An Exploratory Analysis of Blockchain: Applications, Security, and Related Issues

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Abstract

A blockchain is a shared, distributed, and immutable ledger. The blockchain has generated intense interest for use in a variety of industries and domains, ranging from banking, finance, and insurance to healthcare, government, retailing, and manufacturing. Organizations are using blockchains to develop new applications that are more reliable and efficient. In this paper we explore the blockchain technology for building computer information systems. We first conduct a systematic analysis of applications and issues related to blockchain technology, and then identify some issues that require further research in order to be properly addressed. We also discuss the potential application of blockchain in education, and how education systems can benefit from the advent of blockchain technology.

Keywords: Blockchain; Smart Contracts; Security; PKI

1. INTRODUCTION

Blockchain is a distributed and decentralized solution for data management; it takes into account cryptography, consensus mechanism and immutability [1]. Cryptography such as hashing algorithms maintain integrity in blockchain, whereas consensus mechanism provides reliability and data consistency. In the blockchain, data is generated and stored in the form of *blocks*, and each consecutive block is connected to the previous blocks in the form of a chained data structure. Each block has a reference to its immediate previous block. The reference is a hash value of the previous block. The hash value of the current block is calculated using the hash value of the previous block; therefore, any change in the data leads to different hash values, thus allowing the user to detect any data manipulation [2]. Copies of blocks are stored in multiple sites called *nodes*, which are distributed across the Internet. Each of the user nodes is involved in the storage, validation and maintenance of the data blocks. Whenever a new block is added to the blockchain, it must be approved by at least more than half of the users, and updates about the changes are broadcasted to all the nodes in the network for synchronization. Once the information is synchronized, it cannot be changed.

Blockchain has a wide area of applications. The most famous application of blockchain is of course the bitcoin [3]. Built on top of the blockchain technology, bitcoin ensures user anonymity and security.

Besides cryptocurrencies, blockchain can be applied to diverse applications. When developing a computer information system, maintaining the integrity or correctness of the content is essential in earning the user's confidence. Consider educational content development as an example. The curricular information and the faculty/student records must be protected against potential tampering. Blockchain technology offers a trust-based system ensuring authenticity. The technology can be used to store and manage student records, especially information about degrees and certificates, in order to prevent degree frauds. The student assessment records and learning outcomes can be stored and accessed via blockchain-based implementation [64].

The blockchain technology can contribute to development of smart cities through its feature of sharing services [4]. Since blockchain allows transactions without any third party intervention, it can be used in various online financial services, such as management of digital assets like online payment processing and virtual wallets [5]. Blockchain is becoming popular for next-generation systems such as smart contracts [6], Internet of Things (IoT) [7], security services [8], medicine [9], etc.

The rest of this paper is organized as follow. In section 2 we analyze the advantages of using blockchain technology to build information systems. Section 3 is a survey of various applications that use blockchain technology. Section 4 gives

an in-depth analysis of issues related to blockchain technology. We discuss our findings in section 5.

2. ADVANTAGES OF BLOCKCHAINS

Blockchain technology provides an encrypted distributed database. The data is stored in a manner that prevents data tampering, and data can be shared in an open and transparent manner. Below are some of the advantages of the blockchain technology.

Protecting data integrity

Sensitive data stored online can be vulnerable to tampering and modification. Blockchain technology can provide users and developers a secure way to store data online, by ensuring data integrity. Blockchain systems use cryptographic hashing to provide integrity of the ledgers. Any modification in a block would invalidate all the successive blocks; blockchain provides a safe and efficient data model that tracks all changes done to the global states [10] [11]. *Keyless Signature Structure* (KSI) is a blockchain project based on one-way hash functions to generate digital signatures which can validate the time, integrity and attribution of origin [12].

Tamper-proofing

Blockchain stores the data in the form of chained data structure, whenever data is stored in the blocks, a unique timestamp is associated with storage of that data; any further modification to this data after the timestamp is not allowed [13]. This feature makes it computationally infeasible for the hacker to manipulate the existing data within the ledger.

Protecting identities

Digital Identity is essential to ensure secure business transactions. The traditional identity management systems are costly, and are prone to many online security threats [14]. The blockchain technology enables a decentralized digital identity system which offers a secure way to monitor and manage the users accounts [15]. *SecureKey* is a digital identity network built on IBM blockchain; it enables users to verify their identities using their smartphones to sign up for new bank accounts and other utilities.

Another widespread technology, Public key Infrastructures (PKIs), which is often used to implement strong authentication, data encryption and digital signatures, can be used along with blockchains. Such a system can help mitigate the risk of false key propagation by allowing the system to be more robust and trustworthy [16]. The PKI system integrated with the blockchain is able to validate the user identity effectively. *CertCoin* [17] is a blockchain-based PKI. It is a decentralized authentication system that removes the idea of central authority altogether, and maintains a distributed public ledger and its associated keys. *Pomcor* [18] is a research company that uses blockchain for storage of issued hashes and revoked certificates. It also makes verification faster as the user has a local copy of certificates, thus making it efficient to verify the certificate without network access.

Preventing fraud and data theft

Blockchain technologies provides a decentralized and tamper proof methodology, which helps to protect data from hackers, thus preventing potential frauds and decreasing the chance of data being stolen or compromised [19]. The blockchain keeps the record of an asset transfer; any type of fraudulent activity can be detected by tracing through the blockchain [20].

Disaster Recovery

In a blockchain system, every user can generate and store a complete copy of the data. The storage and recording of data is done synchronously at all the user sites, with the help of open source sharing protocols. In an application built on blockchains, every user has the right to generate data, and keep full copy of the data. This mechanism decreases the chances of single-site failure. Large number of user nodes involved in storing a blockchain lowers the hacker's chance of successfully attacking the user nodes [21].

Transparent and incorruptible

Blockchain provides a fully auditable ledger of transactions. Only entries that have been validated by the system can be entered to the blockchain system. Once the entries are made, it is computationally infeasible to modify the data without being detected. This makes it impossible to hide or delete any fraudulent transactions. The data cannot be corrupted, because a huge amount of power is required to make any changes in the blockchain, as an entire network needs to be overridden [22]. High transparency eliminates the need for checkpoints to validate the transactions [23].

Protecting critical infrastructure

Critical infrastructures such as the domain name systems (DNS) are vulnerable to security flaws such as distributed denial of service (DDoS) attacks and man-in-the-middle attack [24]. Blockchain-based DNS offers better security and reliability, since all the domain names are stored locally. This

eliminates the need for client server interaction for DNS queries. Such a system offers better security against man-in-the-middle attacks [24].

3. APPLICATIONS OF BLOCKCHAINS

Below are some of the emerging applications of blockchains.

Blockchain in education

Blockchain can be used to create permanent e-portfolios of intellectual achievement [69] for personal use to store intellectual work or to present the data to the employer. *Blockchai* [70] is blockchain-based startup which enables creative artists to register their work.

Blockchain can also be used as an alternative technology for education reputation currency called *kudos* [69], which measures the learning outcomes that can be further stored in a virtual wallet. *Learning is earning* [69] is a smart contract based application, where students are encouraged to perform better and get rewards for their performance. Blockchain can be used to maintain balance between learning process and its outcome. Due to immutable and secure nature of blockchain, it can be used to store data, which can then be trusted for talent acquisition [71].

Payment of fees via Cryptocurrency

Colleges have started taking cryptocurrency such as bitcoin for payment of tuition fees. For example, the University of Nicosia, King's College in New York, and Simon Fraser University in BC are accepting digital currency for payment of tuition fees [67].

Secure storage of educational records using Blockchain

Blockchain technology can be used as a platform for keeping student's data, such as diplomas, in a secure manner. The data cannot be altered, thus building a trust-based system. The records stored are safe and easily accessible. MIT's media lab has developed a blockchain based application called *blockcerts wallet*, which creates, issues, and verifies blockchain-based certificates. The goal of the project is to enable individuals share their official records in a secure manner without the concern of data tampering. The certificates received after the candidate has passed the assessment will be stored in a blockchain. The certificates received are secure and tamper proof [68]. This prevents data tampering and degree fraud [66].

Blockchain provides a secure and shared platform for storage of the user data. The data is not limited to diplomas, but includes information like transcripts and attendance [62] [63]. Sony and IBM [65] are using blockchain technology to develop a platform for storage of information like transcripts, attendance records. The student can access the data and share the data with the employers.

Blockchain in Finance and Auditing

The emergence of blockchain technologies such as Bitcoin had a great impact in the area of financial services. Blockchain has the potential to facilitate the banking and finance market by providing global money remittance, enabling smart contracts, automating banking ledgers, and preserving digital assets [25]. The blockchain technology can help in building a peer-to-peer (P2P) financial market which is more secure, fast and reliable for multiparty computation [25].

The blockchain is a reliable platform and can be extremely helpful to provide a trust-based service in the field of accounting [26]. It can help to provide a secure way to handle the integrity of records, and complete transparency for automating the audits, thus reducing the cost and time to conduct an audit [27].

Blockchain and the Internet of Things (IoT)

Internet of things, one of the most promising information and communication technologies, is ramping up recently. IoT devices often lack security features such as user anonymity and authentication. Security and privacy are the two major concerns in computer systems that involve IOT devices [28]. Blockchain-based IOT provides a secure trust-based system [29]. Rifi, etc. [30] proposes a fully decentralized blockchain-based architecture using smart contracts to implement secure data access in IOT. Hardjono and Smith [31] proposes a privacy-preserving mechanism to share sensor-data in a secure and reliable manner.

Blockchain as a system of record

Blockchain uses distributed systems called *ledger* to maintain the records. The records can be used to manage the user identity without sharing any personal information. The usage of private keys forms the basis of ownership of digital assets, which ensures security against any manipulation and fraud. It can be used in financial institutions like banks; a bank can use the blockchain technology to create records automatically and to maintain a control on who has the right to access that information. The technology can also be used for managing

health records [32]. Any digital asset that are difficult to protect and manage, like multimedia and email records, can use blockchain to manage data [32].

Blockchain-based Tokenization

Tokenization serves as a platform for identity and access management. Tokens can be of various types, ranging from coin token, assets token to credit token. These tokens are used to bind the physical and the digital assets. Tokens are used for identity and accessibility [33]. These digital tokens are useful for supply chain management, intellectual property, anti-counterfeiting, and fraud detection [34] [35]. Simple Token [37] is a company that helps other companies to deploy their own branded crypto-backed token economies. The company offers tokenization-as-a-service, which is built upon and benefit from the blockchain technology. Tokenization introduces an important concept – that is, assets can be managed directly by the owner, without the involvement of a third party [38] [39].

Smart Contracting

A *smart contract* is a computer protocol used to verify and facilitate execution of contracts; it reduces the cost associated with contracting [40]. Smart contracts were first proposed by Nick Szabo in 1996. *Ethereum* [42] is a blockchain platform that provides medium for smart contract code. Smart contracts facilitate an essential service in the finance industry [43].

Blockchain for automated governance

Bitcoin is an example of automated governance, aka a decentralized autonomous organization (DAO); a DAO is an organization that is maintained through a platform called contracts. The records of financial transaction and program rules are maintained by blockchain [36]. The blockchain technology can help to maintain a digital ownership of assets. The rules on how the system works is coded by the blockchain protocol.

Blockchain as a distributed storage

Blockchain can be used as a decentralized cloud storage, which helps to improve security and decrease dependency on a central system. Hashing and data replication are the key benefits in using blockchain-based cloud storage [47]. Complete decentralization and data redundancy offers better security against attacks and single-site failure. The storage of data using blockchain technology is much cheaper, as compared to other cloud storage such as Amazon. Blockchain storage costs around $2 per terabyte per month, compared with Amazon S3's $25 per terabyte per month [45].

Metadisk is a blockchain-based decentralized file storage application [46]. Storj [44] is beta-testing cloud storage using a blockchain-powered network, to improve security and decrease dependency.

Blockchain-based digital voting

Digital voting using blockchain is a form of distributed ledger, where the block contains records of transactions. Online voting using blockchain provides security and anonymity [48]. *FollowMyVote* [50] is a Virginia-based company, which offers a blockchain-based voting system that ensures voting is done only once by each user. The vote is represented as a token; once a vote is casted and stored, it cannot be tampered, due to the immutable feature of the blockchain technology. [51]Presents a blockchain-based digital voting system for secure and distributed voting.

Blockchain for decentralized notary

Blockchain technology can be used as a digital notary service. The timestamp and the hash in the blockchain validate the existence of particular work at that time, which can be further proved in court [49]. Stamped [52] uses the blockchain technology to notarize ownership proof for digital assets.

4. ISSUES RELATED TO BLOCKCHAIN

Like any technology, blockchain is not a perfect solution. It has some limitations [53] and points of vulnerability, which needs to be examined before adoption. In this section, we discuss some of the limitations.

Scalability

The current mechanism in the blockchain technology requires storage of state of every transaction. This mechanism provides high level of security; however, it brings out the issue of scalability and bandwidth restriction. In Bitcoin, the size of a block is 1MB, and the creation of a block takes about 10 minutes; the size of the block and the latency time, limit the number of transactions [56]. Per the blockchain.info/ website, as of March 24, 2018, the worldwide Bitcoin transactions per day was over 1,787,000 (or about 7,445 transactions per hour). When the number of transaction increases, issues such as size of blocks and latency need to be resolved.

Several approaches have been proposed to improve the scalability issue in blockchain. AfterEther Foundation [54] proposes a new way of improving scalability by introducing blockchain clusters. Croman, etc. [55] explores the scalability issue in blockchain, and concludes that parametrization of the block size and interval in Bitcoin proves significant for throughput and latency improvements, while retaining significant system decentralization.

Throughput of Transactions:

Blockchain application such as Bitcoin is unable to process transactions at a faster rate. The current standard of Bitcoin is 7 transactions per second. With increase in transactions, the throughput of transactions needs to be improved [56].

Performance Issues:

Blockchain has a distributed, peer-to-peer nature. A blockchain-based transaction can be completed only when all the nodes update their respective ledgers, which can take hours to complete [56]. As ledgers grow, the performance will be an issue.

Privacy and Security issue:

Blockchain provides a decentralized, immutable database of transactions, which can be validated and verified by nodes distributed across the network. The users can make a safer transaction as they use generated addresses rather than their real identities. Despite these advantages, the current trend lacks complete privacy. Kosba, etc. [57] explains that the current system in blockchain cannot guarantee transactional privacy as the entire sequence of actions that happen are propagated across the network and are recorded on the blockchain, thus making records visible to all nodes in the network, resulting in lack of complete privacy.

A blockchain may be prone to the *51% attack* [58]. In a 51% attack, a single entity would have full control of the majority of the network's mining hash-rate, and would be able to manipulate the blockchain. Blockchains are also prone to other security attacks such as DAO attack, BGP hijacking attack, and Eclipse attack [39].

In [17], the authors present a technology that combines blockchain and off-blockchain storage (off-blockchain solutions can be used as an alternative for storage, like a centralized cloud might be used to store the data) to construct a personal data management platform that preserves privacy.

Consumption of Resources:

Mining in blockchains requires huge amount of resources, such as computing power and electrical energy. The energy requirement of Bitcoin, for example, is around $15 Million per day [59] [60].

Fairley [61] quoted the Blockchain.info website and said that, in June 2017, the world's bitcoin miners were generating roughly 5 quintillion (5 followed by 18 zeros) 256-bit cryptographic hashes every second. He also estimated that processing a bitcoin transaction would consume more than 5,000 times as much energy as using a Visa credit card.

5. DISCUSSION

The paper provides a systematic review of some blockchain applications. It also analyzes limitations of the blockchain systems that exist today. Blockchains can be used in various fields of application, ranging from education, data analytics, and smart contracts to artificial intelligence.

In education, blockchain can be used as a platform to store the student records securely, building a trust-based system. The data can be accessed and shared easily with reliability. The stored records on blockchain-based system ensures authenticity and immutability. The stored records can serve as repository of work done by the users, and the users can be rewarded based on the quality of work done by them. The information can also be used by the employers to hire the employees based on matching skills [71].

There are a few limitations when it comes to the use of blockchain technology. In education systems, the immutable nature of blockchain prevents even legitimate changes to the student records once the data is already stored in the system.

Scalability and security are another major challenges in building large-scale blockchains. Take Bitcoin as an example. There exist limitations such as the block size and the number of transactions; such limitation poses a challenge to the widespread usage of Bitcoin blockchain. Security is another major challenge of blockchain. For example, Bitcoin is prone to 50% attack and selfish mining attack.

The energy cost of blockchain-based bitcoin is very high as compared to the conventional financial transactions. The consensus algorithms like proof of work and proof of stake requires a lot of computation power, such challenges need to be addressed, to make the blockchain technology more efficient.

The lack of user-friendly interfaces, the lack of skilled developers, and the lack of robust infrastructure [60] are other

challenges that Blockchain technology is facing and which need to be addressed for making it an efficient platform.

6. CONCLUSION

Blockchain is an emerging technology. Many applications have been developed based on blockchain. Its unique nature of being a verifiable distributed ledger opens up opportunities to build new and interesting computer information systems. Despite the advantages and applications of blockchains, there remain issues that need further research, including scalability, security, and performance. The future widespread adoption of the blockchain technology in building large-scale information systems depends on successful resolutions of those issues.

REFERENCES

[1] Gleb Kostarev,Waves Platform. (2018). Review of blockchain consensus mechanisms – Waves Platform. [online] Available at: https://blog.wavesplatform.com/review-of-blockchain-consensus-mechanisms-f575afae38f2 [Jul 31, 2017].

[2] Anon, (2018). [online] Available at: https://www.miracl.com/press/the-essence-of-the-blockchain, https://medium.com/@ConsenSys/blockchain-underpinnings-hashing-7f4746cbd66b [Accessed 24 Feb. 2018].

[3] Nakamoto, S. (2008). "Bitcoin: A peer-to-peer electronic cash system."

[4] Sun, J., etc. (2016). "Blockchain-based sharing services: What blockchain technology can contribute to smart cities " Financial Innovation 2(1): 26.

[5] Venkatesha N. Vysya, A. K. (2017, Infosys Limited). "Blockchain Adoption in Financial Services."

[6] BlockchainHub.(2018). Cryptographic Tokens - Introduction. [online] Available at: https://blockchainhub.net/tokens/ .

[7] Dorri, A., etc. (2016). "Blockchain in internet of things: challenges and solutions." arXiv preprint arXiv: 1608.05187.

[8] Deloitte Nederland. (2018). Blockchain technology – the benefits of smart contracts | Deloitte. [online] Available at: https://www2.deloitte.com/nl/nl/pages/financial-services/articles/3-blockchain-the-benefits-of-smart-contracts.html.

[9] Kuo, T.-T., etc. (2017). "Blockchain distributed ledger technologies for biomedical and health care applications." Journal of the American Medical Informatics Association 24(6): 1211-1220.

[10]Technologies, F. (2018). Ensuring Data Integrity Using Blockchain Technology – FINTERRA | Blockchain Based Financial Services for all. [online] Finterra.org. Available at: https://www.finterra.org/2018/01/10/ensuring-data-integrity-using-blockchain-technology/

[11] Zikratov, I., etc. (2017). Ensuring data integrity using blockchain technology. Open Innovations Association (FRUCT), 2017 20th Conference of, IEEE.

[12] Guardtime.com. (2018). BLT | New Blockchain Standard for Digital Identity. [online] Available at: https://guardtime.com/blog/blt-new-blockchain-standard-for-digital-identity

[13] D. Bhowmik and T. Feng, "The multimedia blockchain: A distributed and tamper-proof media transaction framework," 2017 22nd International Conference on Digital Signal Processing (DSP), London, 2017, pp. 1-5. doi: 10.1109/ICDSP.2017.8096051

[14] Matsumoto, S. and R. M. Reischuk (2017). IKP: turning a PKI around with decentralized automated incentives. Security and Privacy (SP), 2017 IEEE Symposium on, IEEE.

[15] Bond, S. (March 24, 2017). "It Was Only a Matter of Time — Digital Identity on Blockchain".

[16] Al-Bassam, M. (2017). SCPKI: a smart contract-based PKI and identity system. Proceedings of the ACM Workshop on Blockchain, Cryptocurrencies and Contracts, ACM.

[17] Fromknecht, C., etc. (2014). Certcoin: A namecoin based decentralized authentication system.

[18] Lewison, K. and F. Corella (2016). Backing Rich Credentials with a Blockchain PKI, Tech. Rep.

[19]Mauri, R. (2018). Blockchain for fraud prevention: Industry use cases - Blockchain Unleashed: IBM Blockchain Blog. [online] blockchain Unleashed: IBM Blockchain Blog. Available at: https://www.ibm.com/blogs/blockchain/2017/07/blockchain-for-fraud-prevention-industry-use-cases/

[20] Dai, Jun, etc. "Why Blockchain Has the Potential to Serve as a Secure Accounting Information System." The CPA Journal, 2 Nov. 2017, www.cpajournal.com/2017/09/20/blockchain-potential-serve-secure-accounting-information-system-cpe-season/.

[21] Berico, E. (2018). Blockchain for Business Continuity | BC in the Cloud. [online] Bcinthecloud.com. Available at: https://www.bcinthecloud.com/2017/10/blockchain-for-business-continuity-and-disaster-recovery/

[22] Technolocheese. (2018). 7+ Best Blockchain Technology Companies to Invest. [online] Available at: http://technolocheese.com/best-blockchain-technology/ .

[23] Myler, Larry. "Transparent Transactions: How Blockchain Payments Can Make Life Easier For B2B Companies." Forbes, Forbes Magazine, 9 Nov. 2017, www.forbes.com/sites/larrymyler/2017/11/09/transparent-transactions-how-blockchain-payments-can-make-life-easier-for-b2b-companies/#29914e6870b5

[24] Wei-hong, H., etc. (2017). "Review of Blockchain-based DNS alternatives." 网络与信息安全学报 3(3): 71-77.

[25] Peters, G. W. and E. Panayi (2016). Understanding modern banking ledgers through blockchain technologies: Future of transaction processing and smart contracts on the internet of money. Banking Beyond Banks and Money, Springer: 239-278.

[27] "Tokenization-as-a-Service: Blockchain Shall Become Mainstream." JAXenter, 1 Mar. 2018, jaxenter.com/tokenization-service-blockchain-mainstream-140755.html

[28] Tapscott, A. and D. Tapscott (2017). "How blockchain is changing finance." Harvard Business Review 1.

[29] Anderson, N. (2016). "Blockchain Technology: A game-changer in accounting?" Deloitte, March.

[30] A. Kuzmin, "Blockchain-based structures for a secure and operate IoT," 2017 Internet of Things Business Models, Users, and Networks, Copenhagen, 2017, pp. 1-7.
doi: 10.1109/CTTE.2017.8260937

[31] Conoscenti, M., etc. (2016). Blockchain for the Internet of Things: A systematic literature review. Computer Systems and Applications (AICCSA), 2016 IEEE/ACS 13th International Conference of, IEEE.

[32] N. Rifi, E. Rachkidi, N. Agoulmine and N. C. Taher, "Towards using blockchain technology for IoT data access protection," 2017 IEEE 17th International Conference on Ubiquitous Wireless Broadband (ICUWB), Salamanca, 2017, pp. 1-5. doi: 10.1109/ICUWB.2017.8251003

[33] Hardjono, T. and N. Smith (2016). Cloud-based commissioning of constrained devices using permissioned blockchains. Proceedings of the 2nd ACM International Workshop on IoT Privacy, Trust, and Security, ACM.

[34] Ironmountain.com. (2018). What is blockchain and why should records management professionals care?. [online] Available at: http://www.ironmountain.com/resources/general-articles/w/what-is-blockchain-and-why-should-records-management-professionals-care.

[35] Ekblaw, A., etc. (2016). A Case Study for Blockchain in Healthcare: "MedRec" prototype for electronic health records and medical research data. Proceedings of IEEE Open & Big Data Conference.

[36] What Is DAO - Decentralized Autonomous Organizations." BlockchainHub, blockchainhub.net/dao-decentralized-autonomous-organization/.

[37] simpletoken.org. (2018). Simple Token | Cryptocurrency to Power Digital Communities. [online] Available at: https://simpletoken.org/ .

[38] Nolan Bauerle. (2018). What Are the Applications and Use Cases of Blockchains? - CoinDesk. [online] Available at: https://www.coindesk.com/information/applications-use-cases-blockchains/

[39] "Assets Will Be Tokens (And It Will Change Finance)." CoinDesk, 13 Nov. 2017, www.coindesk.com/tokenization-will-make-assets-more-valuable/.

[40] Deloitte Nederland. (2018). Blockchain technology – the benefits of smart contracts | Deloitte. [online] Available at: https://www2.deloitte.com/nl/nl/pages/financial-services/articles/3-blockchain-the-benefits-of-smart-contracts.html.

[41] C. Wright and A. Serguieva, "Sustainable blockchain-enabled services: Smart contracts," 2017 IEEE International Conference on Big Data (Big Data), Boston, MA, 2017, pp. 4255-4264.doi: 10.1109/BigData.2017.8258452

[42] Ethereum Blog. (2018). Privacy on the Blockchain - Ethereum Blog. [online] Available at: https://blog.ethereum.org/2016/01/15/privacy-on-the-blockchain/.

[43] Cant, B., etc. (2016). "Smart Contracts in Financial Services: Getting from Hype to Reality." Capgemini Consulting.

[44] Storj - Decentralized Cloud Storage. (2018). Storj - Decentralized Cloud Storage. [online] Available at: https://storj.io/ .

[45] Herbert, Zach. "Why Blockchains Are the Future of Cloud Storage. – Sia Blog." Sia Blog, Sia Blog, 6 Feb. 2017, blog.sia.tech/why-blockchains-are-the-future-of-cloud-storage-91f0b48cfce9.

[46] Wilkinson, S., etc. (2014). "Metadisk a blockchain-based decentralized file storage application." Technical Report. Source of the report?

[47] Angela karl.Techgenix.com.(2018). Blockchain technology for cloud storage: This looks like the future. [online] Available at: http://techgenix.com/blockchain-technology-for-cloud-storage/.

[48 Arno.uvt.nl. (2018). [online] Available at: http://arno.uvt.nl/show.cgi?fid=143457.

[49] A. Barnes, C. Brake and T.Perry" Digital Voting with the use of Blockchain Technology" Team Plymouth Pioneers – Plymouth University

[50] "The Online Voting Platform of The Future." Follow My Vote, followmyvote.com/

[51] Ayed, Ahmed Ben. "A Conceptual Secure Blockchain Based Electronic Voting System."International Journal of Network Security & Its Applications, vol. 9, no. 3, 2017, pp. 01–09., doi:10.5121/ijnsa.2017.9301.

[52] S. (2017, January 24). Does notarization on the blockchain actually work? – Decentralize Today. Retrieved February 3, 2018, from https://decentralize.today/does-notarization-on-the-blockchain-actually-work-d8006443c0b9

[53] Melanie Swan, Blockchain: Blueprint for a New Economy, O'Reilly Media, Inc., 2015

[54] AfterEther Foundation. (8 Nov 2017). "Blockchain Scalability By Blockchain Clustering."

[55] Croman, K., etc. (2016). On scaling decentralized blockchains. International Conference on Financial Cryptography and Data Security, Springer.

[56] Ken Griffith & Ian Grigg "Bitcoin Verification Latency The Achilles Heel for Time Sensitive Transactions"

[57] Kosba, A., etc. (2016). Hawk: The blockchain model of cryptography and privacy-preserving smart contracts. Security and Privacy (SP), 2016 IEEE Symposium on, IEEE.

[58] Zyskind, G., Nathan, O., & Pentland, A. S. (2015). Decentralizing Privacy: Using Blockchain to Protect Personal Data. 2015 IEEE Security and Privacy Workshops. doi:10.1109/spw.2015.27

[59] Atkin, Emily. "The Environmental Case Against Bitcoin." The New Republic, 5 Dec. 2017, newrepublic.com/article/146099/environmental-case-bitcoin.

[60] Tapscott, D. and A. Tapscott (2017). Realizing the potential of Blockchain: a multistakeholder approach to the stewardship of Blockchain and cryptocurrencies. World Economic Forum.

[61] P. Fairley. (2017). The Ridiculous Amount of Energy It Takes to Run Bitcoin. IEEE Spectrum. Available at https://spectrum.ieee.org/energy/policy/the-ridiculous-amount-of-energy-it-takes-to-run-bitcoin

[62] Lab, Impact Chain. "4 Ways Blockchain Could Change the Education System." Medium, Medium, 7 Dec. 2017, medium.com/@impactchainlab/4-ways-blockchain-could-change-the-education-system-988fc7c3db42.

[63] KMi, Damian Dadswell -. "Open BlockChain." Open BlockChain, blockchain.open.ac.uk/.(The Open University, UK - on the stage of experimenting with use cases)

[64] Rivera, Maricel. "Blockchain Technology In Education: How The Latter Can Be Disrupted."ELearning Industry, ELearning Industry, 7 Jan. 2018, elearningindustry.com/blockchain-technology-in-education-latter-can-disrupted.

[65] "Sony Develops System for Authentication, Sharing, and Rights Management Using Blockchain Technology." Sony Global - Sony Global Headquarters, www.sony.net/SonyInfo/News/Press/201708/17-071E/index.html

[66] Chen, G., et al. (2018). "Exploring blockchain technology and its potential applications for education." Smart Learning Environments 5(1): 1.

[67] "IGrad." IGrad: Financial Literacy and Career Resources, www.igrad.com/articles/from-currency-to-cryptocurrency-using-bitcoin-to-pay-tuition.

[68] Blockcerts. "Blockchain Credentials." Blockcerts, www.blockcerts.org/about.html.

[69] M. Sharples and J. Domingue, "The blockchain and kudos: A distributed system for educational record, reputation and reward," in European Conference on Technology Enhanced Learning, 2016, pp. 490-496: Springer.[70] Ha, Anthony. "Blockai Uses the Blockchain to Help Artists Protect Their Intellectual Property."TechCrunch, TechCrunch, 14 Mar. 2016, techcrunch.com/2016/03/14/blockai-launch/.

[71] G. Chen, B. Xu, M. Lu, and N.-S. Chen, "Exploring blockchain technology and its potential applications for education," Smart Learning Environments, vol. 5, no. 1, p. 1, 2018.