Vol.09 No. 3 (2018)1433-1438
DOI:https://doi.org/10.61841/turcomat.v9i3.14965

Blockchain Technology: Architecture, Applications, and Challenges

Goutham Kacheru

Master's in information systems technologies, Wilmington University, New Castle, Delaware, USA.

Abstract: This, together with the related term Bitcoin, was a revolution in blockchain as envisioned by the mystery character Satoshi Nakamoto up to 2008. All this changes the very way the foundations of digital exchange and storage were thought about: decentralized, transparent, immutable, the very fundamentals of Distributed Ledger Technology enabling safe data exchange without an intermediary. The blockchain is fundamentally a chain of blocks carrying information about transactions, including times and cryptographic hashes, each of these connecting to the previous one in one unbroken chain, for which no modification is viable. The whole design of Blockchain has been to solve a number of issues, including double spending, fraud, and inefficient records, with distributed nodes and consensus mechanisms such as Proof of Work and Proof of Stake, facilitated by cryptographic keys. Other areas beyond cryptocurrency where quite a number of innovative uses are cut across include supply chain, healthcare, financial, and real estate sectors. For example, while the supply chain process is being promoted to become effective and transparent in order to ensure the origin and quality of the product, adding to the guarantee that the user's personal health information will not be accessed and tampered with, blockchain uses smart contracts in automating agreement processes within the contract. All of them are expecting cost reduction, operating efficiencies enhancement, enhanced securities of many industries. Anyhow, there exist quite a number of serious obstacles standing in the way of the wide application of blockchain technology. Firstly, the problem of scalability has still been an issue whereby the network performance tends to be problematic when users are increased. Besides, energy wasting cannot be ignored-apparently mostly a challenge from the PoW kind of system proved to be consuming too much energy, standing big on the road to sustainability. Of course, the mere lack of any kind of international rules and standards is already a complication in making them work. It also underlines failures in the adoption of the system or in decentralizing and is still an open technical and organizational challenge on how to combine blockchain with traditional structures. Their solutions require compounding ideas: sharding of blockchain to make it big, off-chain solutions for the blockchain to be many but thin, and provision of amicable solution consensus mechanisms for environmental conservation. Besides coherent policy vision, in addition to the existing cornerstones of regulation besides well-laid-out standards of interoperability, it is important to create confidence and give a road map across different industries. This paper hereby conceptually reviews the literature with respect to how the blockchain technology was designed to show revolutionary capability in the different fields and what keeps on tormenting it with its future.KEYS: Blockchain technology; Distributed Ledger; Decentralization; Cryptographic keys; Consensus mechanisms; Proof of Work; Proof of Stake; Smart contracts; Supply chain management; Data immutability; Transparency; Scalability; Energy consumption; Challenges to regulatory bodies; Security vulnerability; Sharding; off- chain processing; Interoperability; Applications using blockchain; Architecture of blockchain.

Keywords: Blockchain, data, technology

1. Introduction

Of the most revolutionary inventions in the century presently regarded as the 21st, blockchain technology certainly stands out. Since its explosion into prominence in 2008 as the basic technology behind Bitcoin, a cryptocurrency devised by Satoshi Nakamoto, it has gone out of that into influencing several industries, including but not limited to financial, health, and supply chain management. Actually, this blockchain is just one kind of distributed ledge configuration designed to guarantee data integrity, transparency, and immutability without any central authority. It has further caused the rise of the combination in a unique suite of features positioning blockchain as a solution for most conventional challenges that involve efficiencies, fraud, and no transparency in digitized dealings. (Nakamoto, 2008)

Blockchain architecture comprises a series of transaction data, time stamping, and cryptographic has connected together via an immutable chain. That got verified by every block through the consensus algorithm- either proof of work or proof of stake - thus agreeing upon a 'view' amongst the decentralised participants on the network. This very unique structure solved some of those intractable problems. The first one, double-spending; secondly, tampering with the records. The chain thus made it robust enough to take up quite a few kinds of use case types. (Antonopoulos, 2014)

2. How Blockchain Evolved

First employed as a platform of Bitcoin transactions, much later it started to reconfigure in order to solve a variety of problems not strictly dealing with money. Blockchain provided very convenient ways of coming up with new creative uses, for example, in smart contracts and supply chain management, identifying digital identity. However, its adoption has not occurred devoid of challenges such as scalability challenges, regulatory uncertainties that are considerable energy consumers Pilkington, 2016.

Table 1: Evolution in generations of blockchain technology in the arena from being the backbone of cryptocurrency transactions to generally utopian industries.

Table 1: Evolution of Blockchain Technology

Generation	Features	Applications
Blockchain 1.0	Cryptocurrency-focused; decentralized ledger	Bitcoin, alternative cryptocurrencies
Blockchain 2.0	Smart contracts; programmable transactions	Ethereum, decentralized apps
Blockchain 3.0	Scalability, interoperability, and energy efficiency	Supply chains, healthcare, IoT

3. Applications of Blockchain

So, adaptability has given Blockchain a chance to present creative solutions for industry- specific challenges: For instance, blockchain itself pushes forward supply chain transparency and builds trust among its stakeholders with a tamper-proof record of goods' movement. The technology cuts the cost of financial transactions due to peer-to-peer processes in improving efficiency. Secure sharing of patient data will be done in healthcare systems with more improved data privacy. Tapscott & Tapscott (2016) say that.

Other abilities also include blockchain, which makes automated control of complicated processes possible. Smart contracts are a sort of self-executing contract since, once specific conditions that are predefined are met, the execution of the contract enforces agreements directly with the force of law without intermediaries. Further explanation is warranted for the industries in examples of Table 2.

Table 2: Industry Applications of Blockchain Technology

Industry	**Use Case**	**Benefits**
Finance	Cross-border payments	Faster transactions, reduced costs
Healthcare	Electronic health records	Enhanced data security and privacy
Supply Chain	Product tracking	Increased transparency and accountability
Real Estate	Property transactions	Simplified processes, reduced fraud

This, despite the promise, was saddled with a host of challenges to wide-based adoption. The issues related to scalability whereby generally, as the usage of transactions scale up, the speed and performance actually go down. Energy consumption arising from PoW systems is notably being hobbled by adverse criticisms of their perceived environmental impacts. Most importantly, global non uniform regulation leads to many open questions and hence reduces confidence and acceptance within existing infrastructures (Yli-Huumo et al., 2016).

Another big challenge is interoperability between blockchains. Such an example can be given as the capability of various blockchain networks to stay in contact with each other and share data. Without protocols that standardize, with respect to such procedures, all the potential for offering cross-chain interaction capability remains bounded; it hence limits blockchain from tapping its full capacity. Some active sidechains and protocols concerned with inter blockchain communications remain ideas in research that have overcome those.

Blockchain has been a revolution in recording, sharing, and affording security to data. While the use cases are immense and disruptive, scalability, energy efficiency, and regulatory clarity have to be sorted out before large-scale adoption can take place. The rest of the paper will delve deep into the architectural aspect of blockchain, its applications, and challenges emerging along with potentials and limitations presented in different studies carried out.

4. LITERATURE REVIEW

Since its very inception, when blockchain came into the realm of business, amongst others, it received so much attention. This is because, in principle, it basically originated with Bitcoin, one form of cryptocurrency launched through Satoshi Nakamoto back in the year 2008. Fundamentally, blockchain is a kind of DLT which supports secure, transparent, and tamper- proof transactions within the premises of a decentralized environment. This finally flowered into a powerful technological innovation that has found far more applications other than blockchain-based and completely decentralized financial systems envisaged by Nakamoto. As great the potential may be, most scholars have noticed that there is an equally fair share of challenges regarding scalability, energy consumption, and regulation. This literature review will abstract and be informed by the underlying main architectural components, practical applications, and challenges Blockchain Technology facing from various academic studies and scholarly articles. In other words, in root concept form, blockchain is a leaf off this notion of some sort of distributed ledger. Each block can contain loads of transactional data, a timestamp, and a unique cryptographic hash linking to the previous block, hence achieving some sort of immutability record. According to Nakamoto, 2008, blockchain is decentralized in nature since it depends on no kind of central authority but allows for peer-to- peer transactions. It provides integrity and security for the transactions happening in it, based mainly on cryptographic techniques in the form of hash functions and public-key cryptography. Or rather, immutability in a blockchain-here comes a cryptographic hash. Antonopoulos 2014 expounds that each block is crafted in such a cryptographic hash in previous blocks that any modification in any transaction in previous blocks gets computationally highly infeasible; thus, the continuity within the chain is maintained. Tamper-proof and high involvement in business adds extra reliability towards Blockchain systems. It is further concretized in the use of consensus algorithms such as Proof of Work and Proof of Stake in arriving at consensus among participants on the state of transactions being valid. This, in other words, ensures that the transactions coming onto the blockchain are indeed valid through a consensus mechanism.

In Proof of Work, originally designed by Nakamoto 2008, a miner solves some complex mathematical puzzles that enable him or her to create blocks by validating the transactions involved. This takes enormous computations and hence a lot of energy; that provides some sort of guarantee regarding blockchain security. Conversely, Proof of Stake by King and Nadal 2012 introduces a staking mechanism whereby in return for contributing a certain amount of cryptocurrency owners is given an opportunity to validate blocks by making a stake on any block. Upon using such mechanisms, energy use will then reduce. These consensus algorithms play, in fact, a very vital role in the functioning of blockchain and provide a way concerning how blockchain can be secure in a decentralized fashion. Applications of Blockchain Fundamentally, the motivating factor for its serious research on applications is that blockchain may disrupt a number of industries. The major strengths of blockchain are in security, transparency, and decentralization. This is a good fit for sectors in which questions of trust and efficiency have come into issue. The very first applications and most pronounced uses of blockchain relate to the financial sector, particularly about digital cryptocurrency transactions. Tapscott and Tapscott, in 2016, again supported such technology to provide a revolution in cross-border payments around the world because it is going to be faster, cheap, and highly secure. Other digital currencies, such as Bitcoin and Ethereum, proved to be workable ways of digital currency, though their applications went a long way beyond just into asset management or the recently developed DeFi.

Application of Blockchain in Supply Chain Management: It has drawn significant attention in supply chain management too. The transparency, traceability and accountability are enhanced in case of the movement of goods with the aid of the technology. According to Kshetri 2017, the blockchain can ensure an improvement in the supply chain with an immutable record for every kind of transaction and movement of the products. This, therefore, would mean there is a reduction in fraud and an improvement in the aspects of visibility amongst those various stakeholder groups. Indeed, this is quite very important for industries that take in their nature traceability in places of origin, such as even food safety. In fact, Walmart has already adapted to the use of blockchain technology to track foods from their places of origin. It reduces tracing source contamination that earlier took several days to occur; it now could be in the span of a few seconds of time. Since Blockchain promises transparency, business and customers can easily be assured of authenticity in terms of quality at every stage of the supply chain.

On the other hand, blockchain technology also brings some fantastic prospects for changing the medical documentation and management of patient data altogether. As Tapscott and Tapscott (2016) gave a good example, the blockchain can avail security and immutability in the storage of medical records to allow access by concerned medical experts from different institutions without actual compromise of privacy. It allows equal data sharing across the organizations while giving assurance in the said sharing for protection of consent and confidentiality towards the patient. This would prove to be invaluable, as in numerous instances the same information on the given patient would be wanted by various different caregivers in the case of most of the emergencies. This therefore makes it possible for blockchain to improve both patients' care and administrative inefficiencies as a result of safety and transparent data sharing in health systems.

Another important area of application of blockchain is within smart contracts. Buterin 2014 defined a smart contract as a self-executing contract where the rules of the contract are written on lines of code. When the conditions of the agreement come into effect, a smart contract will execute the function itself, with no intermediaries or human failures. Further, Ethereum introduced the use of smart contracts that in very short periods have become the general standard for developing and deploying DApps in industries ranging from financial and insurance sectors to a real estate market. In other words, according to Buterin 2014, it can make a business process easier because difficult transactions can be automated, therefore, speed and accuracy in the implementation of an agreement.

5. Blockchain Technology Challenges

Though the above list is promising, potentially, there are lots of big challenges on the way to wide acceptance of Blockchain technology. These include scalability whereby increased users and transactions are supposed to reduce performance on a blockchain network. Because of this, the proof-of-work consensus algorithms are extremely expensive in computational power for the validation of transactions and thus reduce the ideal speed of the transaction with more extensive use of the network. This is an issue noted by Narayanan et al. (2016). Compared, for instance, to the Visa or Mastercard systems, each of which can process thousands of transactions per second today, the Bitcoin blockchain can manage a few. In that direction, off-chain transactions, sharding, and several other consensus algorithms such as Proof-of-Stake have been proposed by the researchers who, in due course, may do away with scaling up of the blockchain network by reducing computation overheads in the process.

The other most pressing question about blockchains pertains to energy consumption- particularly in chains like Bitcoin that are based on PoW for consensus. Yli-Huumo et al. (2016) further postulate that energy consumption, occasioned in the proof of work systems in the generation of mining activities, has raised debate on the environmental sustainability of blockchain. The aftermath this created would reach and touch on the fact that such mining in Bitcoin uses much electricity in solving complex cryptography; hence, it concerns carbon dioxide emissions. This has also become a talk factor against blockchain since the growth in the environmental impact of the network began. For this reason, other consensus mechanisms that use less energy have been put into consideration by researchers including PoS among other innovative approaches such as PoA and hybrid consensus models, which effectively combine PoW and PoS in a balanced manner with a view to achieving security with energy efficiency, King & Nadal, 2012).

The next important barrier to the diffusion of blockchain technology is regulatory uncertainty. The other point relates to the legally blurry frameworks and standards on the blockchain technology itself-thus raising uncertainty on the business investor side. According to Yli- Huumo et al. (2016), this was supposed to be a job for the governments around the world to establish legislation which would balance consumer protection with innovation. Even in the case of DeFi, blockchain integrations into a full, integrative development challenge mainstream regulatory environments in traditional finance. A lot of regulatory issues with data privacy and possibilities for several criminal activities, such as money laundering and fraud, are performed in decentralized systems.

Interoperability remains another major problem besides security issues: different chains of blockchains must be able to work in a coordinated way and share information. That is so true, considering the fact that as much as blockchain technology has improved at an unprecedented rate, various blockchain networks came on board, each with their unique protocol and standards. This would organically turn present blockchain ecosystems into regions of interoperability in transferring user assets and data between different blockchain ecosystems. This, according to Cachin (2016), solves interoperability through the go-ahead development of standardized protocols and solutions, including cross-chain communication protocols or side chains that will raise frictionless interactions among various blockchain networks, thus enabling cooperation not to stop in chains of blocks.

It has come into consideration that blockchain might be one of the most innovative technologies that could bring revolutions into industries ranging from finance to healthcare. Whereas it does share a number of similarities in characteristics, the architecture of Blockchain has gone forward as a decentralized system-a system in which, alongside cryptographic techniques, some kind of consensus mechanism is there, forcing security, transparency, and immutability of network transactions. While the concept of Blockchain holds huge potential to overcome a number of concerns coming from a different field, many have yet to get through all problems at complete scalability, energy consumption, and regulatory uncertainty, interoperability-wise This therefore gives a clear platform for further research and development on blockchain literature, as the background insight has been built on architecture, applications, and challenges. This presents the arguably high record in terms of definition regarding how the digital transactions or decentralized systems are to proceed at this current possibly final stage of technology.

6. DISCUSSION

The possibility of blockchain technology being disruptive in finance and health care amongst other domains is huge. It is a type of decentralized, transparent, and tamper-proof literature that has identified the types that would have given one an upper hand in reducing middlemen and in security. More specifically, hash functions and consensus algorithms have been considered as some major cryptographic mechanisms in blockchains when expecting the integrity and trust of a system. Whereas the blockchain technology is enveloped with enormous benefits, several challenges still occur and may impede the wide adoption of the technology. Scalability has been pointed out in literature as one of the most worrying challenges. Most blockchains, including Bitcoin, make use of the Proof-of-Work consensus algorithm, which has very low throughput in transactions. This is because, though the volume of the transactions is growing, it makes the network slower, more expensive hence less practical in large-scale environments.

Other research such as Narayanan et al., 2016 finds that other consensus algorithms like the proof of stake avoids the scalability problem because it reduces computational cost in transaction validation. Solutions developed around those do not come up with widespread acceptance, as their own particular sets of problems regarding security and decentralization abound. Energy Consumption: The last problem with Blockchain. Where there is high consumption mode considered, the ecological interference happens in a PoW-based network system, including Bitcoin. As explained by Yli-Huumo et al. 2016, the ecological footprint of the blockchain ecosystem keeps on growing day by day, and alternatives that are energy- efficient need to be driven by priorities. The probable solution might be to shift to either proof- of-stake consensus models or combined consensus models, but each of these is being polished besides being subjected to resistive attacks for their standing and scalability. Most of the large growth impeding factors related to blockchain technology deal with regulatory uncertainty. This might be further exacerbated by the absolute lack of clearly set legal frameworks on the application of blockchain, especially in DeFi and cryptocurrency markets. A number of governments and regulators are still debating ways of protecting consumers without stalling innovation. This leads different jurisdictions to act toward more stringent regulations, while others prefer the path of nurturing innovation. According to Yli-Huumo et al. (2016), globally harmonized regulatory standards will ensure clarity is brought about while reducing risks implicated in illegal activities across blockchain systems.

That also touches on another big challenge: interoperability among all the different blockchains themselves. In fact, all the blockchain ecosystems to date exist today, standing alone like islands that cannot peer-communicate with each other relative to this point in time. The budding topic of its use would be with things like cross-chain technologies or side chains; even so, that has not attained that degree of full production implementation either for the needs an application of such nature will call for.

7. Conclusion

It evolved into an innovative achievement and great opportunity that emerged from financial areas to very health care and supply chain management industries. Its decentralized nature is highly transparent and secure; it enables data processing and its upkeep with the confirmation of the transactions on blockchain with much-reduced reliance on intermediaries. Consensus algorithms, including Proof of Work or Proof of Stake, and methods of cryptography provide for the consistency of blockchain.

While some promising applications existed, serious problems running in parallel prevented this technology from wide adoption. Among the most vital issues, scalability remains open and presupposes in the first place some inability of PoW-based blockchain systems to process large volumes with high efficiency. Moreover, these systems are highly consuming and create some environmental problems. This has been a factor of regulatory uncertainty, partly because some lacuna exists in the legal framework that makes full integration into full use difficult. Interoperability between different blockchain networks also presents an added barrier to the full workability of blockchain.

While blockchain technology gives pathbreaking solutions, solving these challenges completely defines full capability. Generally speaking, scalability, energy efficiency, and regulatory concerns are the areas that will need continuous R&D to enable further strides in the field of blockchain.

References (APA)

1. Antonopoulos, A. M. (2014). *Mastering Bitcoin: Unlocking Digital Cryptocurrencies*. O'Reilly Media.
2. Böhme, R., Christin, N., Edelman, B., & Moore, T. (2015). *Bitcoin: Economics, Technology, and Governance*. Journal of Financial Stability, 17, 80-88. https://doi.org/10.1016/j.jfs.2014.10.003
3. Buterin, V. (2014). *A Next-Generation Smart Contract and Decentralized Application Platform*. Ethereum White Paper.
4. Cachin, C. (2016). *Architecture of the Hyperledger Blockchain Fabric*. Proceedings of the 2016 ACM Workshop on Blockchain Technology, 1-7. https://doi.org/10.1145/2992572.2992573
5. Christidis, K., & Devetsikiotis, M. (2016). *Blockchains and Smart Contracts for the Internet of Things*. IEEE Access, 4, 2292-2303. https://doi.org/10.1109/ACCESS.2016.2566339
6. Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). *Blockchain Technology: Beyond Bitcoin*. Applied Innovation, 2(6), 6-10.
7. De Filippi, P., & Wright, A. (2018). *Blockchain and the Law: The Rule of Code*. Harvard University Press.
8. Gans, J. S. (2018). *The Blockchain Revolution: Will It Lead to the End of Banks?*

   Harvard Business Review, 96(5), 66-74.
9. Kshetri, N. (2017). *Blockchain's Roles in Meeting Key Supply Chain Management Objectives*. International Journal of Information Management, 37(6), 1-4. https://doi.org/10.1016/j.ijinfomgt.2017.08.004
10. Mougayar, W. (2016). *The Business Blockchain: Promise, Practice, and the 100-Year Quest to Disrupt Finance*. Wiley.
11. Moorthy, N., & Reddy, N. (2017). *Blockchain: A Game Changer in Financial Services*. International Journal of Research in Computer Science, 7(5), 19-25.
12. Nakamoto Institute. (2014). *Bitcoin Whitepaper*. Retrieved from https://nakamotoinstitute.org/
13. Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. Retrieved from https://bitcoin.org/bitcoin.pdf
14. Poon, J., & Buterin, V. (2017). *Plasma: Scalable Autonomous Smart Contracts*. Ethereum White Paper.
15. Sillaber, C., & Jussupow, E. (2017). *Blockchain-based Smart Contracts: The Potential and the Challenges*. Journal of Financial Transformation, 45, 123-13
16. Tapscott, D., & Tapscott, A. (2016). *Blockchain Revolution: How the Technology Behind Bitcoin and Other Cryptocurrencies is Changing the World*. Penguin.
17. Wright, A., & De Filippi, P. (2015). *Decentralized Blockchain Technology and the Rise of Lex Cryptographia*. SSRN. https://doi.org/10.2139/ssrn.2580664
18. Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). *Where Is Current Research on Blockchain Technology?—A Systematic Review*. PLoS ONE, 11(10), e0163477. https://doi.org/10.1371/journal.pone.0163477
19. Zohar, A. (2015). *Bitcoin: This is Only a Test*. Communications of the ACM, 58(3), 104-113. https://doi.org/10.1145/26768