Blockchain Technology: An Overview

Conference Paper · March 2023

Shamima Nasrin Mukta
Chittagong University of Engineering & Technology

Blockchain Technology: An Overview

Shamima Nasrin Mukta

Assistant Professor

Department of Humanities

Chittagong University of Engineering & Technology (CUET)

Chottogram, Bangladesh.

Email: s.mukta91@cuet.ac.bd

Blockchain Technology: An Overview

Abstract: Blockchain technology is relatively a new area of research. This technology has created high expectations as all transactions are performed in a decentralized mode without the help of any third party. There is a scarcity of knowledge and understanding of blockchain technology that hinders its academic research and practical application. It is expected that this paper will be an addition to the existing stock of knowledge regarding blockchain technology. The objectives of this paper are to provide an overview of blockchain technology, to identify the current standing of blockchain technology and to identify major areas of application for which blockchain offers a valuable solution. It also attempts to identify major challenges associated with its application. Literature review approach was adopted in this paper in order to attain the objectives. This research finds that special features of blockchain technology such as privacy, security, anonymity, decentralization and transparency, make it unique to users in different areas. The paper also observes that blockchain technology is being used in very limited areas. It is expected to evolve in functionality and bring revolution in many industries in terms of time, efficiency and accuracy.

Keywords: Blockchain Technology, P2P network, Transparency.

Introduction:

The development of new technologies always brings radical transformations in the ways of doing work and disruptive change in the society. Steam, for example, powered the industrialization of economies and fostered the displacement of large segments of the working populace as well as laying the foundations for seemingly unstoppable environmental decline, (Lewandowsky, 2016; Kittel, 1967). Blockchain promises similarly startling disruption to business and society (Naughton, 2016). Blockchain is a digital, decentralized public ledger that intends to keep a record of each data transaction occurring in its network. Each transaction in the distributed ledger is verified by consensus of a majority of the participants in the network. Once entered, information can never be erased. The blockchain contains a certain and verifiable re¬cord of every single transaction ever made. In other words, blockchain provides an immutable, trusted and secure platform for multiple entities (both individuals and organizations) to exchange data/assets, collaborate and perform transactions (Allladi et al). This prevents fraud and ensures a digital form of verification allowing for "tustless" peer to peer transactions. This technology has been said to "change market paradigms" (Gumsheimer *et al*. 2016), to be able to "reverse the fortunes of the post-crisis financial sector" (Grewe & Bosch, 2016), and is predicted to be the technology "most likely to change the next decade of business" across all industries (Tapscott & Tapscott, 2016a). Blockchains are associated with Bitcoin and other cryptocurrencies such as Ethereum and Ripple. However, it should be emphasized that cryptocurrencies are a by-product of blockchains and blockchains are able to exist independently of any cryptocurrencies (Greenspan, 2015). This disruptive technology will influence significantly national governance, institutional functions, business operations, education, and our daily lives in the 21st century. Swan (2015) indicated that the development of blockchain applications could be divided into three stages; Blockchain 1.0, 2.0, and 3.0. Blockchain 1.0 is the deployment of cryptocurrencies as a peer-to-peer cash payment system. Blockchain 2.0 is the extensive blockchain applications than simple cash transactions including stocks, bonds, loans, smart property, and smart contacts. Blockchain 3.0 is developing blockchain applications beyond currency, finance and markets such as in the areas of government, health, science, literacy, culture, and art. According to the previously mentioned principle, the current application of blockchain is still in the 1.0 and 2.0 stages. Most people do not know about the term “blockchain,” not to mention the potential applications of blockchain technology. Against this backdrop, the study is conducted to achieve the following specific objectives.

Specific Objectives:

- To provide an outline of blockchain technology;
- To identify the current standing of blockchain technology;
- To identify major areas of application for which blockchain offers a valuable solution;
- To identify major challenges associated with its application.

Methodology:

The paper is prepared on the basis of available literatures. In order to complete a review of the current landscape of blockchain technology a systematic literature review is conducted. The major aim of literature review is to assemble the basic types and characteristics of blockchain technology as well as the types of benefits and barriers that have been identified until now. A substantial body of literature exists on blockchain have been collected from various sources, such as blogs, wikis, forum posts, codes, conference proceedings and journal papers. For selecting the articles, the major databases such as IEEE explorer, Springer link, ACM digital library and Google scholar were searched for related articles. In particular, the research began by searching for relevant publications using the following keywords:“blockchain overview”, "blockchain government", "blockchain public sector", "blockchain benefits", "blockchain barriers", "blockchain challenges", "blockchain public services", “blockchain energy”, “blockchain applications”, “blockchain business”, “Blockchain supply chain”, “blockchain opportunities, “Blockchain e voting”, “blockchain healthcare”, “blockchain education”, “blockchain banking” etc. Finally the author conceptualizes the concept ‘blockchain technology’, contextualizes its initial application and traces its subsequent evolution into other fields of studies chronologically. The results of the study are then elaborated followed by a discussion of the blockchain application research landscape and the various fields covered as well as the respective blockchain contributions suggested by the literature.

Organization of the paper:

The paper presents an outline of blockchain technology and its main features along with types first. And then it discusses existing or future use cases found in the literature and the impact that blockchain could have on multiple industries. Moreover, possible concerns that may arise from the expansion of blockchain applications to various sectors are taken into consideration in presentation.

An Outline of Blockchain Technology:

Blockchain has most often been associated with the cryptocurrency bitcoin, as its underlying technology which was first introduced in 2008 in a white paper by Satoshi Nakamoto (2008). Satoshi Nakamoto defined blockchain in the simplest form. He stated blockchain as a chain that is constructed from many blocks that contain information. Blockchain is a decentralized electronic database (decentralized ledger) that is consists of an ever-increasing list of records made up of blocks. Each block typically contains transaction data, a timestamp, and a hash pointer to link to the previous block. Thus a chain is formed by linking blocks with each block containing the hash value of the previous block. Davidson et al. (2016) characterized blockchain as a catallaxy for being a robust, protected and transparent ledger since it implements secured mechanism using cryptography. According to Crosby et al. (2016), blockchain is a distributed online database of all digital events occurred among the participant nodes in a network. He provided an overview of blockchain technology and described some challenges, which can be overcome by blockchain and some limitations to be resolved in future work. Buterin (2015), referred blockchain as a crypto economical secured magic computer that includes self executable programs with records of all previous and current states. Carlozo (2017) described blockchain technology as the backbone of each digital transaction. He also asserted that blockchain would offer more dynamic approaches to business.

Blockchain operates via a generalized process. The process starts with a transaction request from any user (node) in a peer to peer (P2P) network. Then the transaction is broadcasted to all the users in the network. Following that, the verification process takes place where all of the nodes in P2P network verify the transactions via the hashes. Once the verification is completed, the transaction data are stored within a new block. Finally, the new block is connected to blockchain using hashed value of the information from the previous block, which makes it permanent and unchangeable. In every blockchain, the first block is known as the Genesis block which works as foundation of the chain. Every newly created block is then connected with the preceding blocks in the chain; thus, every block is connected eventually to the genesis block. In addition to the information contained in each block, a cryptographic hash is also present. Every block of the chain includes its own hash and the previous's one. The hash is as like as fingerprint that uniquely identifies each block and its contents. Thus, any change in the block's content will result in a change in the associated hash (Beck, 2018). Hashes play a vital role in the blockchain operation since it works as a main guarantee for blockchain security. This technique makes the blockchain technology one of the most secure options in the industry nowadays (Karame & Capkun, 2018). In the case when information in a block is changed, the hash of the block itself will change; however, the hash in the next block will not. This results in indicating all the following blocks as an invalid block. Therefore, a change in the single block in the blockchain results in invalidating all the following blocks in the chain (Karame and Capkun 2018).

The use of hashes provides security in the blockchain. However, with the help of the super-fast computers, hackers could change the information in a single block and then all the hashes of the following blocks can be recalculated in the chain in a few minutes. To overcome this issue, several algorithms have been created, what is known as the consensus (Moubarak *et al.,* 2018). The process of the consensus includes the verification of the transactions before that are added to the blockchain. This allows the blockchain to grow without the fear of the manipulating of the blocks or the information within them. The consensus process takes place in predefined discrete time intervals. These intervals represent the times from the initiation of the transactions to the time of its addition to the blockchain. The confirmation time depends on the block size, transaction volumes, and the consensus algorithms utilized. Consensus algorithms with variable properties have been developed and utilized in the industry nowadays. According to Luke *et al.,* (2018), the four well-known consensus algorithms are:

- Proof of Work (PoW);

- Proof of Stake (PoS);
- Proof of Authority (PoA);
- Practical Byzantine Fault Tolerance (PBFT).

Blockchains are associated with Bitcoin and other cryptocurrencies such as Litecoin and Ripple. However, it should be emphasized that cryptocurrencies are a by-product of blockchains and blockchains are able to exist independently of any cryptocurrencies (Greenspan 2015). Gupta (2017) identified five core elements that constitute the major elements of blockchain technology:

a. ***Distributed database*** -The data is not controlled by any single party. The complete database, including its history is available to each participant of a blockchain. Participants can by themselves validate the records of their transaction partners.
b. ***Peer-to-peer (P2P) transactions*** - Peers communicate directly with each other rather than through a central node and each node keeps and forwards data to all other nodes.
c. ***Transparency with pseudonymity*** -Transactions are observable by any allowed node. Each node can keep its identity anonymous or alternatively provide evidence of its identity.
d. ***Immutability of records*** - When a transaction has occurred, its record is immutable since it is "chained" to all prior transactions.
e. ***Computational logic*** - Algorithms and rules can be created to trigger transactions automatically (e.g. smart contracts).

Some special features make blockchain different from other similar technologies which could be summarized in the following points:

- ***Decentralized:*** There is no need for central authority to handle the transactions of the blockchain.

- ***Resilience:*** Blockchain is resilient to any possible attacks due to its decentralization nature.
- ***Time reduction:*** Transactions are handled quickly in the blockchain without the need for an intermediary.
- ***Reliability:*** This is more reliable due to the detailed and unchangeable history recoded in the blockchain.
- ***Fraud prevention:*** Information sharing and consensus process prevent fraud.
- ***Security:*** It is more secured due to use of unique hash in each block.
- ***Transparency:*** All the changes and the transactions are shared with all the blockchain users.

Initially blockchain technology was introduced with the use of cryptocurrency, Bitcoin. The ways people use blockchain technology vary from case to case. Buterin (2015) roughly categorised blockchain systems into three types: public blockchain, private blockchain and consortium blockchain. Besides this, there is another type of blockchain, known as hybrid blockchain. A brief description of all these types is given below:

a. ***Public blockchain:*** The public blockchain is non restrictive, permission less and open to all of the users. Anybody who has access to internet can join in a blockchain platform, become an authorised node, access all records and verify transactions. Basically public blockchain is used for mining and exchanging cryptocurrencies. Example: Bitcoin, Ethereum, Litecoin.

b. ***Private blockchain:*** A private blockchain can be defined as a permission blockchain that works in a restrictive environment, i.e., a closed network. Private blockchains are usually used within an organization where only selected members have access to a blockchain network. The level of security, authorizations, permissions, accessibility is in the hands of the controlling organization. Private blockchain networks are used for voting, supply chain management, digital identity, asset ownership, etc. Examples: Multichain and Hyperledger projects (Fabric, Sawtooth), Corda, etc.

c. ***Consortium blockchain:*** Here, a single group of the users can be allowed to view, verify or add to the blockchain. Thus, it is controlled by authorized nodes only. The main difference between private blockchain and consortium is that consortium blockchains are governed by a group rather than a single entity. More than one organization can act as a node in this type of blockchain and exchange information or do mining. Consortium blockchains are typically used by banks, government organizations, etc. Examples: Marco Polo, Energy Web Foundation, IBM Food Trust.

d. ***Hybrid blockchain:*** A hybrid blockchain is a mixture of the private and public blockchain. This means that it combines the privacy benefits of a private blockchain with the security and transparency benefits of a public blockchain. With such a hybrid network, users can control who gets access to which data stored in the blockchain. A transaction in a private network of a hybrid blockchain is usually verified within that network. But users can also release it in the public blockchain to get verified. Only a selected section of data or records from the blockchain can be allowed to go public keeping the rest as confidential in the private network. **Example** of a hybrid blockchain is Dragonchain.

Applications of Blockchain:

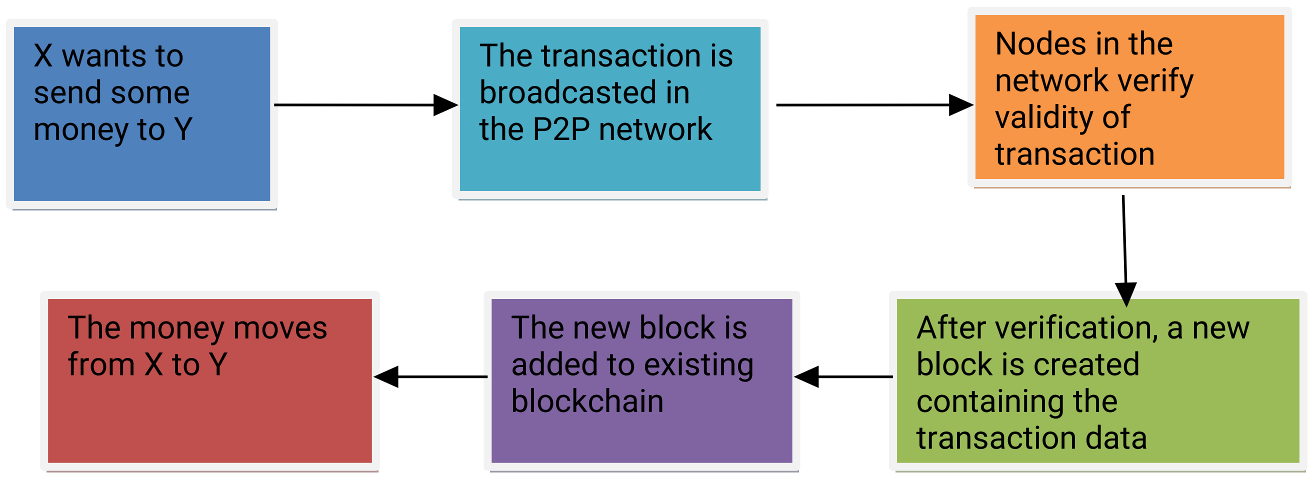
Cryptocurrencies: Cryptocurrencies are first application of blockchain technology and constitute a major application area for the blockchain technology. A cryptocurrency is a medium of exchange like Taka but is digitally created and stored using encryption techniques to control the creation of monetary units and to verify transactions. Cryptocurrency is unique because it has no intrinsic value, no physical form and its supply is not determined by central bank. With the innovation of Bitcoin in January 2009 blockchain had its first real-world application. Other cryptocurrencies have been developed, after the release of bitcoin. For example, Namecoin was released in In April 2011, Litecoin in October 2011. Here, main focus is on the use of cryptocurrencies as a payment solution. Suppose that user X wants to transfer money to user Y. When this transaction happens, it is represented as a block which is transmitted to every node/user of the P2P network. Then, the users have to verify validity of the transaction. The users have to solve a puzzle in order to be the first to validate the transaction. This puzzle requires the use of certain computational power. The puzzle solving procedure is called “mining” and the first miner who will find the solution gets a bitcoin reward, so miners are competing to be the fastest to solve the puzzle. The miner needs to ensure two things before recording any transaction:

i. Ownership of the cryptocur¬rency by sender, through the digital signa¬ture verification on the transaction.

ii. Sufficiency of crypto¬currency in sender’s account (wallet), through checking every transaction against the sender’s account, through checking every transaction against the sender’s account, or “pub¬lic key”, that is registered in the ledger.

The transaction is completed when 51% of the users approve the provided solution. Then, the block of the transaction is added to the blockchain. With the addition of new block, the transaction is finished. The blockchain is a list of blocks that includes every single transaction that has ever been made. The blocks are visible to all users, but they cannot be edited.

Following figure shows how cryptocurrencies use blockchain platform:



E-government: E-government services to citizens, businesses and public bodies are expanding rapidly in recent years. The integration of blockchain into government would allow governments to simultaneously increase the number of services offered while improving the overall quality and processing times of existing services. Blockchain also helps to handle transactions involving digitization of assets (e.g. money, stocks and properties rights) and decentralized exchange (peer to peer exchange). Introducing blockchain based electronic voting systems can establish transparent voting system and secure that nobody can manipulate an election because everyone is capable to read and verify the votes. Hou (2017) analyzes a blockchain system that verifies the origin and genuineness of data during transmission in the e-government and public services, implemented in China.

Using blockchain technology in public sector provides the following advantages:

- Digital ID management
- Secured document handling
- Transparent tax system
- Access to updated public information
- Greater amount of transparency and accessibility between the government and citizens

Land registration: Existing land registry system involves a lot of intermediaries which increases risk of fraud, time delay, and excessive human intervention. Blockchain technology can be applied in land registration to overcome these problems. The land information such as the physical status and related rights can be registered and publicised on blockchain where signers can sign the document and other users can verify it when needed. Any changes made on the land, such as the transfer of land or the establishment of a mortgage can be recorded and managed on blockchain. Besides, in the blockchain land registry platform, a digital, decentralized ID as a seller and buyer can be created which makes ownership transfer simple and quicker than the traditional method. Though blockchain ensures authenticity of transactions in land registration system, great care must be taken to ensure that the information being inputted on the blockchain is in fact true and accurate. Considering its benefits, some developed countries e.g. United States, Netherlands, UK, Sweden have taken steps to integrate blockchain technology into countries existing land registration system.

Power industry: The power industry is facing major transformations over the past several years because of utilities embracing newer technologies and newer sources of power generation. The power grids are becoming very complex to handle due to variability in demand & supply of power and different types of power grid. Blockchain as a tool can accelerate this global energy transformation by lowering the transaction costs and in operating the grid in a more efficient manner (Mengelkamp *et al.* 2017). Utilization of blockchain technology in energy trading process can be summarised as follows:

(i)Power generation: Blockchain technology provides full knowledge about the overall operation status of a power grid in a real-time perspective which helps to develop dispatching plans that would maximize profits.

(ii)Power Transmission and Distribution: Blockchain system overcomes the main challenges faced in the traditional centralized systems through decentralization of the automation and control centers.

(iii)Power Consumptions: Blockchain could be beneficial in this side by managing the energy trading between the prosumers and the different energy storage systems as well as the electric vehicles. According to Munsing *et al*. (2017) blockchain technology helps to conduct transparent transactions in the energy market between consumers and prosumers (active consumers that both produce and consume electricity) at local energy grids consisting of renewable energy resources. This also helps to reduce the time and effort required by removing the intermediaries from the market.

Thus, in blockchain based Peer to Peer (P2P) trading systems, the blocks inside the chain record the units of the generated electrical energy which allows the owners and buyers to have the deals instantly and independently. This gives the users (owners and buyer) the freedom of preferences, choices, and prices instead of relying on an intermediate agent (Otjacques *et al.* 2018). In particular, Aitzhan & Svetinovic (2018) proposed a token-based decentralized energy trading system where peers anonymously negotiate energy prices and are able to securely perform transactions. Examples of active commercial projects of blockchain implementation in the power sector are: Power Ledger in Australia, Greeneum in Israel, Grid+ in USA, Greed Singularity in Germany.

Education: Information about grade point, research experience, skills, online learning experience as well as individual interests, learning behaviour in class, micro academic project experience, and macro educational background, etc. are stored in a block . The blockchain ledger can match all kinds of educational information with the user's unique ID. The data matched with users' ID and stored in blockchain are checked, validated, and maintained by the miners from all over the world. Blockchain distributed ledger is immutable and trustworthy. Since information stored in the blocks cannot be changed, the reliability and authority both are ensured, which will minimise degree fraud. Besides degree management, Blockchain technology has great potentiality for application in formative evaluation, learning activities design and implementation and keeps tracking of the whole learning processes. The University of Nicosia is the first school which uses blockchain technology to manage students' certificates received from MOOC platforms (Sharples and Domingue 2016). Sony Global Education, Holberton School, Massachusetts Institute of Technology (MIT), University of Melbourne also use Blockchain technology for degree management.

Healthcare: Blockchain as a decentralized and distributed technology has enormous applications in healthcare domain. Blockchain technology helps to enhance the quality of healthcare services by storing and sharing medical information frequently among various relevant participants such as patients, doctors, healthcare service providers, pharmacies, insurance companies and researchers among others. Medical chain (2019) is a blockchain architecture which is being used in the UK to maintain the patient data. Clinical trials and the management of trial subject consent are an area where blockchain has the potential to increase transparency, auditability and accountability of medical practitioners and researchers. Within the pharmaceutical industry, blockchain can help to overcome the increasing risks around counterfeit and unapproved drugs. In addition to these, in healthcare blockchain technology can be used for global sharing patient data globally in case of international medical service, maintaining medical history, healthcare data access control, drug supply chain management (Roma *et al.* 2016).

Supply chain: Blockchain helps to reduce cost and risk across the supply chain. Blockchain increases transparency of supply chain by giving access to all parties in the supply chain to same information. In supply chain, blockchain technology ensures identification of product provenance and facilitates tracking of processes (Zhao *et al.,* 2016). Aspects of blockchain such as data accessibility and immutability greatly increase the transparency, reliability, and effciency of the entire supply chain industry (Perboli *et al.* 2018). Blockchain is helpful to ensure food traceability, solve logistics inefficiencies and product management. It can identify the source of problematic parts and ensure trustworthiness in whole supply chain. Everledger, an application of blockchain in supply chain, constitutes a worldwide ledger of diamonds in the luxury goods market and ensures their ownership (Ølnes, 2016)). Walmart, Ford Motor Company, De Beers, United Parcel Service, FedEx are successfully using blockchain technology in supply chain. Some commercial projects of blockchain application in supply chain domain:

i. *IBM Blockchain* - TradeLens: IBM Blockchain provides solutions that cover all aspects of supply chain management, with a specific focus on logistics. Transparency and traceability are the most critical aspects of logistics, and IBM Blockchain can streamline business exchanges, Scott (2018) transactions and trading associations with secure, worldwide business systems and networks.

ii. *OriginTrail:* OriginTrail (2019) has been on a mission to bring transparency to complex international supply chains since 2013.

iii. *Blockverify:* It is a blockchain-based anti-counterfeit solution presenting transparency in the supply chains. It is effectively being utilized in diamonds, pharmaceuticals and a couple of electronic industries (Hulseapple, 2015).

Banking: Financial institutions are now testing transactions on blockchain platform. Implementation of blockchain technology in banking provides some comparative advantages such as decentralised trust, enhanced security, decreased costs, and increased efficiency. Goldman Sachs, J.P Morgan, Citi bank, Wells Fargo and other banking giants, have all established their own blockchain laboratories collaborating with blockchain platforms. Standard Chartered bank uses "Ripple", an enterprise level blockchain platform to operate its first cross-border transactions (Guo & Liang, 2016)). Blockchain enables banks to process transactions in 10 seconds which would take 2 days previously and thus increases the efficiency of clearing and settlement of financial assets after transactions. In addition to that, blockchain application could help banks facilitate foreign exchanges and real-time payments by gathering nodes in a blockchain, rather than having a central bank to deal with payments (Tsai *et al.* 2016). It also enable transactions to be processed 24/7. As information is stored in blocks using a temper –proof format, it lets them improve the mobility of data and decrease the time taken for KYC efforts. It also allows fully automated transactional processes—from payment to settlement and removes any delays in documentation caused by duplication. Blockchain data is secured, complete, accurate, and reliable. Moreover, making all transactions available to a single, publicly available ledger eliminates the disorder and complexity associated with multiple ledgers. In 2016, hackers stole 100 million dollars from Bangladesh Bank via its accounts with the Federal Reserve Bank of New York. Such occurrence can be prevented through implementation of blockchain. Prime bank Ltd. is the first Bangladeshi bank to execute interbank blockchain LC transaction partnering with HSBC through Contour, the global trade finance blockchain network.

Challenges:

Blockchain technology can be termed as the most significant technological innovation that already has attracted many industries. Growth in adopting blockchain is growing exponentially in recent years. Now it is time to discuss about major challenges of blockchain technology:

Scalability: With gradual increase in transactions, blockchain also becomes heavy and all transactions need to be stored for validating the transaction. Blockchain also has restriction on block size and time interval between creation of new block. So it cannot fulfil the requirement of processing millions of transactions in a real-time fashion. Small transactions might be delayed since miners prefer those transactions with a high transaction fee. The ability to handle a large number of users at a single time is still a challenge for the blockchain industry.

Hackers and shadow dealing: Lack of a set of regulatory oversight makes blockchain volatile. There is always a risk of hacking and blocking by government due to shadowy practices.

Complex to understand and adopt: The complexities in Blockchain technology makes it difficult for a layperson to understand and realise its benefits. Before adopting one need to study a lot and understand the principles of encryption and distributed ledger. Moreover, financial institutions are adequate to provide secure payment gateways and other services at affordable prices compared to the costs incurred with blockchain.

Privacy: Even though blockchain technology can provide transparency in the clinical trial and precision medicine, this could lead to privacy concerns (Shae & Tsai, 2017). Financial systems, such as the banking systems, must provide high privacy in contrast to the current blockchain technology, which has a low privacy level (Tsai *et al.* 2016). The ledger needs to be remodelled in such a way that allows restricted access if necessary and will be accessed by people who are authorized to view it.

Costs: Blockchain implementation helps to eliminate the expenses related to the third parties and intermediaries involved in the process of transferring values.

Though blockchain technology can bring revolution in different industries it is still in the early stages of innovation making it tough to integrate into the legacy systems. Special hardware consuming higher energy is necessary for blockchain implementation. It makes blockchain adoption by the government as well as private firm an expensive affair.

Conclusion:

Initial focus of blockchain technology was on bitcoin, the first application of blockhain. Its usage domain is increasing rapidly (Kittell, 1967). Though research on blockchain technology is increasing, still it is in infant stage. In this study, the author tried to provide an overview and substantiated analysis of future potential applications of blockchain techniques. It makes a little contribution to the limited literature that considers the application of blockchain in different domains. The outcome of this research will provide future researchers fundamental knowledge to integrate blockchain in their development of future technological solutions. Considering the potential impact of blockchain technology and the scarcity of knowledge about it, efforts should be made to improve the awareness of scholars and business practitioners. With potential application ranging from wider banking and business to voting and international trade, blockchain could redefine many aspects of our life. Future research should examine the development and impact of blockchain. The benefits and barriers to its adoption will require better understanding. Some applications of blockchain have capacity to radically alter aspects of society. The legal and ethical ramifications of such developments need adequate research before and during their implementation. Therefore, further critical research is needed to exploit its capabilities and overcome the limitations when applied in a large scale.

References

1. Lewandowsky, S. (2016). Future Global Change and Cognition. *Topics in Cognitive Science (topiCS), 8(1)* , pp. 7-18.

2. Kittel, A.H. (1967). The Revolutionary Period of the Industrial Revolution: industrial innovation and population displacement in Belgium, 1830-1880. *Journal of Social History,* 1(2), 119-148.

3. Naughton, J. 2016. Is Blockchain the Most Important IT Invention of our age? *The Guardian.* Available at: http://www.theguardian.com/commentisfree/2016/jan/24/blockchain-bitcoin-technology-most-important-tech-invention-of-our-age-sir-mark-walport?

4. Alladi, T., Chamola, V., Parizi, R., & Choo, K.R. (2019). Blockchain Applications for Industry 4.0 and Industrial IoT: A Review. *IEEE Access, 7* , 176935-176951.

5. Gumsheimer, T., Felden, F., & Schmid, C. (2016). Recasting IT for the digital age, BCG perspectives, The Boston Consulting Group. http ://www.bcgperspectives .com/content/articles/technology -innovation-recasting-it-for-the-digit al-age

6. Grewe, I., & Bosch, R. (2016). Can the financial services industry master cryptofinance? *BearingPoint Institute.* http://www.bearingpoint.com/ecomaXL/files/BearingPoint-Insti tute_006-01_Can-the-financial-services-industry-master-cryptofinance.pdf&download=0. Accessed 1 February, 2021

7. Tapscott, D., & Tapscott, A. (2016a). The impact of the blockchain goes beyond financial services. *Harvard Business Review.* https ://hbr.org/2016/05/the-impact-of-the-block chain -goes-beyond-financial-services

8. Greenspan, G. (2015). Ending the bitcoin vs blockchain debate - Is there any value in a blockchain without a cryptocurrency? *MultiChain*. Accessed February 2021. http://www.multichain.com/blog/2015/07/bitcoin-vs-blockchain-debate/

9. Swan, M., (2015). Blockchain: Blueprint for a New Economy. *Sebastopol, CA: O'Reilly Media*

10. S. Nakamoto. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System*. Accessed: Nov. 5, 2020. *(Online)*. Available: https://bitcoin.org/bitcoin.pdf

11. Davidson, S., Filippi, P. D., & Potts, J., (Mar. 8, 2016). Economics of Blockchain. *(Online)*. Available: SSRN: https://ssrn.com/abstract=2744751 or http://dx.doi.org/10.2139/ssrn.2744751

12. Crosby, M., Nachiappan, Pattanayak, P., Verma, S., & Kalyanaraman, V., (2016) Blockchain technology: Beyond bitcoin. *Applied Innovation Review* 2:6–19

13. Buterin, V., (2014). Ethereum White Paper: A NEXT GENERATION SMART CONTRACT & DECENTRALIZED APPLICATION PLATFORM. Available at http://www.theblockchain.com/docs/Ethereum_white_papera_next_generation_smart_contract_and_decentralized_application_platform-vitalik-buterin.pdf. Accessed 23 January 2021

14. Buterin, V., (2015). On Public and Private Blockchains. *Ethereum Foundation Blog.* Available at https://blog.ethereum.org/2015/08/07/onpublic-and-private-blockchains/.

15. Carlozo, L., (2017). What is blockchain?' *Journal of Accountancy*, vol. 224, no. 1, p. 29.

16. Beck, R., (2018). Beyond bitcoin: The rise of blockchain world. *Computer*, vol. 51, no. 2, pp. 54-58.

17. Karame, G. & Capkun, S., (2018). Blockchain security and privacy. *IEEE Security Privacy*. vol. 16, no. 4, pp. 11-12.

18. Moubarak, J., Filiol, E., & Chamoun, M. (2018). On blockchain security and relevant attacks.*2018 IEEE Middle East and North Africa Communications Conference (MENACOMM)*, 1-6.

19. Luke M. N., Lee S. J., Pekarek Z., & Dimitrova A,. (2018). Blockchain in Electricity: A Critical Review of Progress to Date. *NERA Economic Consulting, eurelectric.* Pages 2018-05

20. Gupta, M., (2017). Blockchain for Dummies IBM Limited Edition.*John Wiley & Sons Inc.*, p. 31-35

21. Hou, H. (2017). The Application of Blockchain Technology in E-Government in China. *26th International Conference on Computer Communication and Networks (ICCCN).* pp. 1-4. https://doi.org/10.1109/ICCCN.2017.8038519

22. Munsing, E., Mather, J., & Moura, S. (2017). Blockchains for decentralized optimization of energy resources in microgrid networks.*2017 IEEE Conference on Control Technology and Applications (CCTA)*, 2164-2171.https://doi.org/10.1109/CCTA.2017.8062773

23. Otjacques, B., Hitzelberger, P., Naumann, S. and Wohlgemuth, V., (2018). From Science to Society.*Springer International Publishing.* https://doi.org/ 10.1007/978-3-319-65687-8

24. Sharples, M., Domingue, J., (2016). The Blockchain and Kudos: A Distributed System for Educational Record, Reputation and Reward. In: Verbert K., Sharples M., Klobučar T. (eds) Adaptive and Adaptable Learning. EC-TEL 2016. Lecture Notes in Computer Science, vol 9891. *Springer, Cham*. https://doi.org/10.1007/978-3-319-45153-4_48

25. Medicalchain (2019). Accessed: January 2021. (Online). Available: https://medicalchain.com/en

26. Roma, P., Quarre, F., Israel, A., Johnston, M., & Flores, A., (2016). Blockchain: an enabler for life sciences and healthcare blockchain: an enabler for life sciences healthcare. *Delotte.* pp. 1–16.

27. Zhao, J., Fan, S., & Yan, J. (2016). Overview of business innovations and research opportunities in blockchain and introduction to the special issue. *Financ Innov*. 2, 28. https://doi.org/10.1186/s40854-016-0049-2

28. Perboli, G., Musso, S., & Rosano, M. (2018). Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases. *IEEE Access, 6*, 62018-62028.

29. Ølnes, S. (2016). Beyond bitcoin enabling smart government using blockchain technology. In: Scholl, H.J., Glassey, O., Janssen, M., Klievink, B., Lindgren, I., Parycek, P., Tambouris, E.,Wimmer, Maria A., Janowski, T., Sá Soares, D. (eds.) EGOVIS 2016. LNCS, vol. 9820, pp. 253–264. *Springer, Cham.* https://doi.org/10.1007/978-3-319-44421-5_20

30. Scott, T. (2018). TradeLens: How IBM and Maersk are Sharing Blockchain to Build a Global Trade Platform. *(Online)*. Accessed: February 12, 2021.Available: https://www.ibm.com/blogs/think/2018/11/tradelens-how-ibm-and-maersk-are-sharing-blockchain-to-build-a-global-trade-platform/

31. OriginTrail (2019). *(Online).* Accessed: Nov. 5, 2020. Available: https://origintrail.io/

32. Hulseapple, C., (2015). Block Verify Uses Blockchains to End Counterfeiting and Make World More Honest. Accessed: March 17, 2021. *(Online).* Available:

https://cointelegraph.com/news/block-verify-usesblockchains-to-end-counterfeiting-and-make-world-more-honest

33. Guo, Y. & Liang, C. (2016). Blockchain application and outlook in the banking industry.*Financ Innov* 2(24) https://doi.org/10.1186/s40854-016-0034-9

34. Tsai, W., Blower, R., Zhu, Y., & Yu, L. (2016). A System View of Financial Blockchains.*2016 IEEE Symposium on Service-Oriented System Engineering (SOSE)*, 450-457.

35. Shae, Z. & Tsai, J. (2017). On the Design of a Blockchain Platform for Clinical Trial and Precision Medicine.*2017 IEEE 37th International Conference on Distributed Computing Systems (ICDCS)*, 1972-1980. https://doi.org/10.1109/ICDCS.2017.61

36. Buterin, V. (2015). Visions, part 1: The Value of Blockchain Technology. *Ethereum Foundation Blog*. vol. 23.

37. Mengelkamp, E., Notheisen, B., Beer, C., Dauer, D., & Weinhardt, C. (2017). A blockchain-based smart grid: towards sustainable local energy markets.*Computer Science - Research and Development, 33*, 207-214.

38. Aitzhan, N.Z., & Svetinovic, D. (2018). Security and Privacy in Decentralized Energy Trading Through Multi-Signatures, Blockchain and Anonymous Messaging Streams.*IEEE Transactions on Dependable and Secure Computing, 15*, 840-852.