International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Scalability and Performance Challenges in Block Chain Technology

Dr. Himanshu Patel

Assistant Professor, School of Computer Science, Dr. Babasaheb Ambedkar Open University, Ahmedabad
Email: *himanshu.patel[at]baou.edu.in*
ORCID iD: 0000-0001-8012-3577

Abstract: ***Blockchain is a decentralized and unalterable ledger that simplifies the recording of transactions and tracking of assets within a business network. Assets include a wide range of items, comprising both physical possessions like houses, cars, cash, and land, and non-physical entities like intellectual property, patents, copyrights, and branding. The versatility of blockchain allows virtually anything of value to be tracked and traded on its network, thereby reducing risks and cutting costs for all participants involved [1]. While blockchain technology has gained significant attention and adoption in recent years, it still encounters challenges that necessitate resolution for widespread implementation. This paper aims to elucidate the intricacies of blockchain technology, highlighting its key features, types and applications. This paper reviews related work done by other researchers for performance and scalability challenges and give comparison among various blockchain platforms. It also discuss Performance and Scalability challenges of Blockchain technology, factors influencing performance of blockchain and gives comprehensive overview of notable scalability challenges in blockchain, along with an outline of relevant solutions.***

Keywords: Block Chain, features of blockchain technology, Application of blockchain, Scalability, Performance

1. Introduction

Blockchain is a digital ledger that operates in a decentralized and distributed manner, ensuring secure recording of transactions across multiple computers or nodes. It is a technology that enables the creation and maintenance of a transparent and tamper-proof record of transactions, without the need for a central authority or intermediary.

In a blockchain network, each transaction is bundled together with other transactions into a block and added to a chain of previously validated blocks. Each block contains a unique identifier called a cryptographic hash, which ensures the integrity of the data and links it to the previous block, creating a chronological order of transactions.

Block: Each chain is comprised of numerous blocks, and every block contains three fundamental components:

- The **data** in the block.
- The **nonce:** It stands for "number used only once." It is a whole number that's randomly generated when a block is created, which then generates a block header hash.
- The **hash:** It is a number permanently attached to the nonce.

When the initial block of a chain is formed, a nonce is generated to produce a cryptographic hash. The information contained within the block becomes signed and permanently associated with the nonce and hash, unless it undergoes the mining process.

Miner: In the framework of blockchain technology, a miner is a contributor in the network who performs the crucial task of authenticating and adding new transactions to the blockchain. Miners play a important role in maintaining the decentralized and secure nature of blockchain networks.

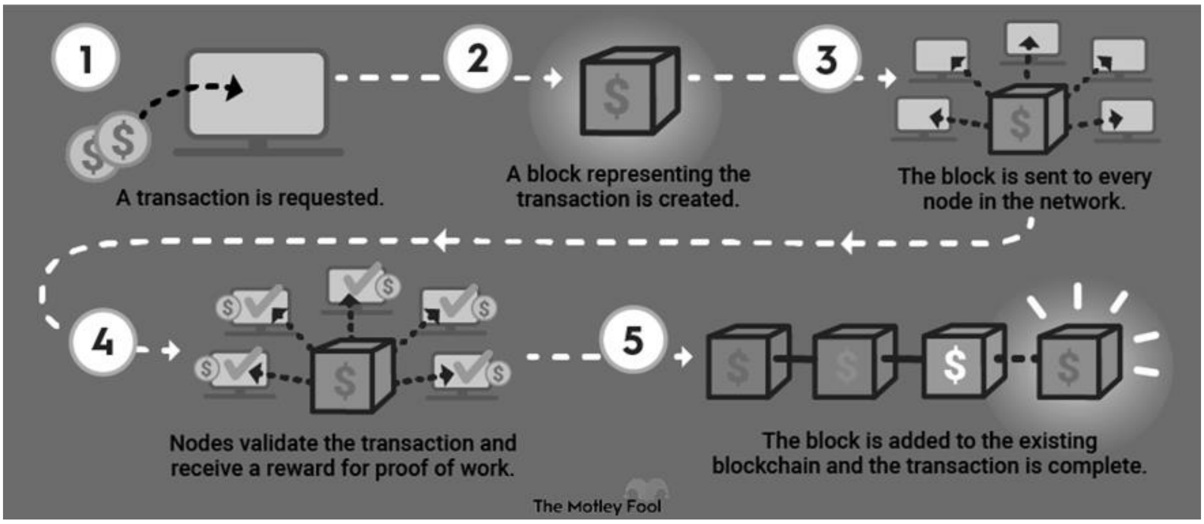

Figure 1: How Blockchain Works. Image source: The Motley Fool [3]

When a user starts a transaction on the blockchain, it is disseminated to the network. Miners gather these transactions and package them into blocks, which are basically groups of transactions. However, before a block can be added to the blockchain, miners must compete to solve a complex mathematical puzzle called proof-of-work.

Once a block is effectively mined, the alteration is universally acknowledged by all nodes within the network, leading to a monetary reward for the miner.

Decentralization: It is one of the most important concepts in blockchain technology. A chain refers to a decentralized ledger accessible through interconnected nodes. These nodes, which can be various electronic devices, uphold copies of the chain and play a crucial role in sustaining the network's operations.

Each node possesses its individual replica of the blockchain, and for the chain to be updated, trusted, and validated, any newly mined block must receive algorithmic approval from the network. Due to the transparency of blockchains, all activities within the ledger can be readily examined and observed, resulting in inherent security. Furthermore, each participant is assigned a distinctive alphanumeric identification number that denotes their transactions.

A chain is comprised of multiple blocks, with each block consisting of three fundamental elements. Essentially, blockchains can be seen as a technological means to scale up trust. [4]

2. Key Features of Block Chain Technology

Fundamentally, a blockchain is a sequence of interconnected blocks, with each block containing a collection of transactions. These blocks are linked together in a chronological order, creating a permanent and unalterable record of all the transactions. The decentralized nature of blockchain means that no single entity has control over the entire network, and transactions are verified by consensus among the participating nodes.

Outlined below are several essential attributes of blockchain technology:

- **Decentralization:** Unlike traditional centralized systems where a single authority maintains and controls the database, blockchain operates on a network of computers, each having a copy of the entire blockchain. The decentralization aspect enhances transparency, security, and resilience.
- **Security:** Each block in the blockchain is linked to the previous block using cryptographic hashes, creating an immutable record. Changing the data in one block would require changing all subsequent blocks, making it extremely difficult to tamper with the information stored in the blockchain.
- **Transparency:** Every participant in the network has access to view all transactions recorded on the blockchain. This transparency fosters trust among users as it allows for verification and auditing of transactions.
- **Immutability:** Once a transaction is recorded on the blockchain, it becomes extremely challenging to modify or delete. This feature ensures that the integrity of the data is maintained and provides a reliable audit trail.
- **Smart Contracts:** Blockchain platforms like Ethereum allow the execution of programmable contracts called smart contracts. Smart contracts automatically enforce predefined rules and conditions, eliminating the need for intermediaries in certain transactions and reducing costs.

3. Types of Blockchain Technology

Various types of blockchains exist, each possessing unique characteristics and catering to specific use cases. Here are some commonly observed types:

- **Public Blockchain:** This is the most well-known type of blockchain, where anyone can participate and validate transactions. Public blockchains are decentralized and typically rely on a consensus mechanism, such as proof of work (PoW) or proof of stake (PoS), to validate transactions and create new blocks. Examples include Bitcoin and Ethereum.
- **Private Blockchain:** Also known as permissioned blockchains, private blockchains are restricted to a specific group of participants who have been granted permission to access and validate transactions. These blockchains are often used by organizations or consortiums for internal purposes, such as supply chain management or intercompany transactions.
- **Consortium Blockchain:** Consortium blockchains represent a hybrid model that combines elements of both public and private blockchains. They are governed by a group of organizations or entities instead of a single central authority. Consortium blockchains offer more scalability and privacy compared to public blockchains, while still allowing multiple organizations to participate in the consensus process.
- **Hybrid Blockchain:** Hybrid blockchains integrate features from both public and private blockchains. They allow for a public-facing network that can be accessed and audited by anyone, while also incorporating private or permissioned components for specific use cases or participants. Hybrid blockchains are often used in industries where a balance between transparency and privacy is required.
- **Federated Blockchain:** Federated blockchains are similar to consortium blockchains, but they rely on a group of pre-selected nodes to validate transactions and maintain the blockchain network. The consensus mechanism is controlled by these selected nodes, providing faster transaction processing compared to public blockchains.
- **Sidechain:** A sidechain is a separate blockchain that is interoperable with the main blockchain, known as the parent chain. Sidechains allow for the creation of new functionalities and applications that can interact with the parent chain, while still benefiting from its security and stability. Sidechains can be public or private, depending on the desired use case.
- **Blockchain as a Service (BaaS):** It refers to cloud-based blockchain platforms that provide infrastructure and tools to deploy, manage, and scale blockchain applications. These platforms abstract the underlying complexities of blockchain technology, making it easier

for organizations to adopt and integrate blockchain solutions.

These are just a few examples of the types of blockchains available. The blockchain ecosystem is continuously evolving, and new variations and combinations of blockchain types are emerging as the technology matures.

4. Applications of Blockchain Technology

Blockchain technology is a decentralized and distributed ledger system that enables secure and transparent recording and verification of transactions. Originally introduced as the underlying technology for cryptocurrencies like Bitcoin, blockchain has found applications in various industries beyond finance. Here are some common uses of blockchain technology:

- **Cryptocurrencies:** Blockchain technology is most associated with cryptocurrencies, where it serves as a public ledger for recording all transactions. It ensures transparency, security, and immutability of the transaction history.
- **Smart Contracts:** Blockchain can support the execution of smart contracts, which are self-executing agreements with predefined conditions. These contracts automatically execute when the conditions are met, removing the need for intermediaries, and increasing efficiency and trust in various sectors, such as supply chain management and real estate.
- **Supply Chain Management:** Supply chain management can benefit from blockchain technology by enhancing transparency and traceability in the process. It enables the tracking of goods from their origin to the end consumer, providing a verifiable record of each transaction and ensuring the authenticity and quality of products.
- **Identity Management:** Blockchain technology can be utilized for secure identity management. It allows individuals to have control over their digital identities, reducing the risks of identity theft and providing a more reliable and efficient way to authenticate individuals.
- **Healthcare:** Blockchain can be used to securely store and share medical records, ensuring data integrity and privacy. It can enable interoperability between different healthcare providers and streamline processes like insurance claims and drug supply chain management.
- **Voting Systems:** Blockchain offers a transparent and tamper-resistant platform for conducting elections. It can enhance the security and integrity of the voting process, prevent fraud, and increase trust in the democratic system.
- **Financial Services:** Blockchain technology has the potential to transform various aspects of the financial industry. It can enable faster and more secure cross-border payments, reduce the costs of remittances, and facilitate peer-to-peer lending and crowdfunding without intermediaries.
- **Intellectual Property Protection:** Blockchain can be used to establish proof of ownership and timestamp creations, helping protect intellectual property rights. Artists, musicians, and writers can utilize blockchain to record and authenticate their work, providing evidence of originality and ownership.
- **Internet of Things (IoT):** Blockchain can enhance the security and efficiency of IoT networks by providing a decentralized and tamper-resistant platform for managing device identities, data integrity, and automated transactions between IoT devices.
- **Energy Trading:** Blockchain can facilitate peer-to-peer energy trading by allowing consumers to directly buy and sell electricity from each other. It enables transparent tracking of energy production and consumption, promoting renewable energy and decentralization of the energy grid.

These instances represent only a fraction of the diverse applications enabled by blockchain technology. As the technology continues to evolve, new innovative use cases are likely to emerge. The next section discusses comparison among various blockchain platforms.

5. Related Works

Yasaweerasinghelage proposed a simulation framework and performance modeling [6] to forecast the latency of blockchain-based systems. Dinh introduced the Block bench framework [5] to test the performance of private blockchain platforms. In this study, a performance comparison is conducted among various private blockchain platforms, namely Parity, Ethereum, and Fabric. Kocsis presented a performance evaluation model for blockchain technology, with a specific emphasis on Hyperledger Fabric v0.6 [8]. In their work, Sukhwani introduces a performance modeling framework designed for a permissioned blockchain network that incorporates a Practical Byzantine Fault Tolerance consensus protocol [7]. Suporn et al. presented a performance evaluation of two private blockchain implementations, Ethereum and Hyperledger Fabric, by varying the number of transactions [10]. Vuckolic et al. compared proof of work and Byzantine fault tolerance-based blockchains in terms of scalability and performance [9]. Additionally, other works in this field concentrate on evaluating the security, performance, and scalability aspects of both public and private blockchains [11], [12], [13], [14], [15]. Based on this literature survey, table-1 shows a comparison among various blockchain platforms.

Table 1: Comparison Among Blockchain Platforms

Blockchain Platforms	Ethereum	Hyper ledger Fabric	Quorum	Corda
Type	Public	Enterprise	Enterprise	Enterprise
Purpose	Cross-Industry	Cross-Industry	Cross-Industry	Financial Services
Application	Business to Client (B2C)	Business to Business (B2B)	Financial Service Industry	Financial Service Industry
Smart Contract Programming Language	Solidity	GoLang, NodeJs	Solidity	GoLang, NodeJs
Currency	Ether	Can be built using chaincodes	Ether	No native Cryptocurrency

Paper ID: SR24403150522 DOI: https://dx.doi.org/10.21275/SR24403150522

				(Corda coin)
Governance	DAO	Linux Foundation	Ethereum Foundation	R3
Consensus Algorithm	PoW	PBFT	RAFT	Pluggable Consensus
Throughput	A few 100s	> 200 tps	200 tps	200 tps

6. Performance and Scalability Challenges of Blockchain Technology

Blockchain was designed as a decentralized network that enables interactions among participants without the need for a central authority. In this network, each participating node holds equal rights and takes on the responsibility of governing and managing transactions. However, the performance and scalability of blockchain systems are critical considerations for assessing their readiness in real-world implementations.

Performance and scalability have always been key non-functional requirements for evaluating the effectiveness of any IT system. This holds true for blockchain networks, especially due to their distributed and decentralized nature, which relies on peer collaboration and trust-building across a business network. Each peer node is responsible for performing computations, communicating with other peers, validating transactions, achieving consensus, and updating the shared ledger's state. Understanding the factors influencing blockchain performance and identifying areas for improvement are crucial for making informed architectural decisions when developing blockchain-based solutions.

Blockchain network performance is typically measured by the average time required for a transaction to be validated and stored in each peer node in an irreversible and non-revocable manner. This metric, often referred to as throughput, should not be confused with the number of concurrent transactions processed within a given timeframe. On the other hand, scalability of blockchain networks refers to their ability to handle an increasing load of transactions and accommodate a growing number of nodes in the network.

However, the ever-expanding number of nodes has presented a challenge to blockchain scalability. Despite blockchain's existence for over a decade, scalability issues can hinder its widespread adoption. The following discussion provides a comprehensive overview of notable scalability challenges in blockchain, along with an outline of relevant solutions.

- **Scalability:** Blockchain networks, particularly public blockchains like Bitcoin and Ethereum, struggle with scalability as the number of participants and transactions increases. The consensus mechanisms, such as Proof of Work (PoW) or Proof of Stake (PoS), require all nodes to validate and store a copy of the entire blockchain. This results in limited transaction processing capacity and increased network latency. As a result, the transaction throughput is low, and the network becomes congested during peak times.
- **Transaction throughput:** The current blockchain architectures face limitations in terms of transaction throughput. Bitcoin, for example, has a maximum block size and block interval, which limits the number of transactions that can be processed per second. Similarly, Ethereum's current architecture also faces scalability challenges, resulting in network congestion during periods of high demand.
- **Latency:** Blockchain networks have inherent latency due to the consensus mechanisms and the time required for block confirmation. In some cases, transactions can take several minutes or even hours to be confirmed. This latency is impractical for real-time applications that require faster transaction processing, such as payment systems or supply chain tracking.
- **Energy consumption:** Traditional blockchain networks that rely on PoW consensus consume a significant amount of energy. The process of solving complex mathematical puzzles to validate transactions and secure the network requires substantial computational power. The environmental impact of blockchain technology has become a concern due to its energy consumption.
- **Interoperability:** Blockchain scalability is also hindered by interoperability challenges. Different blockchain platforms and networks often operate in isolation, making it difficult for them to communicate and share data seamlessly. Interoperability solutions are necessary to enable cross-chain transactions and communication between different blockchain networks.

7. Factors influencing performance of blockchain

The performance of a blockchain is influenced by several possible factors[2], including:

- **Consensus mechanism:** The consensus protocol or algorithm is the mechanism through which transactions are propagated, validated, and finalized in a blockchain network. This consensus mechanism plays a crucial role in achieving a balance between decentralization, scalability, and security within the network. Therefore, the choice of consensus mechanism directly impacts the performance of the blockchain network.
- **Network Latency**: Within a distributed architecture, network performance is a critical factor that significantly impacts the overall performance of the network. When a transaction requires validation, it must be broadcasted to all nodes, and their responses need to be collected to reach a consensus based on majority agreement. Therefore, having a dedicated network bandwidth is essential to minimize network delays and enhance the overall throughput of the system.
- **Node Infrastructure:** Node infrastructure in blockchain comprises a runtime engine and a database, which can be hosted either on-premise or in the cloud. However, if the infrastructure resources such as CPU, memory, and hard disk are insufficient, it is highly likely that the performance of the nodes will be negatively impacted. Therefore, it is crucial to properly size the infrastructure and allocate sufficient IOPS (Input Output Operations Per Second) to ensure optimal node performance.

- **Number of nodes:** With an increase in the number of nodes, the time required for transaction propagation and consensus achievement also increases, thereby degrading overall performance. To address this problem, various techniques are being implemented to minimize communication overhead and allow nodes to depend on the validation history of a leader node or other peer nodes. These techniques strive to alleviate the issue by offering more efficient and streamlined methods to achieve consensus within the network.
- **Smart contract complexity:** Many benchmarking studies or claims are often derived from tests conducted in controlled laboratory environments, focusing on simple transactions. However, as the complexity of smart contracts grows, with more intricate validation logic and an increased number of reads and writes to the ledger, the processing latency also increases. Consequently, this has a direct impact on the overall performance of the system. It is important to consider these factors when evaluating the real-world performance of blockchain networks handling more complex transactions.
- **Transaction Payload size:** Due to the need to relay transactions and their payloads across the network to all nodes, larger payloads require more time for replication across the network. To address this, a recommended best practice is to store large payloads and documents in an off-chain storage solution and only record their references or metadata on the blockchain. By doing so, the network can minimize the storage and bandwidth requirements while still maintaining the necessary integrity and traceability through the blockchain references.
- **Node local storage:** Typically, blockchain networks employ key-value pair data stores to handle transaction and ledger state management. As a considerable amount of read-write operations take place, the efficiency of the underlying database plays a crucial role in influencing the overall performance of the network. Choosing an efficient and well-optimized database is essential to ensure smooth and high-performing operations within the blockchain network.
- **Transaction pooling / queuing:** Although a blockchain network consists of multiple nodes that collectively offer high availability, the transaction handling capacity of each individual node determines the number of transactions accepted from client applications for further processing. This directly impacts the overall throughput of the network. Therefore, the transaction handling capacity of each node plays a crucial role in determining the network's ability to process transactions efficiently and maintain a high throughput.

8. Proposed Solutions for Performance and Scalability Issues

Blockchain scalability refers to the capability of a blockchain network to effectively manage and accommodate an increasing volume of transactions or users without compromising its overall performance. Blockchain performance solutions refer to various approaches and techniques used to enhance the efficiency and scalability of blockchain networks. Blockchain technology, while revolutionary, often faces challenges in terms of transaction speed, scalability, and resource consumption. To address these issues, several performance solutions have been developed. Here are some commonly employed solutions:

- **Sharding:** Sharding involves partitioning the blockchain network into smaller shards or subsets, each capable of processing its own transactions and smart contracts. By distributing the workload across multiple shards, the overall network throughput can be increased significantly.
- **Off-chain scaling:** Off-chain scaling solutions aim to reduce the burden on the main blockchain by conducting certain transactions off the main chain. Techniques like payment channels (e.g., the Lightning Network for Bitcoin) allow participants to conduct numerous transactions off-chain and only settle the final result on the main chain, thereby increasing scalability.
- **Layer 2 protocols:** Layer 2 protocols build additional layers on top of the main blockchain to handle transactions. These layers can process transactions more quickly and then periodically settle the results on the main chain. Examples include the Ethereum network's layer 2 solutions like Optimistic Rollups and zkRollups.
- **Consensus algorithm improvements:** The consensus algorithm used in a blockchain network affects its scalability. Some algorithms, such as Proof of Work (PoW), have inherent limitations on scalability due to the computational requirements. Shifting to more efficient consensus algorithms like Proof of Stake (PoS) or Delegated Proof of Stake (DPoS) can significantly enhance scalability.
- **Sidechains:** Sidechains are independent blockchains that are interoperable with the main blockchain. They can process transactions separately from the main chain, relieving congestion. Sidechains can be used for specific purposes or applications, and the results can be settled on the main chain.
- **State channels:** State channels are similar to payment channels but extend beyond just payments. They allow participants to conduct multiple interactions off-chain and only settle the final state on the main chain. State channels can greatly enhance scalability for applications requiring frequent and rapid interactions.
- **Blockchain interoperability:** Interoperability solutions aim to connect multiple blockchains, enabling assets and data to move seamlessly across different networks. By leveraging interoperability protocols, the burden on a single blockchain can be reduced, improving scalability.
- **Blockchain pruning:** Pruning involves removing unnecessary data from the blockchain while maintaining its integrity. This technique reduces the storage requirements for running a full node, enabling more participants to join the network and improving scalability.
- **Optimized smart contract execution:** Smart contracts on blockchain networks can sometimes be resource-intensive, leading to slower transaction processing. Optimizations in the execution environment, such as just-in-time compilation or more efficient virtual machines, can improve the performance of smart contracts.
- **Parallel processing:** Blockchain networks can leverage parallel processing techniques to execute transactions concurrently. This involves dividing transaction

Paper ID: SR24403150522 DOI: https://dx.doi.org/10.21275/SR24403150522

processing tasks across multiple nodes or processors, enabling faster execution and improved scalability.

- **Interoperability and cross-chain solutions:** Blockchain interoperability protocols allow different blockchain networks to communicate and share information securely. Cross-chain solutions enable the transfer of assets or data across multiple blockchains, reducing congestion on a single chain.
- **Governance and consensus upgrades:** Upgrades to the governance and consensus mechanisms of a blockchain network can facilitate faster decision-making and consensus formation. This, in turn, can lead to more efficient block creation and validation, improving overall network performance.

It's important to note that the effectiveness of above performance solutions may vary depending on the specific blockchain network and its underlying architecture. Different projects and platforms may adopt different combinations of these solutions or develop their own unique approaches to enhance blockchain performance. Blockchain platforms may employ different scalability solutions, and the effectiveness of these solutions can vary based on the specific blockchain's design and requirements. Additionally, ongoing research and development in the blockchain space continue to explore new approaches to further enhance scalability and new advancements are expected to improve the scalability and performance of blockchain technology in the future.

9. Conclusion

Due to the multitude of factors that can influence the performance of a blockchain network, conducting performance testing for blockchain is a complex endeavour. Moreover, when processing end-to-end business transactions, it is crucial to consider the implemented use case, as well as the architecture and design of off-chain components in a blockchain-based solution.

As blockchain technology gains acceptance and finds applications across various use cases, discussions and investigations into blockchain performance and scalability will persist. While there have been notable advancements in the performance of blockchain networks, widespread adoption is still on the horizon. Prior to a wish to find a high performing blockchain platform that can handle thousands of transactions in a second, it is crucial to conduct a comprehensive evaluation to determine if the envisioned solution...

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Statements and Declarations

I confirm that this manuscript has not been published previously and is not under consideration for publication elsewhere. I also declare that this research was conducted in accordance with the ethical standards.

Declaration of interests

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Available at: https://www.ibm.com/topics/blockchain
[2] Available at: https://www.wipro.com/blogs/hitarshi-buch/improving-performance-and-scalability-of-blockchain-networks/
[3] Available at: https://www.fool.com/investing/stock-market/market-sectors/financials/blockchain-stocks/what-is-blockchain/
[4] Available at: https://builtin.com/blockchain
[5] T. T. A. Dinh et al., "Blockbench: A framework for analyzing private blockchains" in Proc. 2017 ACM International Conference on Management of Data, 2017, pp. 1085-1100 [doi:10.1145/3035918.3064033].
[6] R. Yasaweerasinghelage et al., "Predicting latency of blockchain-based systems using architectural modelling and simulation" in IEEE International Conference on Software Architecture (ICSA), vol. 2017. IEEE, 2017, pp. 253-256 [doi:10.1109/ICSA.2017.22].
[7] K. Zheng et al., "Model checking pbft consensus mechanism in healthcare blockchain network" in 9th International Conference on Information Technology in Medicine and Education (ITME), vol. 2018. IEEE, 2018, pp. 877-881 [doi:10.1109/ITME.2018.00196].
[8] T. Nakaike et al., "Hyperledger fabric performance characterization and optimization using goleveldb benchmark" in IEEE International Conference on Blockchain and Cryptocurrency (ICBC), vol. 2020. IEEE, 2020, pp. 1-9 [doi:10.1109/ICBC48266.2020.9169454].
[9] Q. Nasir et al., "Performance analysis of hyperledger fabric platforms," Sec. Commun. Netw., vol. 2018, 1-14, 2018 [doi:10.1155/2018/3976093].
[10] S. Pongnumkul et al., "Performance analysis of private blockchain platforms in varying workloads" in 26th International Conference on Computer Communication and Networks (ICCCN), vol. 2017. IEEE, 2017, pp. 1-6 [doi:10.1109/ICCCN.2017.8038517].
[11] H. Sukhwani et al., "Performance modeling of hyperledger fabric (permissioned blockchain network)" in 17th International Symposium on Network Computing and Applications (NCA), vol. 2018. IEEE. IEEE, 2018, pp. 1-8 [doi:10.1109/NCA.2018.8548070].
[12] Z. Ma et al., "Performance analysis of blockchain consensus system with interference factors and sleep stage," IEEE Access, vol. 8, pp. 119010-119019, 2020 [doi:10.1109/ACCESS.2020.3005919], P. 119.
[13] K. S. Hald and A. Kinra, "How the blockchain enables and constrains supply chain performance," IJPDLM, vol. 49, no. 4, 376-397, 2019 [doi:10.1108/IJPDLM-02-2019-0063].
[14] M. Kuzlu et al., "Performance analysis of a hyperledger fabric blockchain framework: Throughput, latency and scalability" in IEEE international conference on blockchain (Blockchain), vol. 2019. IEEE, 2019, pp. 536-540 [doi:10.1109/Blockchain.2019.00003].
[15] H. Kalodner et al., ¨ and A, Narayanan, "Blocksci: Design and applications of a blockchain analysis

platform," in 29th {USENIX} Security Symposium ({USENIX} Security 20), 2020, pp. 2721–2738.