Innovative Blockchain-Based Applications - State of the Art and Future Directions

Hada Alsobhi(✉), Abeer Mirdad, Suhair Alotaibi, Mwaheb Almadani, Inam Alanazi, Mohrah Alalyan, Wafa Alharbi, Rania Alhazmi, and Farookh Khadeer Hussain

Faculty of Engineering and Information Technology, University of Technology Sydney, 15 Broadway, Ultimo, Sydney, NSW 2007, Australia
{Hada.Alsobhi,Abeer.Mirdad,Suhair.Alotaibi,Mwaheb.Almadani,Inam.Alanazi, Mohrah.S.AlAlyan,WafaMatarA.Alharbi,Rania.Alhazmi}@student.uts.edu.au, Farrokh.Hussain@uts.edu.au

Abstract. Recently, blockchain technology has increasingly being used to provide a secure environment that is immutable, consensus-based and transparent in the finance technology world. However, significant efforts have been made to use blockchain in other fields where trust and transparency are required. The distributed power and embedded security of blockchain leverage the operational efficiency of other domains to be immutable, transparent, and trustworthy. The trust of the published literature in blockchain technology is centered on crypto-currencies. Therefore, this paper addresses this gap and presents to the user several applications in many fields, including education, health, carbon credits, robotics, energy, pharmaceutical supply chains, identity management, and crypto-currency wallets. This paper overviews the knowledge on blockchain technology, discusses the innovation of blockchain technology based on the number of applications which have been introduced, describes the challenges associated with blockchain technology, and makes suggestions for future work.

Keywords: Blockchain · Applications · Blockchain research challenges

1 Introduction and Background

In 2008, blockchain technology was first introduced to the public, along with the emergence of Bitcoin. Blockchain is considered a technological innovation that has broad implications and applications after Ethereum launched the smart contracts [1]. As technological communities and industrial giants are rapidly moving towards service-directed frameworks with distinct application specifications, blockchain applications have come under comprehensive investigation. These systems will allow users to obtain services with more sophisticated features. Many blockchain applications are utilized as an immutable ledger where there is a lack of trust between entities so that a trustworthy third party is no longer needed in

L. Barolli et al. (Eds.): AINA 2021, LNNS 227, pp. 323–335, 2021.
https://doi.org/10.1007/978-3-030-75078-7_33

such systems. Given that centralized storage technologies have become controversial and inadequate, a blockchain-based application can increase transparency, provide immutability, and create trust between organizations. Thus, blockchain technology has attracted the attention of many researchers and practitioners due to blockchain's more advanced functionalities and features over traditional technology systems. In addition to the range of new blockchain use cases occurring every day, including supply chains, healthcare, digital identities, energy, and intellectual property systems. Blockchain technology has recently been used in a number of different applications as a way to maintain trustworthy records and information in a distributed and reliable manner [2].

Researchers have defined blockchain as a distributed ledger technology (DLT) that contains a sequence of blocks to store valuable data and information that can be shared over the network between parties [1]. Blockchain has the following key characteristics: decentralization, persistency, auditability, and anonymity. Blockchain is a technological solution to solve security issues, such as ensuring all transactions are secured with cryptographic hashes and asymmetric-key pairs to sign and verify any type of transaction. Therefore, once the data is recorded in a blockchain, it becomes difficult to change.

Within the blockchain network, all historical transactions between nodes are recorded in distributed ledgers. Nodes or peers are connected to a P2P network and hold a copy of the shared ledger. In order to add and verify the transactions within the system, the miners or crypto miners need to agree on whether any new blocks are valid or not by applying consensus algorithms. The essential operation of the blockchain rely on the consensus process. Since blockchain features work without a leader or a trusted third party, it uses consensus mechanisms to make a decision and guarantee ledgers are compatible in various nodes. There are advantages and disadvantages for each consensus mechanism, but it is important to sustain a system state agreement by following the guidelines of consensus mechanisms. Also, there are several consensus models such as the Proof of Work Consensus Model, Proof of Stake Consensus Model and Proof of Authority Consensus Model. The Consensus Comparison Matrix in [1]. compares the different consensus models. Cryptography and hashing mechanisms are used to construct a chain of data blocks to ensure immutability in the append-only distributed ledgers in the blockchain network. Thus, all data blocks contain a series of transactions appended to the previous blocks using the hash values as part of the stored data.

Smart contracts are a set of codes that are executed by miners. The smart contract was defined in 1994 by Nick Szabo as "a computerized transaction protocol that executes the terms of a contract" [3]. The overall goals of smart contracts are designed to satisfy common contractual conditions, such as payment terms, to minimize both malicious and occasional exceptions and to reduce the need for reliable intermediaries. The smart contract is executed by nodes through the blockchain network; all the executed nodes must derive the same results from the execution, and the results of the execution are recorded on the blockchain. However, not every blockchain can run smart contracts [1].

This objective of this paper is to expose the reader to range of innovation blockchain applications in many sectors such as education, identity management and carbon credit management. A significant amount of the extant literature on blockchain technology in the field of computer science is focused on its use in the finance sector in the form of crypto-currencies. However, there are numerous use cases of blockchain outside crypto-currencies. The purpose of this paper is to enlighten the reader to a number of innovative applications of blockchain technology across a number of domains, each of which has the potential to have a high impact in the respective sector of the application. It explains how integrating such technology can significantly reshape advanced industries of blockchain technology in diverse disciplines, such as education, carbon credits, robotics, energy, pharmaceutical supply chains, identity management, and crypto-currency wallets.

2 Innovative Blockchain-Based Applications

In this section, we outline and discuss a number of blockchain applications across a number of sectors.

2.1 Blockchain in Education

A recent development in the education sector has been the emergence of micro-credentials [4]. Micro-credentials give students the ability to undertake 'micro' offerings such as short courses from different universities. These short courses could be of various lengths - ranging from a few hours to a few weeks. Students also have the flexibility to select bespoke offerings from different universities. The micro-credential content is delivered online as opposed to face- to-face content delivery. This gives students complete flexibility to select micro-credentials from multiple universities, and importantly tailor their learning experience depending on their availability. A significant issue facing the emergence of micro-credentials is the lack of fool-proof mechanisms to verify on-the-fly a micro-credential issued by another institution. Furthermore, technological solutions for managing micro-credentials are in their infancy, so proposing blockchain-based solutions can help not just in the authentication of micro-credentials, but using some of the emerging artificial intelligence approaches to manage and recommend micro-credentials for students.

Over the last few years, the higher education sector worldwide has grown which has resulted in the emergence of new educational offerings, including online courses, online certificates, online degrees, and more recently micro-credentials. The growth of these educational offerings is evidence of the trend towards continuous lifelong learning. A new ecosystem of educational providers, including technology companies, is beginning to emerge with a view to imparting the 'on-demand' and 'just-in-time' skills (using emerging skills) that are required by employers and which are advantageous for employees to have in their portfolio of skills [5].

The higher education (HE) domain is a suitable domain for adopting blockchain technology. Blockchain can make administrative procedures faster and easier when credentials need to be verified. A small number of higher education institutions (HEIs) have started to use blockchain in several applications to share, verify, and validate learning outcomes and certificates [6]. Blockchain technology can help in managing the micro-credentials of academic achievements that a learner accrues over a lifetime. The development of such a reliable, trustworthy, robust, and scalable approach including new technologies will be crucial in supporting community acceptance and the uptake of micro-credentials [5].

Universities around the world are finding ways to recognize micro-credits officially. The Australian Qualification Framework has now opened the door for micro-credentials and most Australian universities, such as the University of Technology Sydney (UTS), RMIT, the University of Melbourne, Griffith University, the University of New South Wales, and the University of Western Sydney recognize short courses, known as micro-credentials. UTS launched its micro-credentials in 2020 [7].

2.2 Blockchain in Managing Carbon Credits

There is a strong movement around the world to reduce carbon emissions. Many countries such as New Zealand, Finland and Australia have plans to entirely cut their carbon emissions in the next few decades. New Zealand, U.K. and Scotland have plans for net zero carbon emissions by 2050 [8]. Carbon credits is a term used for any type of permit that gives the holder the right to produce one to One of carbon dioxide or the same amount of other greenhouse gases [9]. There will be an urgent need for the carbon credits market by 2021, and systems will be needed to allow individuals to trade in carbon credits. Hence, strategies, technologies and the corresponding exchange of carbon credits are needed to measure the carbon credit trade [10].

Currently, carbon credits are used as a mechanism to reward companies and countries that are emitting less CO2. However, the technology around digital management and digital trading is suffering from many shortcomings such as double counting and a lack of transference in exchange for carbon credits. Hence, it is essential to introduce improvements to the current system. One such solution is blockchain. Using blockchain to manage and trade carbon credits is one of its many uses that has received relatively very little research attention so far. Proposing blockchain technology as a solution will help to create a market that enables the trade of carbon credits as well as to solve the problem of double counting. Blockchain technology can provide a secure, trustworthy and transparent system in which all the information of carbon credits can be managed in a reliable manner.

2.3 Blockchain in Robotics

Over the last few decades, the demand to investigate robotics technology in other industries, such as logistics services, education, healthcare, agriculture and many more has increased [11]. This has led to a dramatic growth in robotics manufacturing [12]. A large number of robotics providers offer robots with a wide variety of capabilities to perform a wide range of functions. Some of these capabilities are combined and integrated in a multipurpose robot that is engineered to provide similar or overlapping services [13]. Integrating blockchain technology in the robotics field has attracted researchers' attention over the last few years. The robotics research areas have a number of research gaps or issues that need to be solved. Blockchain technology presents a promising next-generation approach to solve these pressing research issues. In the remainder of this sub-section, we discuss some of these issues and potential solutions involving blockchain.

Due to the variety of robotic alternatives and the advanced features of robots, the identification and selection of the most suitable robot for a particular task is one of the challenges that face robot service requesters, especially non-expert requesters. So, establishing a reputation system that manages data on robots and robot providers could address the robot selection problem and help robot requesters to make a decision. All reputation systems are prone to manipulation by malicious users which include robot providers who may give high ratings to themselves and/or give their competitors low ratings [14]. So, there is a strong argument for using tamper- proof mechanisms to store reputation values. The secure and verifiable blockchain structure may be used to store the reputation values and prevent data manipulation since the blocks are created and stored in a distributed manner by different peers.

In the case of complex tasks, the robot requesters can now build a cooperation mechanism to formulate a robot swarm from homogeneous or heterogeneous robots to perform the required tasks [15]. Such a swarm structure is highly vulnerable to attack by malicious or byzantine robots. Thus, a number of blockchain-based methods have been proposed to secure the swarm and validate the robots' behaviour [16,17]. Obviously, these blockchain-based methods could bring other great benefits to the robotics swarm such as rewarding valid robots, selecting swarm leaders and allocating tasks to a robot based on its behaviour history.

2.4 Blockchain in Energy Markets and Trading

In the energy sector, large centralized energy providers, who primarily produce electricity (e.g., power grid) using non-renewable energy fossil fuels, are the primary sources for energy production to support the huge energy demand. This traditional power supply has a severe impact on both the environment (e.g., environmental pollution and climate change) and consumers (e.g., energy shortage and increased electricity cost). Driven by these impacts, new clean renewable energy sources (RES), such as solar energy, wind energy and water energy have been developed [18].

The distribution and integration of RES into the energy system requires a new energy marketplace schema to manage and maintain the increasing RES production and consumption and intelligently connect both power providers and consumers in an effective way [19]. This is one of the greatest challenges in the energy sector because, to date, the existing marketplace is unable to handle the dramatic increase of RES in real-time. Furthermore, energy prices in these markets are determined on a national level without considering local energy demand and supply. Therefore, several local energy marketplace (LEM) approaches have been proposed to successfully integrate distributed renewable resources for the local community into the energy system [18].

This local energy market mechanism provides a market that facilitates local trade and access to the local RES for a practical community. A community is a group of energy consumers and prosumers (e.g., a homeowner, a commercial company, an industrial factory or a farm) who have a smart meter and battery storage. There are three main participants in the LEM: an energy producer, an energy consumer and a prosumer, who consumes and produces energy as well.

To ensure the long-term sustainability of this LEM, an innovative, secure and decentralized information technology using blockchain, is needed. Blockchain creates a safe, decentralized, transparent and trustworthy network that empowers the energy trading marketplace and makes it affordable for local residents. Blockchain, as a distributed computing technology, opens a new future direction for the decentralized energy trading market by providing a secure, transparent and trustworthy network trading environment for communities [20].

The LEM is also known as a peer-to-peer (P2P) online trading marketplace. The business model for this blockchain marketplace is based on an interaction between sellers and buyers via an intelligent platform. This trustworthy blockchain platform will allow energy producers to meet and sell their excess electricity at a desired price to consumers directly without an intermediate party. For instance, a producer will create a smart contract on the blockchain through the platform to sell his surplus energy and when a consumer is willing to purchase that electricity, the smart contract will be executed. In practice, the purchased energy will be transferred from the producer's smart meter to the consumer's smart meter and when the consumer receives all the agreed energy, then the money will be transferred from the consumer's wallet on the blockchain to the producer's wallet.

2.5 Blockchain in the Pharmaceutical Sector

Implementing an effective strategy to ensure the existence of reliable and equitable pharmaceutical supply chains is one of the highest priorities in healthcare systems. In developing countries, the distribution of medicines is an urgent issue due to the complexity of managing the pharmaceutical supply chain as there are many stakeholders and it also involves human wellbeing [21].

A pharmaceutical supply chain consists of a set of players, processes, information, and resources which transfers raw materials, and components to finished products or services and delivers them to the customers [22]. The drug industry is facing several problems such as finding a balance in terms of producing drugs to meet consumer demand, tracking every entity in the supply chain, and reducing the number of counterfeit drugs. Blockchain (in conjunction with other approaches such as artificial intelligence) offers a powerful means to solve these problems.

Optimizing the process and management of the pharmaceutical supply chain and sub- standard drug proliferation is a major research challenge. An imperfect supply chain system and the lack of traceability are the two main reasons for the appearance of counterfeit drugs. This problem is due to the lack of shared information between nodes in the supply chain system [22,23]; for instance, manufacturers are not aware of the location of their products after exporting their drugs. Hence, better tools for managing information on drugs are urgently required. The risk to human life due to counterfeit medicines is becoming a global issue. The World Health Organization (WHO) reported increased sales of counterfeit drugs around the world, and it is expected to increase by 35% over the next five years [24]. Developing countries in Africa and Asia are the main areas suffering from counterfeit drugs, which represent around 30% of total medicine sales.

The security and traceability of pharmaceutical companies and pharmacy distributors is becoming extremely highly important to control this problem [25]. Many technologies have been used to improve medicine supply chain systems, but there are still many issues. The introduction of blockchain technology can reap several benefits. Drugs, for example, can be tagged and scanned to be stored securely in a distributed ledger; this ledger will be updated in real-time as the drugs are transferred from one entity to another in the supply chain [26].

2.6 Blockchain in Identity Management

Identity (ID) management is a critical topic that focuses on managing individual characteristics. An ID management system is paramount in personal and organisational communication to provide health, education, business, transportation and government services amongst others. People aim to obtain a secure and reliable ID given its significant value. Thus, blockchain is an ideal technology that securely stores data.

Many institutions use the traditional ID system for data storage in a centralised database that relies on a third party, leading to a lack of interoperability and many security and privacy issues. Moreover, a number of privacy acts outline the ownership of personal ID information (PII) and grant legal rights to certain organisations to use individuals' PII. In 2019, Malaysia was ranked fifth among the nations with the worst personal data security system. Its number of reported data breach cases increased significantly from 64 in 2018 to 178 in 2019 [27].

To address some of the above emergent challenges in ID management, Blockchain ID management studies have recently grown. Different authentication mechanisms were applied, including smart cards and passwords and biometric methods that use fingerprint, facial recognition etc. For example, Estonia is one of the first countries that uses a public-permissioned network in blockchain and digitised their ID system since 2007 through the citizen digital ID. They also started signing documents digitally through a combination of a citizen ID and PIN and have been providing non-citizens digital IDs since December 2014 to become e-residents for commercial activities [29].

A self-sovereign ID facilitates individuals to fully access their IDs without third parties. Blockchain uses a high-security system in ID management to enable users to authenticate and authorise resource access through a digital signature in a digital ID. Furthermore, blockchain can solve data storage problems associated with most ID management systems and provide a secure decentralised network and minimise ID theft [30]. It is a smart way to reduce fraud by increasing transparency and an ideal solution to protect and recover communities' ID in case of disasters, such as fire and earthquake. On the other hand, a federated ID has valuable benefits that allow users to use one authentication in accessing different services while minimising digital ID management and its cost. The most important solutions currently existing are SAML, Shibboleth, Liberty Alliance framework, openID and WS [31]. Blockchain in ID not only focuses on data storage but also offers economic ID to save individuals' reputation data. Storing transactions between different users in blockchain builds a trust relationship.

Blockchain based approaches for managing user identities have universal applications that allows users to own and control their IDs and easily integrate and manage them. Data will be encrypted and stored securely to enhance transparency, privacy and security. Research in the area of Blockchain-based approaches for identity management is in its infancy; hence, there are a number of opportunities and research challenges to be addressed in this space.

2.7 Blockchain-Based Wallet

Payment systems have developed from a traditional payment system that utilizes physical or pocket wallets to a digital payment system that utilizes digital or E-wallets. Digital wallets have become extremely prevalent because large companies such as Google, PayPal, and Facebook have embraced the trend of global payments and offer more e-wallet payment services. The benefits of adopting digital wallets include a convenient and secure payment process, efficient funds transfer, and utility costs reduction. However, when applying traditional digital transactions that leave digital footprints, certain data security risks arise, and entities' sensitive information is available to banks and service providers [32]. On the other hand, blockchain as a payment system is a relatively recent trend driven by the success of Bitcoin and its ability to build a trusted ecosystem due to its decentralization and immutability features. By implementing blockchain technology as a payment medium, a financial business can significantly reduce transaction time and decrease operational transaction costs as it removes many intermediaries [33].

The cryptocurrency system requires a blockchain-based wallet to send and receive cryptocurrencies within the network. Blockchain-based wallets are software or hardware devices that allow individuals to send and receive digital currency within the blockchain network. It contains no currency, and it is more like a keychain that holds private keys with each key being associated with a public key address. Digital wallets in blockchain technology play a significant role in securely maintaining user's public-private key pairs. Deciding on the appropriate and secure blockchain-based wallets is critical when joining the blockchain network since losing private keys means losing the cryptocurrencies associated with that private key [34].

Although blockchain is a promising technology and blockchain-based wallets are here to stay, there is a lack of studies which investigate the security mechanisms that should be used on top of blockchain-based wallets, such as two-factor and biometric authentication. A limited number of studies have introduced a risk-based mechanism for users to determine what security mechanisms they should utilize to secure their wallets based on their requirements. Furthermore, there is a lack of a decision-making model to make trust- based assessments when interacting with other entities. Therefore, there is a critical dilemma in relation to which procedures provide a secure and more trustworthy management scheme for the blockchain-based wallet so that it becomes more reliable, efficient, and stable.

3 Blockchain Adoption Challenges

The emergence of blockchain has had a profound effect on how information is stored and processed securely. However, blockchain adoption in public sectors is still very limited [35]. This section provides an in-depth study on the challenges of the adoption of blockchain in real-world contexts.

One of the biggest challenges in implementing blockchain is the lack of a clear understanding of this technology. This lack of information has led to insufficient recognition of technical compliance, subsequent benefits of acquisition, and potential use cases [36]. Moreover, there is inadequate awareness of the level of organization, where managers have shown unwillingness to adopt novel technology because of their failure to recognize the significant returns on investment and the lack of effective technology use cases. Confusion between Bitcoin and blockchain has also led to this misconception [36]. Technology should isolate itself from the negative connotations of cryptocurrency and the concerted efforts of educated consumers are needed to spread greater awareness of blockchain and its benefits beyond cryptocurrencies alone.

The initial cost of adopting blockchain is very high owing to its complexity. Moreover, the adoption of blockchain technology currently requires either the development of a proprietary solution or soliciting the services of blockchain technology providers, which are very scarce [37]. Because of the technical infancy of blockchain, there is a shortage of skilled professionals in this field. In addition, the new system may require hardware resources owing to the computation-intensive nature of the technology [38]. Therefore, the adoption of a blockchain-based solution currently exceeds the limited financial and operational limits for medium and small enterprises and generally speaking is only being used by large organizations.

Blockchain technology has attracted the attention of many organizations due to its prospects of multi-sector applications outside the finance field where it first began. However, the adoption of blockchain technology experiences challenges such as insufficient knowledge of blockchain and initial costs.

4 Discussion

The above sections in this paper, have outlined a number of innovative blockchain applications across a number of different sectors. Although the above applications of lockchain is not exhaustive, it is extensive in the sense that a smorgasbord of blockchain applications have been outlined and discussed. Each of the blockchain applications presented in paper opens and presents a unique set of research challenges that require further investigation. For example, considering the Carbon Credit Blockchain application presented in Sect. 2.2, a niche research problem specific to this application is that of the development of automated trading algorithms to be able to autonomously transact on behalf of the end users. Another example of a unique research issue is that of Machine Learning methods needed to be able to rank the blockchain wallets in a personalized manner. Discussing each and every research problem emanating from the above mentioned blockchain application is not in the scope of this paper. However, we would like to outline and discuss a few research challenges that are common across most, it not all of the aforesaid mentioned blockchain application.

- **Approaches for ascertaining veracity of the subjective information**
  Most Blockchain applications in the literature assume that the originating source of information is from a reputable or objective source. The existing literature lacks approaches for verifying the validity of subjective information sources prior to it being mined. If the blockchain is taking into account subjective information or information from subjective sources (such as social media), then its legitimacy needs to be ascertained, before it is added as a Block in the blockchain.
- **Novel consensus approaches for mining information from subjective sources**
  Various protocols such as PoW, PoS and PoC or PoA are used by the miners during the mining process. While the working of each of these protocols vary, they are consistent in checking the legitimacy of the source information prior to the mining process. These consensus approaches have been designed to work well when the input information source/s are from objectives sources; however, this observation does not hold true when the input information source is a subjective source. To cater for scenarios wherein the input information source is subjective, there is need for further research to develop mining protocols that can take into account subjective sources of information.
- **Blockchain adoption methodologies**
  With each of the above mentioned blockchain applications, there is a pressing need to develop informed methodologies with a view to maximise the adoption of the niche blockchain application in the respective domain. While there could be some learning derived from the development and use of blockchain adoption strategies from one domain to another domain (for example there could be some commonality between the factors impacting Micro-credential blockchain adoption and Identity management blockchain; the overall developed methodology would have to be bespoke to the specific blockchain application.

5 Conclusion and Future Work

Blockchain technology plays a critical role in the digital transformation of centralized susceptible data structures into a distributed, trackable and auditable data structure. Moreover, blockchain technology is new, and it is continuing to be utilized in new applications and to be developed globally. Therefore, it is necessary to keep developing blockchain applications in many different areas for a future which is free of fraud and deception. This paper highlighted the significance of blockchain technology in different disciplines, including education, carbon credits, robotics, energy, pharmaceutical supply chains, identity management, and cryptocurrency wallets. This could have broader implications to leverage the applications' operational efficiencies to be more secure, transparent, and trustworthy. Also, this is the first research study that provides a collection of applications that introduce the technology of blockchain to the field.

Our future work involves tackling a number of research issues and challenges. One line of enquiry that we intend to keep on pursuing is that of developing innovative blockchain applications in various sectors/realms. The second line of enquiry that we intend to work on is to develop solutions to pressing Blockchain problems such as the ones outlined in Sect. 4.

References

1. Yaga, D., Mell, P., Roby, N., Scarfone, K.: Blockchain technology overview arXiv preprint arXiv:1906.11078 (2019)
2. Woodside, J.M., Augustine, F.K., Jr., Giberson, W.: Blockchain technology adoption status and strategies. J. Int. Technol. Inf. Manag. **26**(2), 65–93 (2017)
3. Zheng, Z., Xie, S., Dai, H., Chen, X., Wang, H.: An overview of blockchain technology: architecture, consensus, and future trends. In: 2017 IEEE International Congress on Big Data (BigData Congress), , pp. 557–564. IEEE (2017)
4. Ralston, S.J.: Higher education's microcredentialing craze: a postdigital-deweyan critique. Postdigital Science and Education, p. 1
5. Turkanović, M., Hölbl, M., Košič, K., Heričko, M., Kamišalić, A.: Eductx: a blockchain-based higher education credit platform. IEEE Access **6**, 5112–5127 (2018)
6. Jirgensons, M., Kapenieks, J.: Blockchain and the future of digital learning credential assessment and management. J. Teach. Educ. Sustain. **20**(1), 145–156 (2018)
7. Gallagher, S.: A new era of micro-credentials and experiential learning. University world news, the global window on higher education (2019)
8. Patel, D., Britto, B., Sharma, S., Gaikwad, K., Dusing, Y., Gupta, M.: Carbon credits on blockchain. In: 2020 International Conference on Innovative Trends in Information Technology (ICITIIT), pp. 1–5. IEEE (2020)
9. Kenton, W.: How does the carbon credit work? December 2020. https://www.investopedia.com/terms/c/carbon_credit.asp
10. Kim, S.-K., Huh, J.-H.: Blockchain of carbon trading for un sustainable development goals. Sustainability **12**(10), 4021 (2020)
11. Atkinson, R.D.: Robotics and the future of production and work. Tech. Rep, Information Technology and Innovation Foundation (2019)

12. Vavra, C.: Electronics manufacturing driving industrial robotics market growth. Control Eng. **64**(12), 14 (2017). Name - Robotic Industries Association; Copyright - Copyright CFE Media Dec 2017; Last updated - 2020-11-18. [Online]. Available: http://ezproxy.lib.uts.edu.au/login?url=https://www-proquest-com.ezproxy.lib.uts.edu.au/trade-journals/electronics-manufacturing-driving-industrial/docview/2130711949/se-2?accountid=17095
13. Hsu, K., Tsai, W., Yang, H., Huang, L., Zhuang, W.: On the design of cross-platform social robots: a multi-purpose reminder robot as an example. In: International Conference on Applied System Innovation (ICASI) 2017, pp. 256–259 (2017)
14. Ahn, J., Park, M., Shin, H., Paek, J.: A model for deriving trust and reputation on blockchain-based e-payment system. Appl. Sci. **9**(24), 5362 (2019)
15. Le Thi Thuy, N., Nguyen Trong, T.: The multitasking system of swarm robot based on null-space-behavioral control combined with fuzzy logic. Micromachines **8**(12), 357 (2017)
16. Strobel, V., Castelló Ferrer, E., Dorigo, M.: Blockchain technology secures robot swarms: a comparison of consensus protocols and their resilience to byzantine robots. Front. Robot. AI **7**, 54 (2020)
17. Strobel, V., Castello Ferrer, E., Dorigo, M.: Managing byzantine robots via blockchain technology in a swarm robotics collective decision making scenario (2018)
18. Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., Weinhardt, C.: Designing microgrid energy markets: a case study: the brooklyn microgrid. Appl. Energy **210**, 870–880 (2018)
19. Schleicher-Tappeser, R.: How renewables will change electricity markets in the next five years. Energy Policy **48**, 64–75 (2012)
20. Gencer, A.E., Basu, S., Eyal, I., Van Renesse, R., Sirer, E.G.: Decentralization in bitcoin and ethereum networks. In: International Conference on Financial Cryptography and Data Security, pp. 439–457. Springer (2018)
21. Dowling, P.: Healthcare supply chains in developing countries: situational analysis. Arlington, Va.: USAID— DELIVER PROJECT (2011)
22. Barchetti, U., Bucciero, A., De Blasi, M., Mainetti, L., Patrono, L.: Rfid, epc and b2b convergence towards an item-level traceability in the pharmaceutical supply chain. In: 2010 IEEE International Conference on RFID-Technology and Applications, pp. 194–199. IEEE (2010)
23. Rossetti, C.L., Handfield, R., Dooley, K.J.: Forces, trends, and decisions in pharmaceutical supply chain management. Int. J. Phys. Distrib. Logist, Manag (2011)
24. ten Ham, M.: Health risks of counterfeit pharmaceuticals. Drug Saf. **26**(14), 991–997 (2003)
25. Mackey, T.K., Liang, B.A.: The global counterfeit drug trade: patient safety and public health risks. J. Pharm. Sci. **100**(11), 4571–4579 (2011)
26. Yu, X., Li, C., Shi, Y., Yu, M.: Pharmaceutical supply chain in china: current issues and implications for health system reform. Health Policy **97**(1), 8–15 (2010)
27. Ghani, F.A., Shabri, S.M., Rasli, M.A.M., Razali, N.A., Shuffri, E.H.A.: An overview of the personal data protection act 2010 (pdpa): Problems and solutions
28. Lim, S.Y., Fotsing, P.T., Almasri, A., Musa, O., Kiah, M.L.M., Ang, T.F., Ismail, R.: Blockchain technology the identity management and authentication service disruptor: a survey. Int. J. Adv. Sci. Eng. Inf. Technol. **8**(4–2), 1735–1745 (2018)
29. Sullivan, C., Burger, E.: E-residency and blockchain. Comput. Law Secur. Rev. **33**(4), 470–481 (2017)
30. Panait, A.-E., Olimid, R.F., Stefanescu, A.: Identity management on blockchain–privacy and security aspects. arXiv preprint arXiv:2004.13107 (2020)

31. Kallela, J., et al.: Federated identity management solutions. In: TKK T-110.5190 Seminar on Internetworking (2008)
32. Biryukov, A., Tikhomirov, S.: Security and privacy of mobile wallet users in bitcoin, dash, monero, and zcash. Pervas. Mobile Comput. **59**, 101030 (2019)
33. Zaghloul, E., Li, T., Mutka, M.W., Ren, J.: Bitcoin and blockchain: security and privacy. IEEE Internet of Things J. **7**(10), 10 288–10 313 (2020)
34. Sethy, A., Ray, A.: Leveraging blockchain as a solution for security issues and challenges of paperless e-governance application. Progress in Computing, Analytics and Networkingk, pp. 651–658. Springer (2020)
35. Stratopoulos, T.C., Wang, V.X., Ye, J.: Blockchain technology adoption. Available at SSRN 3188470 (2020)
36. Janssen, M., Weerakkody, V., Ismagilova, E., Sivarajah, U., Irani, Z.: A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors. Int. J. Inf. Manag. **50**, 302–309 (2020)
37. Koens, T., Poll, E.: The drivers behind blockchain adoption: The rationality of irrational choices. In: European Conference on Parallel Processing, pp. 535–546. Springer (2018)
38. Sadhya, V., Sadhya, H.: Barriers to adoption of blockchain technology (2018)