a paradigm shift for industrial and manufacturing companies, renowned as Smart Industry or the Industrial Internet-of-Things (IIoT). This concept, also advertised as Industry 4.0, leverages the power of smart machines fused with real-time analytics, cyber-physical systems, cloud and cognitive computing to capture and exploit massively produced and communicated data. This aims at promoting multi-disciplinary business intelligence and supporting efficient quality control and a traceable supply chain, predictive maintenance, enhanced field services, asset tracking, as well as sustainable green practices. An IIoT ecosystem mainly focuses on effectively controlling the physical world comprising smart devices distributed among the entire industry to collect and securely exchange and analyze massive ambient data. While cloud computing constitutes the fertile soil for handling such issues, it however necessitates high-end servers and high-speed networks to provision storage-related/computation-related services. In this regard, a centralized cloud-enabled IIoT framework is perceived by IoT services as a black box with impeding factors of resilience, adaptability, fault tolerance, trust, security and privacy, maintenance costs, and asthenic time-critical IoT applications' support. Stepping toward coping with these challenges, blockchain represents one of the most suitable candidate technologies able to support a secure and distributed IIoT ecosystem. The blockchain is an amalgamation of cryptography, public key infrastructure, and economic modeling, applied to peer-to-peer networking and decentralized consensus to achieve distributed database synchronization. Its perks of decentralization, immutability, auditability, and fault-tolerance render it more attractive to enclasp the benefits of the decentralized framework in the IIoT environment. Various industry solutions and platforms from Lola, COSMOS, Dajie, Filament, Slock.it, SmartAxiom, BlockVerify, Xage Security, Ubirch, Multichain, ShoCard, Chronicled, Uniquid, Riddle and Code, and Datum are already floated in the market for public, private, and federated blockchains to address privacy, monetization, security, trust, identity and data management issues.

From the perspective of blockchain employment across the wide range of IIoT use-cases (e.g., in the food industry, cybersecurity, voting, music, real estate, healthcare, insurance, supply chain and logistics, energy and smart grid, apparel, textile and fashion industry), there exist numerous operational and technical exposures to the development and deployment of IIoT-related applications outlining significant challenges that stand in the way of achieving absolute IIoT decentralization using blockchain, given the vast diversity of the devices these applications involve. Such technical challenges include but are not limited to risks and regularity issues as well as other associated integrating factors related to processing, storage, communication, and availability, together with the appropriate role assignment that jointly considers issues of security, privacy, trust and scalability in addition to the choice of suitable consensus algorithms.

This special issue of *IEEE Internet of Things Magazine* (IoTM) has solicited high-quality manuscripts that:

- Describe in-depth the breadth of real-world blockchain-based multi-disciplinary IIoT deployments that go in-line with the above-elaborated special issue.
- Present actual experiences in resolving contextual blockchain-related challenges.
- Develop and share best practices, vision realizations and lessons learned in this integrated environment.
- Establish guiding principles for technical, operational and business successes.

The special issue received around 40 high-quality articles that were general, independent of technical or business specialty, and intended for an audience consisting of all members of the IoT community. The Guest Editors (GEs) assigned these articles to expert reviewers whose comments and reviews were to the point and highly beneficial in improving the quality, readability and presentation of the manuscripts. After the final round of reviews, the GEs have been exposed to quite a difficult selection process of nine out of 11 accepted papers for publication within this SI, whereas the remaining two papers have been highly recommended for publication as regular papers that will appear in upcoming issues of the IoTM. Below is a brief summary for each one of these accepted papers.

Blockchain-Enabled Safety-as-a-Service for Industrial IoT Applications

The integration of Industrial Internet of Things (IIoT)-based technologies with the existing industrial manufacturing processes helps to improve the on-site safety of workers, reduce downtime of machines, improve the productivity rate, and

minimize near-miss incidents and casualties. However, prior information of the various safety-related information may minimize the probability of accidents on the factory floor and casualty rates. A Safety-as-a-Service (Safe-aaS) infrastructure provides customized safety-related decisions to the registered end-users. The end-users register to the infrastructure and select certain decision parameters through a Web portal. On the other hand, the decision provided to the end-users may be generated from the combination of multiple sensor data. Moreover, the data sensed by the sensor nodes are primarily processed in the cloud/edge, based on the time-criticality of the data. One of the major challenges in a Safe-aaS platform is to provide security and privacy in a decentralized manner, considering the Quality of Service (QoS) and user-level agreement. Recently, blockchain technology has been widely applied across various industries to provide trustworthiness, privacy, and security in a decentralized manner. Typically, blockchains are referred to as distributed ledger, which help to secure the transactions in the network. Motivated by these facts, the authors incorporate a distributed blockchain-enabled decision virtualization layer into the Safe-aaS infrastructure to secure the data sensed by the sensor nodes and the transactions among different Safety Service Providers (SSPs) and registered end-users. The authors observed that the integration of blockchain improves the privacy for identity management of end-users and provides secure decisions to the registered end-users in Safe-aaS.

Blockchain, AI and Smart Grids: The Three Musketeers to a Decentralized EV Charging Infrastructure

The accustomed perception of our future is a collaborative environment where humans and machines seamlessly interact together to accomplish everyday tasks, i.e., a self-driving vehicle transporting medical tools to a doctor who is preparing to perform surgery from the convenience of his home lab. Although this image of the future seems inconceivable, it is becoming more of a reality thanks to the IoT paradigm. With the advancements in sensor and networking technologies, IoT services are becoming more ubiquitous in our everyday lives. Further, to realize a seamless future as described, different IoT services would overlap, giving rise to new collaborative services. A case in point, Electric Vehicles (EV) and their charging infrastructure are a pure manifestation of such overlap between two different IoT services: Smart Grids and Intelligent Transportation Systems (ITS). The EV industry has been booming over the past few years to the point that every car manufacturer has at least one model of EV. From small-sized/mid-sized sedans, up to luxury SUVs and super cars, the existence and continuation of these vehicles relies on the abundance of a proper charging infrastructure. Accordingly, the EV charging station industry has also been booming with companies procuring different models from one side, to governments providing incentives for their purchase of the stations from the other side. Moreover, lately, these charging stations have transitioned to the IoT paradigm making them smarter, easily managed, and inter-connected. Despite such growth, there is a level of mediocre satisfaction surfacing EV adoption, mainly due to inefficiencies in the charging infrastructure. These inefficiencies are best summarized in poor deployment strategies, poor scheduling mechanisms and poor security and privacy implementations. With that in mind, we take a dive into this world of inefficiencies with the objective of not exploiting but mitigating them for a more efficient and secure charging ecosystem. For that, we focus on two technologies: Blockchain and AI for their proven record of providing insights through detecting complex patterns and anomalies (AI), as well as building a secure, open, and decentralized economy for digitized assets (Blockchain). We explore the different use cases of these two technologies, individually and collaboratively, in both industry and academia within the context of EV charging. We further suggest novel use cases in which these two technologies could collaborate for a better charging ecosystem.

A Blockchain-Enabled Multi Domain Edge Computing Orchestrator

This paper proposes an architecture relying on multi-domain edge orchestration entrusted by blockchain. The blockchain-enabled multi-domain edge orchestrator has a modular design based on network slicing and resource sharing from edge to core. Slices consider the multi-constraint QoS capabilities. The blockchain ensures trustworthiness between different telecom operators, introduces transparency and automates the fulfillment of service level agreements through smart contracts. Experimental simulation results are presented for the burst and response times of the proposed framework.

Industrial Wastewater Management using Blockchain Technology: Architecture, Requirements, and Future Direction

This paper introduces an interesting IoT application of a wastewater management system, where blockchain is taken as a graceful vehicle for achieving distributed secure management. In addition to describing the detailed design of the system, the article provides three use cases that demonstrate the advantages of the proposed blockchain based approach.

Ethereum-Blockchain Based Technology of Decentralized Smart Contract Certificate System

Traditional paper certificates and electronic certificates have difficulty in preservation and management, not to mention other problems concerning inconvenient verification, poor reliability, anti-counterfeiting and anti-tampering. A scheme designed to build a decentralized certificate system that is based on Blockchain technology and smart contract is proposed in this paper. The authors developed a Blockchain certificate system aiming at providing Blockchain certificate services for college students' innovation and entrepreneurship competition. In this system, certain functions of the certificate about management, issuing, verification and revocation are realized via smart contract. Signer information, certificate template and certificate information are stored in a smart contract that adopts structured data, thereby realizing more convenient callings in querying and validating certificate.

Leveraging IoT and Fog Computing in Healthcare Systems

Efficiency and security are still a challenge in IoT-based healthcare systems. The authors address this issue, and present a fog based efficient architecture for an IoT-based healthcare system. The aim of the proposed architecture is to introduce an idea of VM portioning in a fog node to smoothly run the body sensor network and medical IoT devices data. They employ a VM creation mechanism in the fog node for computation and storage purposes. The data generated by the body sensor network is processed and managed by the body sensor network data processing and record management VM. Clinical and health data is also managed in the health record document management and clinical document management VM, respectively. The authors define the multiple user roles and each user has access to perform specific functions. Moreover to avoid privacy breaches in the healthcare application, they present the user authentication through identity management technique. To manage the identities of users in secure way, SHA-512 and Elliptic Curve Cryptography technique is applied.

Emerging Smart Logistics and Transportation Using IoT and Blockchain

The authors of this paper developed a framework that integrates IoT and Blockchain in transportation and logistics to make it resilient against many security attacks. The proposed framework is validated using two real-world case studies belonging to transportation and logistics.

Blockchain-Enabled Reliable Osmotic Computing for Cloud of Things: Applications and Challenges

Blockchain has already been proven for providing the reliable interaction among multiple independently operating entities. This article covers the usage of Blockchain for improving the reliability of osmotic computing. The authors highlight the Blockchain features that can be used for handling the challenges of osmotic computing. As a future work, they identify some of the challenges and open issues associated with the integration of Blockchain and osmotic computing.

AI, Blockchain and Vehicular Edge Computing for Smart and Secure IoV: Challenges and Directions

Nowadays, nobody neglects the fact that intelligent vehicles are the future. Nevertheless, many problems stem from letting machines take control of the streets without embedding a sophisticated decision-making process within. This article spotlights the importance of security in the smart Internet-of-Vehicles paradigm, and the integration of Blockchain and Artificial Intelligence for acquiring safety on the road by investigating in an architecture that benefits from the decentralized authority and network topology of a hybrid Blockchain in order to leverage highly accurate decision models. Challenges and future directions of such a combination are listed and discussed in this article.

Biographies

Mohamed Abdallah received a B.Sc. degree from Cairo University in 1996. He received his M.Sc. and Ph.D. degrees from the University of Maryland at College Park in 2001 and 2006, respectively. From 2006 to 2016, he held academic and research positions at Cairo University and Texas A&M University at Qatar. Currently, he is a founding faculty member with the rank of associate professor at the College of Science and Engineering at Hamad bin Khalifa University (HBKU). His current research interests include wireless networks, wireless security, smart grids, and Blockchain applications for emerging networks. He has published more than 150 journal and conference articles and four book chapters, and co-invented four patents. He is the recipient of the Research Fellow Excellence Award at Texas A&M University at Qatar in 2016, the best paper award at multiple IEEE conferences including IEEE BlackSeaCom 2019 and the IEEE First Workshop on Smart Grid and Renewable Energy in 2015. His professional activities include associate editor for *IEEE Transactions On Communications* and *IEEE Open Journal of the Communications Society*, track co-chair of the IEEE VTC Fall 2019 conference, and a technical program chair of the 10th International Conference on Cognitive Radio Oriented Wireless Networks.

Octavia A. Dobre [M'05, SM'07, F'20] is a professor and Research Chair at Memorial University, Canada. She was a Royal Society and a Fulbright Scholar, and a visiting professor at Massachusetts Institute of Technology. Her research interests include technologies for beyond 5G, as well as optical and underwater communications. She has published over 300 refereed papers in these areas. She serves as the Editor-in-Chief (EiC) of the *IEEE Open Journal of the Communications Society*. She was the EiC of *IEEE Communications Letters*, a senior editor and an editor with prestigious journals, as well as General Chair and Technical Co-Chair of flagship conferences in her area of expertise. She is the recipient of diverse awards, such as Best Paper Awards at IEEE ICC, IEEE Globecom, and IEEE WCNC conferences. She is a Distinguished Lecturer of the IEEE Communications Society and a fellow of the Engineering Institute of Canada.

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Maurice J. Khabbaz received his Ph.D. degree in electrical engineering in 2012 from Concordia University in Montreal, Canada. Currently, he is a distinguished associate professor of electrical, computer and communications engineering at the Notre-Dame University of Louaize, Lebanon, as well as an affiliate assistant professor at Concordia University's CIISE Department in Montreal, Canada. In 2019, he was appointed as an area editor for *IEEE Communications Letters* as well as an associate editor for *IEEE Transactions on Network and Service Management*, IEEE *Access*, and *IEEE Open Journal of the Communications Society*. In 2020, he joined the Editorial Board of *IEEE Internet-of-Things Magazine*. He has served as a TPC member of flagship IEEE conferences (e.g. GLOBECOM, WCNC, NetSoft, CloudNet, 5G World Forum). He is also a member of the organizing committee of the IEEE ACTEA'19, the Chair for the Vehicular Communications Symposium of the IEEE IWCMC'20 and the Co-Chair of the Results Track of the IEEE VTC'20. He is a Senior Member of the IEEE and a member of the ASEE. His research interests include the Internet-of-Things, intelligent transportation systems, smart cities, 5G/5G-B, cloud datacenter networking (e.g. SDN, NFV, etc), mobile edge computing, modelling/performance analysis and network optimization.

Joel J. P. C. Rodrigues [S'01, M'06, SM'06, F'20] is a professor at the Federal University of Piauí, Brazil; a senior researcher at the Instituto de Telecomunicações, Portugal; and a collaborator of the Post-Graduation Program on Teleinformatics Engineering at the Federal University of Ceará (UFC), Brazil. Prof. Rodrigues is the leader of the Next Generation Networks and Applications (NetGNA) research group (CNPq), an IEEE Distinguished Lecturer, a Member Representative of the IEEE Communications Society on the IEEE Biometrics Council, and the President of the scientific council at ParkUrbis — Covilhã Science and Technology Park. He was Director for Conference Development — IEEE ComSoc Board of Governors; Technical Activities Committee Chair of the IEEE ComSoc Latin America Region Board; a Past-Chair of the IEEE ComSoc Technical Committee on eHealth; a Past-chair of the IEEE ComSoc Technical Committee on Communications Software; a Steering Committee member of the IEEE Life Sciences Technical Community and Publications co-Chair. He is the editor-in-chief of the *International Journal on E-Health and Medical Communications* and an editorial board member of several highly respected journals. He has been general chair and TPC Chair of many international conferences, including IEEE ICC, IEEE GLOBECOM, IEEE HEALTHCOM, and IEEE LatinCom. He has authored or coauthored over 900 papers in refereed international journals and conferences, three books, two patents, and one ITU-T Recommendation. He has been awarded several Outstanding Leadership and Outstanding Service Awards by IEEE Communications Society and several best papers awards. He is a member of the Internet Society, and a senior member ACM.