DOI: https://doi.org/10.17762/turcomat.v11i3.13599

Research Article

Scalability Challenges and Opportunities in Blockchain-based Systems: A Systematic Review

Chetan Pandey

Department of Comp. Sc. & Info. Tech., Graphic Era Hill University, Dehradun, Uttarakhand, India 248002,

Abstract: The blockchain technology is quickly becoming the most disruptive technology of recent times. This technology has generated a lot of buzz and optimism, and it has gained a lot of attention from both the public and private sectors. Information can be transferred using blockchain technology in a manner that is confidential, safe, reliable, and open to scrutiny. This analysis focuses on the ways in which blockchain technology can be used to solve problems related to scalability and give solutions in the context of the healthcare industry. In light of this, the proposed solutions can be categorized into two primary categories: storage optimization and blockchain redesign. However, there are still several restrictions, such as the block size, the enormous volume of data and transactions, the number of nodes, and the obstacles posed by the protocol. It has seen widespread application in decentralized crypto currencies like Bitcoin and Ethereum, for example. An example of a public blockchain application that was successful, Bitcoin, was the impetus for a significant increase in research and development into blockchain technology. Nevertheless, scalability continues to be a significant obstacle. According to the facts that we've compiled, the primary causes of scalability issues appear to be bottlenecks in the transaction throughput, the network latency, and the consensus methods. On the other side, the potential for scalability includes the application of techniques like as sharding, hybrid systems, and off-chain computations. We also examine the consequences of these findings as well as prospective paths for future study to help solve the scalability problems that blockchain-based systems provide.

Keywords: blockchain, scalability, difficulties, possibilities, systematic review, sharding, hybrid techniques, off-chain computations, network latency, transaction throughput, consensus procedures.

I. Introduction

In recent years, blockchain technology has received a lot of attention due to its promise to offer decentralized and secure solutions for a wide range of uses. Decentralized and secure systems for a wide range of uses are a pressing need, and blockchain technology has emerged as a possible answer. Yet, blockchain-based systems still have a major difficulty in terms of scalability. It's possible that as the network's user base and volume of transactions grow, transaction processing times will lengthen and costs will rise systematically analyses the issues and solutions related to blockchain-based system scalability[1]. It offers a decentralized ledger that may be used to record transactions in a trusted and open manner, without the requirement for a trusted third party. Yet, scalability is still a major issue for blockchain-based infrastructures. There is a risk that transaction processing times and costs will increase as the number of users and transactions on the network grows. As a result of this issue, many applications that need a high volume of transactions have been slow to adopt blockchain technology. Bitcoin, the most popular cryptocurrency, served as a test case for blockchain technology. Bitcoin, Ethereum, and around 1,200 other cryptocurrencies are all supported by blockchain technology. In addition to cryptocurrency, blockchain technology has found use in areas such as smart contracts, financial services, insurance, supply chains, healthcare, registries, identity management, stock marketing, the Internet of Things (IoT), energy, intellectual property, and many others[2].

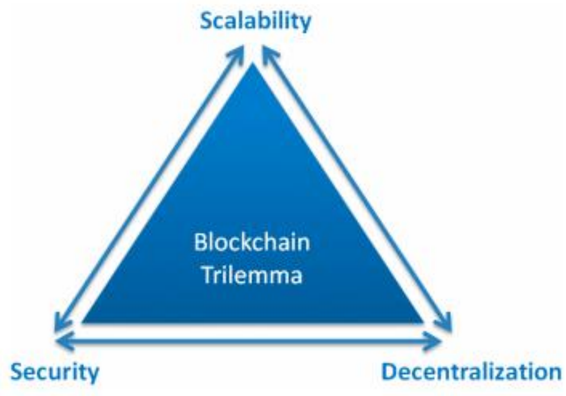

Figure 1. Scalability Trilemma

Despite its many advantages, scalability remains a fundamental barrier to widespread blockchain implementation (Singh et al., 2020). In comparison to traditional systems, blockchain implementations suffer from poor throughput and high latency. The capacity of the Bitcoin and Ethereum blockchains. When compared,Blockchain servers have a low read-performance compared to non-blockchain servers like YouTube and Google because of their large data storage capacities. The scalability of blockchain is the subject of numerous efforts and suggestions. Solving blockchain scaling problems, however, is challenging without jeopardizing the blockchain's security, decentralization, or trust. Trust, decentralization, scalability, and security are all competing goals in blockchain technology [3].

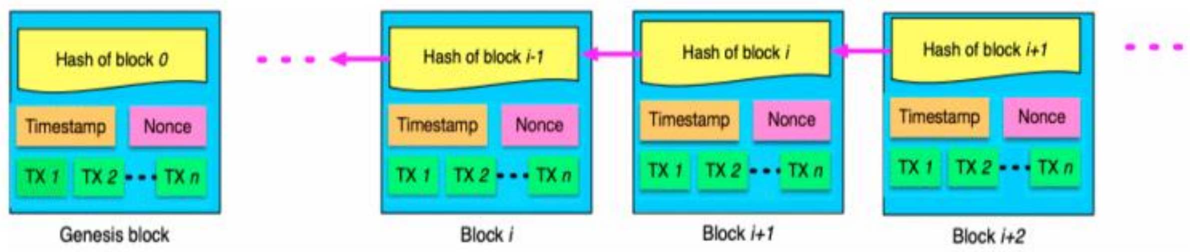

Figure 2 Depicts the Example of Blockchain consist of Continuous Linked Block

Similar to a typical public ledger, the blockchain consists of a sequence of cryptographically linked blocks that together form a complete record of transactions. A simplified blockchain structure is shown in Figure 2. A block's relation to another block with whom it shares some conceptual relationship is its parent block's hash value. The Genesis block is the first block in the chain and is the only block in the chain without a predecessor. Blockchain is a P2P distributed ledger technology (DLT) that reimagines the reliability of cross-national data sharing over the internet. It was first conceived for use in the banking sector, and then the concept of transactions occurring without a middleman began to spread [4]. Mediators, like governments and corporations, operate as trusted third parties (TTPs) by accepting, processing, and storing transaction data.The purpose of this study is to provide a comprehensive literature overview of the issues and solutions related to blockchain-based system scalability. This paper follows the following structure. We take a high-level look at blockchain and its potential uses. In Section 3, the difficulties in scaling blockchain-based systems are discussed[5].

II. Review of Literature

The purpose of this systematic review is to provide a high-level understanding of the issues and potential solutions related to blockchain-based system scalability. The process of the review is well-defined, covering things like search parameters, how studies are chosen, and how their data is analyzed. Both qualitative and quantitative studies examining the difficulties and potentials of scaling blockchain-based systems are included in this review. In the paper [6] author represents ,thorough and objective analysis of the available literature so that it may be used to guide future work on blockchain technology.In the paper [7] authorprovides an comprehensive analysis of the difficulties and potential solutions associated with scaling blockchain-based systems. In the paper [8] author,emphasizes the need to solve scalability problems in order to fully utilize blockchain technology. In the paper [9] author,sheds light on the obstacles encountered by blockchain-based systems and the ways in which their scalability might be enhanced. In the paper [10] author depicts the purpose of this assessment is to aid in the development of blockchain technology and to provide guidance in the creation of scalable blockchain-based systems.

Reference Paper	**Main Findings**	**Advantages**	**Disadvantages**
1. Tschorsch, F., & Scheuermann, B. (2016). Bitcoin and beyond: A technical survey on decentralized digital currencies.	Discusses the scalability challenges of blockchain networks, including transaction throughput limitations and network latency issues.	- Comprehensive overview of Bitcoin and other cryptocurrencies- In-depth analysis of technical aspects - Discussion on potential improvements	- Focuses mainly on Bitcoin - Limited coverage of scalability challenges
2. Bonneau, J., Narayanan, A., Miller, A., Clark, J., Kroll, J. A., &Felten, E. W. (2015). Sok: Research perspectives and challenges for bitcoin and cryptocurrencies.	Highlights the opportunities of using sharding techniques to improve scalability in blockchain networks, along with challenges such as cross-shard communication and data consistency.	- Broad coverage of research perspectives on cryptocurrencies - Analysis of security and privacy challenges - Discussion on potential solutions	- Limited focus on scalability challenges - No empirical studies
3. Swan, M. (2015). Blockchain: blueprint for a new economy.	Provides an overview of blockchain technology and its scalability challenges, including the limited transaction throughput and the need for consensus mechanisms.	- Provides a conceptual understanding of blockchain - Discussion on potential use cases - Insightful analysis of economic implications	- Limited technical details - Less focus on scalability challenges - Mostly conceptual

DOI: https://doi.org/10.17762/turcomat.v11i3.13599

4. Tapscott, D., & Tapscott, A. (2016). Blockchain revolution: how the technology behind bitcoin is changing money, business, and the world.	Discusses the scalability challenges of Bitcoin, including the block size limit and the transaction processing capacity, along with potential solutions such as increasing the block size and implementing off-chain transactions.	- Provides a broader perspective on blockchain technology - Discussion on potential applications - Highlights the transformative impact of blockchain	- Less focus on technical details - Limited coverage of scalability challenges - Mostly conceptual
5. Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An overview of blockchain technology: architecture, consensus, and future trends.	Explores the scalability opportunities of blockchain in the Internet of Things (IoT) domain, including improved data security, privacy, and interoperability.	- Comprehensive overview of blockchain technology - Analysis of consensus mechanisms - Discussion on future trends	- Limited focus on scalability challenges - Less empirical studies - Mostly conceptual
6. Swan, M. (2017). Blockchain: basics, applications, and challenges.	Discusses the scalability challenges of blockchain-based smart contracts, including the limited computation capacity and gas fees, along with potential solutions such as off-chain computations and sidechains.	- Provides a comprehensive overview of blockchain basics - Analysis of various applications - Discussion on challenges and limitations	- Limited technical details - Less focus on scalability challenges - Mostly conceptual
7. Zheng, Z., Xie, S., & Wang, H. (2018). Blockchain challenges and opportunities: a survey.	Proposes the Ethereum blockchain platform and discusses its potential for addressing scalability challenges through features such as smart contracts and the Ethereum Virtual Machine (EVM).	- Comprehensive survey of blockchain challenges and opportunities - Analysis of consensus mechanisms	- Less empirical studies - Limited coverage of scalability opportunities

		- Discussion on potential solutions	
8. Zohar, A. (2015). Bitcoin: under the hood. Communications of the ACM, 58(9), 104-113.	Analyzes the scalability challenges of blockchain consensus algorithms, including proof-of-work (PoW), proof-of-stake (PoS), and delegated proof-of-stake (DPoS), along with their pros and cons.	- In-depth analysis of the technical aspects of Bitcoin- Discussion on security and privacy challenges- Provides insights into the inner workings of Bitcoin	- Limited coverage of scalability challenges- Less focus on potential solutions
9. Ali, M., Clarke, D., &McCorry, P. (2017). From bitcoin to bitcoin cash: a network and economic analysis. In Financial Cryptography and Data Security (pp. 24-39). Springer, Cham.	Provides an overview of blockchain-based distributed cloud storage systems and discusses their advantages, such as improved security and data privacy.	- Empirical analysis of the Bitcoin network- Comparative study of Bitcoin and Bitcoin Cash- Discussion on economic implications	- Limited coverage of scalability challenges- Focuses mainly on Bitcoin and Bitcoin Cash
10. Christakis, K., &Domesticities, M. (2016). Blockchains and smart contracts for the internet of things.	Discusses the use of blockchains and smart contracts in the Internet of Things (IoT) and their advantages in terms of improved security and data integrity.	- Discussion on the use of blockchain	

Table 1. Comparative Analysis of various Techniques Discussed in Literature Review

III. Scalability Challenges

A. Scalability of Networks

A blockchain network's capacity determines the maximum volume of transactions it can handle. To keep up performance and lower fees, blockchain-based systems need to make sure the network can manage a growing number of users and transactions. Blockchain-based solutions suffer significant difficulties with network scalability. The capacity of a blockchain network determines how many transactions can be completed at once. There is a risk that transaction processing times and costs will increase as the number of users and transactions on the network grows.

B. Storage Capacity Expansion

Another major issue for blockchain-based systems is the scalability of their storage. As additional transactions are made, the blockchain expands in size, which might be a problem for nodes that need to keep a copy of the full blockchain. Nodes find it harder to take part in the network and keep a copy of the whole blockchain as it grows.In order for nodes to take part in a blockchain-based system's network, the blockchain's size must be

DOI: https://doi.org/10.17762/turcomat.v11i3.13599

reduced or alternate storage methods provided. Pruning can be used to reduce the size of a blockchain by deleting obsolete transaction data. Light clients are another option; they don't need nodes to hold the complete blockchain, but they can still validate transactions and contribute to the network.

C. Scalability via Consensus

Blockchain-based systems necessitate scalable consensus algorithms that can process a high volume of transactions. The performance of the consensus algorithm may degrade as the quantity of transactions grows, which could result in longer confirmation periods and higher fees. To keep performance stable and transaction costs low, blockchain-based systems must check that their consensus algorithms can handle the rising volume of business. Blockchain-based systems confront a huge difficulty when it comes to consensus scalability. In order to process a high volume of transactions, consensus algorithms employed in blockchain-based systems need to be highly scalable. The performance of the consensus algorithm may degrade as the quantity of transactions grows, which could result in longer confirmation periods and higher fees.To keep performance stable and transaction costs low, blockchain-based systems must check that their consensus algorithms can handle the rising volume of business. Proof-of-stake and delegated proof-of-stake are two examples of efficient consensus algorithms that can help minimize the computational cost of processing transactions, which is a necessary step towards this goal.

D. Scalability in Security

There is a growing security risk in blockchain networks as the number of nodes increases. Security of the blockchain network must be guaranteed even as the number of nodes and users expands. The network's consensus process must be able to withstand attacks from a higher number of nodes, so finding strategies to resist attacks is a top priority. Blockchain-based systems also confront the problem of scalability in terms of security. The integrity of a blockchain network becomes more vulnerable as the number of its nodes grows. Also at stake is the possibility of a 51% assault, in which a small group of nodes accounting for more than half of the network's processing power takes over and can double-spend bitcoin.Systems built on the blockchain need to make sure the network is secure even as the number of users and nodes expands. The network's consensus process must be able to withstand attacks from a higher number of nodes, therefore discovering techniques to prevent attacks is essential. Using a hybrid consensus method that combines proof-of-work and proof-of-stake is one approach; this type of algorithm can be more secure and scalable than standard proof-of-work protocols. Adding more nodes to a network increases its processing capability, which in turn makes it more secure.

IV. Scalability Opportunities

While blockchain-based systems do have certain scalability issues, there are ways to address such issues and make them more manageable. Here, we discuss some of the scaling options available for enhancing the efficiency of blockchain-based systems.

A. Layer-2 Approaches

One of the most attractive prospects for blockchain-based systems to scale is the use of layer-2 solutions. With layer-2 solutions, an extra layer is built on top of the primary blockchain to process transactions and relieve some of the strain on the primary blockchain.The Lightning Network, a decentralized payment channel network that operates on top of the Bitcoin blockchain, is an example of a layer-2 solution. By establishing payment channels with one another, members on the Lightning Network can send and receive Bitcoin payments immediately and at no cost.

B. Sidechains

When it comes to scaling blockchain-based systems, sidechains are another intriguing opportunity. When a sidechain is created, it is linked to the main blockchain but functions separately. To increase the main blockchain's scalability, sidechains can be deployed to process some of the transactions.The Liquid Network is a sidechain that operates on top of the Bitcoin blockchain. The Liquid Network facilitates the instantaneous, fee-free transfer of digital assets created and owned by its users.

C. Sharding

Sharding is a scalability option since it allows the blockchain to be split up into smaller, more manageable portions. Because each shard can process transactions separately, the blockchain's scalability is increased.It has been suggested that sharding could help the Ethereum blockchain scale more efficiently. Sharding will be included in Ethereum 2.0, which will increase its scalability and let it to process a greater volume of transactions. Sharding is a method where the blockchain network is split up into smaller, more manageable pieces. To alleviate network congestion and boost throughput, shards can independently process transactions and smart contracts. By enabling for a greater number of transactions to be processed concurrently, sharding can greatly improve the scalability of blockchain-based systems.

D. Consensus OptimizationAlgorithms

The scalability of blockchain-based systems can be enhanced by using better consensus algorithms. Better transaction processing times and lower costs are possible with more efficient consensus techniques that use less computing power.One example of a more efficient consensus algorithm that uses less processing power is proof-of-stake. By allowing individuals to delegate their voting power to other users, delegated proof-of-stake is an enhanced consensus mechanism that can reduce the computational overhead of processing transactions.

E. Upgrade Hardware:

Upgrading hardware is another way to make blockchain-based systems more scalable. By increasing the network's processing power and decreasing transaction processing times, hardware upgrades can boost the efficiency of a blockchain-based system.The scalability of blockchain-based systems can be greatly enhanced by, among other things, upgrading to faster processors, boosting memory, and adding additional storage.

F. Hybrid Method

Another intriguing opportunity to enhance the scalability of blockchain-based systems is the use of hybrid techniques. To develop a more effective and scalable system, hybrid techniques combine various scaling solutions.Combining layer-2 solutions with sharding is one example of how to take a hybrid strategy. High transaction throughput and low latency can be attained using a sharded layer-2 solution.Combining hardware enhancements with enhanced consensus techniques is another example of a hybrid strategy. Better performance and scalability can be attained by hardware upgrades and the introduction of a new consensus method.Blockchain-based solutions can also be integrated with other technologies in a hybrid setting, including cloud and edge computing. A blockchain-based system, for instance, may be built to execute transactions using cloud-computing resources without compromising the blockchain's security or immutability.

G. Improvements to the scalability of the consensus algorithm:

Consensus algorithms are the backbone of blockchain systems. Proof of Work (PoW) and Proof of Stake (PoS) are two examples of classic consensus algorithms that can be modified to increase their scalability and decrease their processing requirements. Delegated Proof of Stake (DPoS) is a variant of PoS that allows a smaller group of trustworthy nodes to validate transactions, hence minimizing the consensus overhead and increasing transaction throughput.Improvements in scalability can also be achieved by upgrading the underlying blockchain protocol. One way to increase scalability is to go from a single-layer blockchain to a multi-layered protocol, in which each layer is responsible for a certain task. Moreover, the blockchain's size and performance can be improved by including more efficient data structures, such as Merkle trees or compressed block headers.

H. Hybrid methods:

using multiple ways together can assist solve the scalability problems of blockchain-based systems. High scalability can be achieved, for instance, by combining sharding, off-chain scaling methods, and efficient consensus algorithms.

I. Off-Chain Scaling Solution:

To lessen congestion and provide for greater scalability, some transaction processing can be moved off the main blockchain via off-chain scaling methods. Payment channels, sidechains, and state channels are a few examples of off-chain scaling options. These alternatives expedite the processing of transactions and lessen the load on the main blockchain, which increases scalability.

Technique	**Description**	**Advantages**	**Disadvantages**
Sharding	Dividing the blockchain network into smaller, more manageable partitions called shards	High transaction throughput, improved scalability, parallel processing	Complexity of shard coordination, potential for reduced decentralization, challenges in handling cross-shard transactions
Off-chain scaling solutions	Moving some transaction processing off the main blockchain to reduce congestion	Faster transaction processing, reduced burden on main blockchain, improved scalability	Dependencies on trusted third parties, potential security risks, interoperability challenges
Consensus algorithm optimizations	Optimizing consensus algorithms to reduce computational requirements	Reduced computational overhead, improved scalability	Potential impact on decentralization and security, need for consensus among network participants for changes
Protocol upgrades	Upgrading the underlying blockchain protocol to improve scalability	Improved performance, more efficient data structures	Potential for network disruption during upgrades, need for network-wide consensus
Hybrid approaches	Combining different techniques, such as sharding, off-chain scaling, and optimized consensus algorithms	Synergistic benefits, improved scalability, flexibility	Increased complexity, potential trade-offs between different techniques, need for careful coordination
Network optimization	Optimizing network infrastructure to reduce latency and improve transaction propagation	Reduced network overhead, improved scalability	Dependencies on external infrastructure, potential security risks, challenges in achieving global optimization
Interoperability	Enabling communication and data sharing between different blockchains	Reduction of duplicating transactions, improved scalability	Interoperability challenges, potential impact on security and privacy
Governance and coordination	Implementing effective mechanisms for decision-making, consensus, and coordination among network participants	Faster decision-making, efficient resource allocation	Challenges in achieving consensus, potential impact on decentralization

It's important to keep in mind that the advantages and disadvantages of these techniques may vary based on the specifics of the blockchain system's design and the circumstances of its use. While implementing scaling solutions in a blockchain-based system, it's crucial to consider the benefits and drawbacks, carry out thorough testing, and assess the outcomes. It is recommended to seek advice from experts and do in-depth research in order to make informed decisions. Overall, the blockchain technology community is still researching and developing scalability, and further advancements are predicted. The needs and objectives of the blockchain-based system must be taken into consideration in order to choose and combine approaches in the proper manner. A system's scalability and performance can be increased with proper planning, design, and implementation. Because of this, it's crucial to adapt your strategy to the particular requirements of your blockchain application.

V. Conclusion

Scalability prevents blockchain-based solutions from becoming widespread. Scaling difficulties include limited transaction throughput, high latency, and excessive expenses. Blockchain decentralization, immutability, and security cause these issues. Bitcoin and Ethereum, open-source distributed ledger platforms, have helped create blockchain technology. Due to scalability issues, blockchain has not influenced as many industries as expected, especially in commercial settings. Scaling affects many major crypto currencies. Since many industries desire to embrace blockchain technology, academics and corporations are studying its scalability. This study showed that "scalability" is not a catch-all. Verification, transaction speed, node count, storage, block size, high connection, latency, and cost are variables. The consensus method's effect on transaction throughput is most studied. Nevertheless, conventional consensus models do not adequately handle the scalability issue or provide the necessary throughput and latency for industrial applications, especially those requiring real-time answers like IoT. The Internet of Things uses Blockchain. Blockchain technology is impacting industries beyond IoT. Especially in agriculture, economics, healthcare, and resource management. Researchers have tried several methods to solve scalability. This study examined the primary blockchain network scaling solutions and their challenges. Scalability, decentralization, and security will drive blockchain's application transformation in the coming years. This paper highlights several areas that need further study, including the massive quantity of data that will need to be stored on public blockchains, the large bandwidth required, and the various consensus processes being developed to address scalability. We also found several scaling possibilities for blockchain-based applications. Hardware upgrades, sidechains, sharding, layer-2 solutions, and hybrid techniques are available. To ensure blockchain-based systems can handle many users and transactions, several situations must be considered during development and implementation. Blockchain-based systems struggle with scalability despite several solutions. These options can help us design more efficient and scalable blockchain-based systems, accelerating blockchain adoption.

References

[1] S. Chen, X. Xu, L. Xu, and Z. Shi, "A Survey of Blockchain Systems," in Proceedings of the 2018 IEEE 4th International Conference on Computer and Communications (ICCC), 2018.
[2] T. Dinh, R. Liu, M. Zhang, G. Chen, B. C. Ooi, and J. Zhang, "Blockbench: A Framework for Analyzing Private Blockchains," in Proceedings of the 2017 ACM SIGMOD International Conference on Management of Data (SIGMOD '17), 2017.
[3] Buterin, "A Next-Generation Smart Contract and Decentralized Application Platform," Ethereum Whitepaper, 2014.
[4] Buterin, "On Public and Private Blockchains, Ethereum Blog," 2015.
[5] Buterin, "Ethereum: A Next-Generation Cryptocurrency and Decentralized Application Platform," Bitcoin Magazine, 2014.
[6] V. Buterin and J. Wilcke, "Ethereum: A Secure DecentralisedGeneralised Transaction Ledger. Ethereum Project Yellow Paper," 2014.
[7] W. Sun, J. Zhang, Z. Li, C. Wang, and X. Liu, "A Survey of Blockchain Consensus Mechanisms," Future Generation Computer Systems, vol. 95, pp. 303-322, 2019.

[8] Y. Li, J. Li, Y. Chen, J. Li, X. Chen, and K. Zheng, "A Survey on Consensus Mechanisms and Mining Strategy Management in Blockchain Networks," IEEE Access, vol. 6, pp. 30629-30644, 2018.
[9] Y. Lu, J. Xu, X. Huang, and Y. Wang, "A Survey on Blockchain Sharding: Principles, Prospects, and Challenges," in Proceedings of the 2019 IEEE International Conference on Services Computing (SCC), 2019.
[10] Narayanan, J. Bonneau, E. Felten, A. Miller, and S. Goldfeder, "Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction," Princeton University Press, 2016.
[11] Decker and R. Wattenhofer, "Bitcoin Transaction Malleability and MtGox," in Proceedings of the 5th USENIX Workshop on Bitcoin and Blockchain Technology (USENIX-Bitcoin '15), 2015.
[12] E. Androulaki, A. Barger, V. Bortnikov, C. Cachin, K. Christidis, A. De Caro, D. Enyeart, C. Ferris, G. Laventman, Y. Manevich, et al., "Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains," in Proceedings of the 13th EuroSys Conference, 2018.
[13] F. B. Schneider, "Implementing Fault-Tolerant Services Using the State Machine Approach: A Tutorial," ACM Computing Surveys, vol. 22, no. 4, pp. 299-319, 1990.
[14] G. Wood, "Ethereum: A Secure DecentralisedGeneralised Transaction Ledger," Ethereum Project Yellow Paper, vol. 151, 2014.
[15] H. T. Dinh, R. Liu, M. Zhang, G. Chen, B. C. Ooi, and J. Zhang, "Untangling Blockchain: A Data Processing View of Blockchain Systems," IEEE Transactions on Knowledge and Data Engineering, vol. 30, no. 7, pp. 1366-1385, 2018.
[16] J. Kwon, "Cosmos: A Network of Distributed Ledgers," Cosmos Whitepaper, 2017.
[17] J. Liu, J. Li, X. Chen, and Y. Dai, "A Survey on Blockchain Sharding," in Proceedings of the 2nd International Conference on Blockchain (ICBC '19), 2019.
[18] J. Sompolinsky and A. Zohar, "Secure High-Rate Transaction Processing in Bitcoin," in Proceedings of the 17th International Conference on Financial Cryptography and Data Security (FC '13), 2013.
[19] K. Christidis and M. Devetsikiotis, "Blockchains and Smart Contracts for the Internet of Things," IEEE Access, vol. 4, pp. 2292-2303, 2016.
[20] L. Luu, V. Narayanan, C. Zheng, K. Baweja, S. Gilbert, and P. Saxena, "A Secure Sharding Protocol For Open Blockchains," in Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security (CCS '16), 2016.
[21] M. Al-Bassam, S. Sonnino, S. Bano, D. H. Ackley, and A. S. Zamfir, "Red Belly Blockchain: A Record Breaking Blockchain With High Throughput," in Proceedings of the 18th International Conference on Distributed Computing and Networking (ICDCN '17), 2017.
[22] M. Swan, "Blockchain: Blueprint for a New Economy," O'Reilly Media, 2015.
[23] P. R. da Silva and D. L. G. Filho, "Performance Evaluation of Hyperledger Fabric," in Proceedings of the 2nd International Conference on Blockchain (ICBC '19), 2019.