A Systematic Review on Blockchain Scalability

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Abstract—**Blockchain is an exciting new technology that has garnered attention across multiple industries. This new technology offers several advantages, including decentralization, transparency, and immutability. However, several issues limit the effectiveness of this technology, such as scalability, interoperability, and privacy. A systematic review of blockchain scalability research was conducted using three primary databases: ACM, Science Direct, and IEEE. The review examined the state of the art in blockchain scalability, identifying the most important research trends and challenges. The solutions that have been established can be categorized into two main groups: those that pertain to block storage and those that pertain to the underlying blockchain mechanism. Numerous solutions were suggested for each main group. The most common proposed solutions for improving the scalability of blockchain networks in the literature are improving the consensus algorithm and using sharding. Most of the solutions were proof of concept and need more investigation in the future.**

Keywords—Blockchain; scalability; sharding; consensus algorithm

I. Introduction

Blockchain is another form of digital value exchange that has gained attention from different sectors [1]. The idea of blockchain was first introduced by Haber and Stornetta in 1991. Nakamoto later used blockchain in 2008 as the most well-known example: cryptocurrencies [2],[3]. This technology has found its way into various industries and applications, including banking, insurance, supply chain management, healthcare, identity verification, stock market analysis, IoT, energy, and intellectual property management. According to [4], the reasons for its popularity are its advantages, which include decentralization, security, immutability, efficiency, and transparency.

Despite the many advantages of blockchain technology, researchers and developers have identified several challenges and bottlenecks that need to be addressed before blockchain can be widely adopted, as [4] mentioned. Scalability is a significant challenge preventing the system from growing up. Scalability issue occurs for many reasons. According to [5], the main two are the blockchain mechanism and the block size.

To address this challenge, researchers and developers have made significant efforts to improve the scalability of blockchain technology [5]. Efforts can be categorized based on the areas they focus on. Some solutions aim to enhance the chain mechanism, while others, such as [6], concentrate on managing stored data.

This paper aims to review current blockchain scalability solutions and research trends systematically. This systematic literature review (SLR) briefly overviews blockchain technology and its scalability problems. The different ways blockchain scalability has been addressed and the results of performance evaluations of these solutions are categorized. The paper identifies several potential areas for future research on blockchain scalability, such as improving the consensus mechanism, using sharding, and off-chain scaling.

This systematic review article consists of seven sections. Section I specifically covers the introduction and significance of this review. Section II provides a background about the blockchain and the scalability challenge. This is followed by Section III, highlighting the related reviews and surveys conducted on this topic. Section IV underlines the reasons for conducting this review. The following is Section V, which highlights the methodology of this review, including the research questions, study selection, and the inclusion and exclusion criteria. The results of this study, including the answers to the research questions, are discussed in Section VI. Lastly, this article is concluded in Section VII.

II. Background

A. Blockchain

A blockchain is a chain of blocks that serves as a public ledger and contains complete records of all transactions committed [7], as illustrated in Fig. 1. The list of transactions in this chain expands as new blocks are added. This record of the list continues to grow.

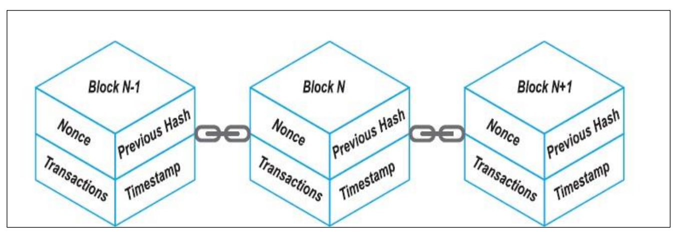

Fig. 1. A Standard structure of a blockchain [8].

Blockchain technology was first used in the field of cryptocurrencies in 2008. The success of blockchain technology in the world of cryptocurrencies has led other industries to explore and adopt it. The idea of blockchain was first introduced by Haber and Stornetta in 1991. Nakamoto later used blockchain in 2008 as the most well-known example, cryptocurrencies. This technology has found its way into various industries [12].

The success of blockchain technology is limited due to its inability to be implemented on a large scale [9]. In simple terms, scalability issues exist due to the limited block size and the current blockchain mechanism. This issue grows as the number of transactions increases, demanding additional nodes to maintain the network while also increasing the number of steps required for the transaction to travel and attain full consensus with every node. For instance, according to [10], Bitcoin, which utilizes the Proof of Work (PoW) consensus algorithm, has a peak limit of processing only seven transactions per second.

Blockchain systems have lower throughput and latency performance than non-blockchain system [11] . The number of transactions completed per second is called throughput [10], while the delay between making a blockchain data request and getting a response to that request is referred to as latency.

This scalability issue has been studied, and many solutions have been proposed to enhance the ability to scale up the blockchain, which will be tackled later. It is not easier to propose a scalability solution because the features of blockchain will be affected, like decentralization and security [12]. Therefore, creating a trade-off between the proposed solution and the other related aspects is necessary, as illustrated in Fig. 2. The proposed solution must provide a trade-off between scalability, decentralization, and security. These characteristics can be challenging to balance, but it is essential to consider them when making decisions.

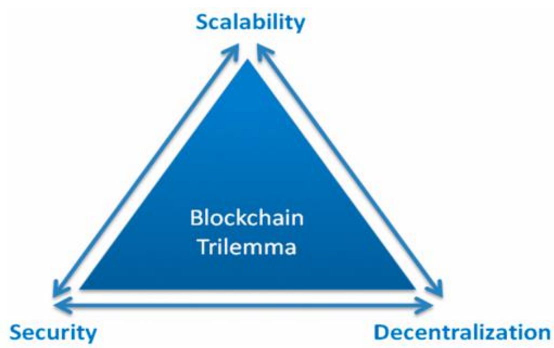

Fig. 2. Scalability trilemma [4].

III. Related Works

With the growth of blockchain in various sectors, warning bells ring about the scalability issue. As a progression of this issue, researchers have thoroughly probed into this problem, and tens of papers have been published regarding this issue. Furthermore, scalability issues have been widely investigated recently. Tens of papers were published on this bottleneck. Moreover, reviews and surveys were conducted on this issue. Table I illustrates the relevant reviews and surveys on this SLR. Some related works focused on a special domain like healthcare [13] or the Internet of Medical Things [14]. This paper thoroughly explores blockchain scalability issues in general and evaluates proposed solutions to determine their effectiveness in practice rather than just as a proof of concept.

IV. Reason for Conducting Systematic Review

The reason for doing this Systematic Review is the critical importance of the scalability challenge within the blockchain. Extensive research has been conducted, and numerous attempts have been made to address the issue. However, there is still a need for enhancing and discovering more efficient methods to enhance the scalability of the blockchain. Therefore, within this systematic review, we seek to highlight findings, identify gaps, and pave the way to discovering innovative, more effective methods to improve blockchain scalability. The output of this research may help to assist blockchain technology in evolving and changing, making it even more reliable, scalable, and flexible to meet the many demands of modern applications and industries.

V. Review Method

A systematic literature review identified, evaluated, and interpreted all available research related to a specific research question, topic area, or phenomenon of interest. The authors used guidance from [16], as a step and guide for doing the review, which served as a framework for their methodology. The goal of following this guidance was to ensure the review process was methodical and precise. The authors followed the suggested procedures, methods, and instructions in Fig. 3. An explanation for that will be provided.

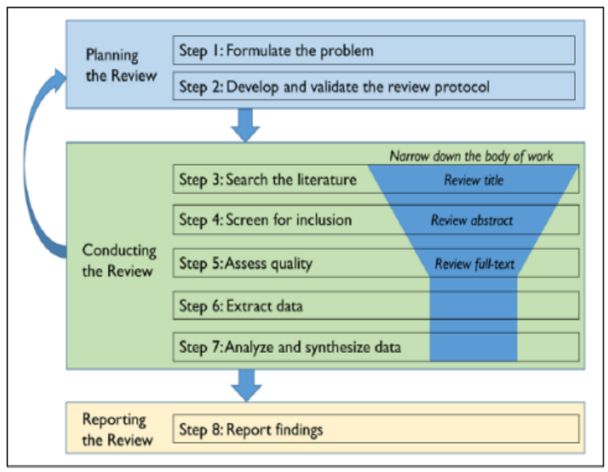

Fig. 3. Systematic review steps.

A. Research Question

The goal of this study is to investigate the scalability challenge of blockchain. The following research questions were formulated to conduct the investigation:

- RQ1: Where are the studies on the scalability of blockchain being conducted?

This research question aims to understand the current research and study trends on blockchain scalability.

- RQ2: How the scalability issues in blockchain have been addressed? What are the techniques and aspects used to address the scalability?

The second research question is to identify the current approaches and solutions by looking at the techniques and aspects used to solve blockchain scalability.

- RQ3: How did the proposed solutions succeed in achieving scalability?

The last research question is to evaluate the impact of prior efforts and pave the way for more effective and scalable blockchain systems in the future.

TABLE I. RELATED REVIEWS AND SURVEYS

Ref	Year	Title	Summary	Main Future direction
[12]	2021	A systematic review of blockchain scalability: Issues, solutions, analysis, and future research	In this review, the available solutions were categorized according to their performance in three areas: writing, reading, and storage.	This paper proposes integrating two or more scalability solutions to create a more effective and secure scaling solution. The goal is to enhance the read performance of the blockchain and optimize the query language. Additionally, it recommends implementing more robust cross-shard communication methods.
[14]	2021	A Survey on Blockchain-Based IoMT Systems: Towards Scalability	The survey presented the various factors that can affect a blockchain's ability to scale, whether directly or indirectly. Additionally, it categorized the potential solutions into two types: on-chain and off-chain.	• They recommend two methods to solve the scalability issue: either through on-chain or off-chain solutions.
[15]	2020	A Review on Scalability of Blockchain	• The review outlined the key approaches and technologies put out to address the scalability issue in the blockchain. • There are three primary factors that contribute to blockchain scalability bottlenecks. These include performance inefficiency, significant confirmation delays, and function extension limitations.	The review provided suggestions for further studies as below: • Studying a large-scale, high-performance peer-to-peer (P2P) network. Without advancements in network technology, enhancing the performance of blockchain systems will remain challenging. • A high-performance programmable computing engine is crucial for utilizing various smart contracts that are written in different programming languages.
[13]	2020	Scalability Challenges in Healthcare Blockchain System—A Systematic Review	• Defined the main reasons leading to healthcare scalability issues: the block size, huge amounts of data, the number of nodes, and the consensus protocol. • It provided a map of the main 16 proposed solutions according to the reasons. This review covers 16 solutions that fall into two main categories: storage optimization and blockchain redesign. There are three solutions for storage optimization and 13 solutions for blockchain redesign, including blockchain modeling, read and write mechanisms and bi-directional network.	**NA**
[16]	2022	Scalable blockchains — A systematic review	• This review classified the current solutions into solutions related to payment Channel Networks like lightning networks, sharding, blockchain delivery networks, hardware-assisted networks, Parallel Processing, and blockchain redesigning. • It highlighted the sharding as the main potential solution.	This review offers these recommendations.: • Developing new consensus algorithms. • Exploring the use of off-chain solutions. • Investigating the potential of sharding and sidechains to improve the scalability of blockchains. • Developing new metrics evaluate scalability of blockchains. • Investigating the impact of blockchain scalability on various application domains. • Developing new tools and frameworks to facilitate the development and deployment of scalable blockchain applications.
[4]	2021	Systematic Literature Review of Challenges in Blockchain Scalability.	• This review analyzed the main factors that affected the scalability of blockchain: the number of transactions per second, and the consensus mechanism and how it affects the scalability. • The review explores the on-chain and off-chain solutions to the scalability issue. Consensus algorithm and sharding were the most important solutions.	**NA**
[6]	2020	Solutions to Scalability of Blockchain: A Survey	The scalability problem with blockchain systems is discussed in this study along with a number of suggested solutions. Some of the suggested solutions include sharding, sidechains, cross-chain solutions, DAG-based solutions, and off-chain solutions including payment channels and state channels. These solutions are grouped into many typical blockchain layers. The authors also go through alternative consensus techniques and how they can help blockchain systems become more scalable, including Proof of Work (PoW), Proof of Stake (PoS), and Delegated Proof of Stake (DPoS).	Future work will involve building more effective and safer sharding approaches, researching the possibilities of off-chain solutions like payment channels and state channels, and examining alternative consensus mechanisms that might increase the scalability of blockchain systems. The authors also advise investigating the use of artificial intelligence and machine learning methods to enhance the functionality of blockchain systems. Finally, they advise looking into the possibility of combining blockchain with other cutting-edge technologies like edge computing and the Internet of Things (IoT).

B. Study Selection

Through a systematic review process, various research works have been found in published papers to explore the research trends and state-of-the-art advancements in blockchain scalability. The initial search used ACM, Science Direct, and IEEE databases. They were chosen based on the availability of these papers as full texts through the Universiti Teknologi Malaysia library. This phase was conducted by using the following search string: ("blockchain scalability" OR "scalable blockchain"), which is summarized in Table II. After conducting an initial search of the three databases, a total of 146 papers were found. These papers went through different stages of filtering, based on the criteria shown in Fig. 2. Finally, the 35 studies were reviewed to identify trends and advancements in blockchain scalability.

C. Inclusion and Exclusion Criteria

Inclusion criteria are established in the SLR to find papers related to the research goals. These standards guarantee that studies directly related to the study issue are included, whereas studies that do not conform to the established standards or are irrelevant to the research emphasis are excluded. The paper selection process is illustrated in Fig. 4. The main inclusion criteria for this study are:

- Being published in English.
- Being cited at least once.
- Describing the scalability issue on a blockchain.
- Providing solutions for scalability obstacles.

The exclusion criteria are:

- Papers that are written in another language rather than English
- Papers in which the concept is not described clearly.
- Do not specifically address scalability challenges in the blockchain.
- Papers that are not cited in other studies.

TABLE II. PAPERS SELECTION FROM THE DATABASES

Data Source	Documentation	
	No. of Articles Found on Primary Search	*Selected Articles*
ACM (Journal)	304	9
Science Direct	307	6
IEEE	109	20
Total	720	35
Total		35

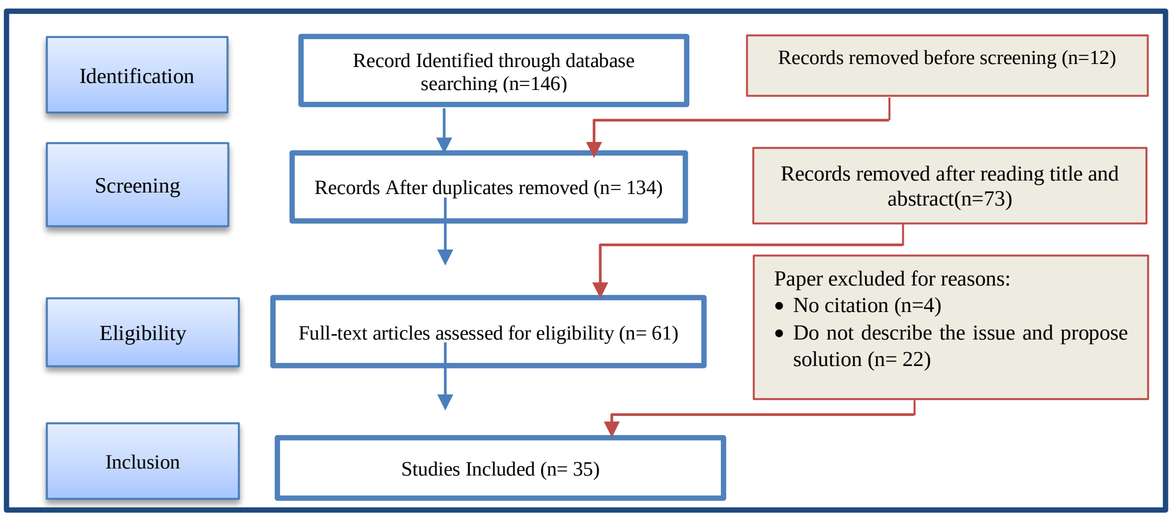

Fig. 4. Papers selection process.

VI. RESEARCH FINDINGS

In this section, we will discuss the results of our systematic review to answer the research questions listed below.

RQ1: Where are the studies on the scalability of blockchain being conducted?

The issue of scalability has captured the attention of researchers, resulting in the publication of numerous papers in both journals and conferences. These studies explained the reasons that lead to the scalability issue, and accordingly, Numerous techniques have been proposed to address the scalability problem in blockchain from various perspectives.

Previous reviews on this issue have commonly classified the solutions based on their relationship to the blockchain, distinguishing between on-chain and off-chain approaches. On-chain solutions primarily focus on improving scalability by modifying elements within the blockchain, while off-chain solutions prefer to conduct transactions outside the network [4] or based on the purpose or objective of the proposed solution [11].

The approaches presented in this systematic review were broken down into two groups: related to the Blockchain mechanism and related to block storage. The largest share of proposed solutions dealt with the mechanism of the blockchain, followed by those that dealt with block storage, as illustrated in Fig. 5.

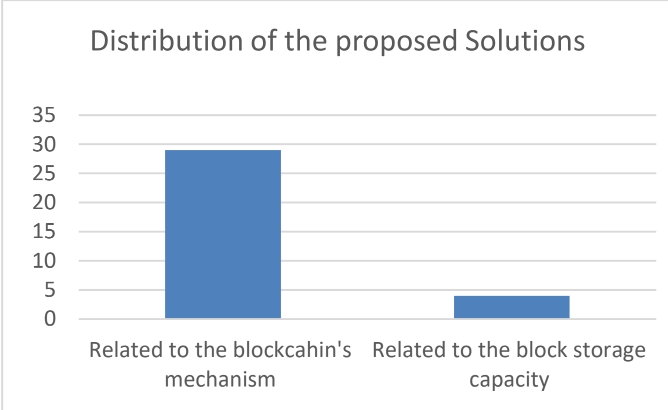

Fig. 5. Distribution of the founded solutions.

RQ2: How the scalability issues in blockchain have been addressed? What are the techniques and aspects used to address the scalability?

As mentioned previously, there are two main classifications in this systematic literature review. Under each main classification, several techniques were employed to address the issue of scalability. Fig. 6 illustrates the classification, whereas Fig. 7 illustrates the distribution of the proposed technique. The techniques found under each group are illustrated below:

A. *Related to the Blockchain's Underlying Mechanism*

1) Optimizing the consensus algorithm: The consensus protocol is a crucial component of blockchain that facilitates the creation of new blocks and the maintenance of the network. It involves reaching an agreement among network users on sustaining the network. The consensus protocol outlines the process for selecting the author of a new block [10].

Various applications have been implemented to utilize these techniques to improve the scalability of the blockchain. Based on the findings of this SLR, the consensus protocol is most frequently discussed to propose solutions to the scalability issue. Many studies concluded that the ineffectiveness of the consensus protocol primarily causes the main blockchains' scalability problems. So, to address the scaling issue, researchers have looked for novel consensus methods [4].

The consensus algorithm has been developed from different aspects: reducing the complexity [17], scaling according to the incoming traffic rate [18], and using checkpoints that allow the block to have its own hash chains to add more transactions [19]. The implementation results encourage more investigation and development to generate a better scaling rate. Table III shows the major consensus solutions found in this review.

2) Using sharding: The concept of sharding has gained popularity, particularly because it has been successfully applied in the field of databases in the past. It is becoming more well-known as one of the viable ways to improve blockchain performance [16]. Sharding has been used widely as a solution for scalability bottlenecks in the blockchain. It enables blockchains to expand effectively. Furthermore, it divides the workload across different subsets of nodes to handle different parts of the blockchain to reduce the overhead of consensus protocol [20] [21]. As a result, each node is no longer required to process the whole network's transactional load. Each node only stores the information relevant to the partition or shard responsible for it. Among all the other scaling solutions, sharding seems the most effective solution as it holds the core functionalities of blockchain with it. Each shard works like a separate blockchain network, operating completely as Satoshi Nakamoto envisioned a blockchain to work[22]. However, applying sharding to the blockchain presents several difficulties, and there are no fully prepared methods to increase the blockchain's scalability. For instance, security inside the sub-shards and the inter-shard communication method are issues [23]. Furthermore, researchers found a problem with sharding with the node generation process [24]. Finally, many shard-based solutions were proposed with different benefits for increasing the scalability of the blockchain. Many are still theoretical concepts that need real implementation for further evaluation, as is clear in Table IV.

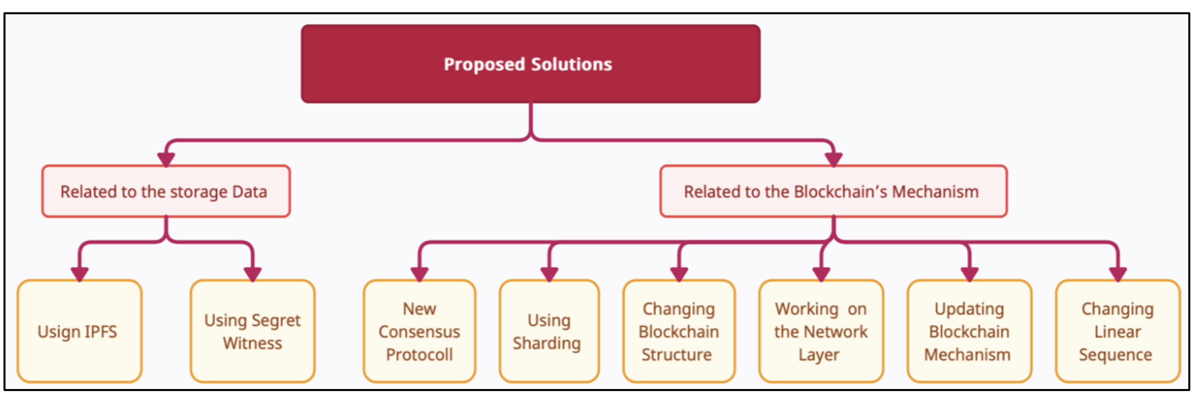

Fig. 6. Proposed solutions classifications.

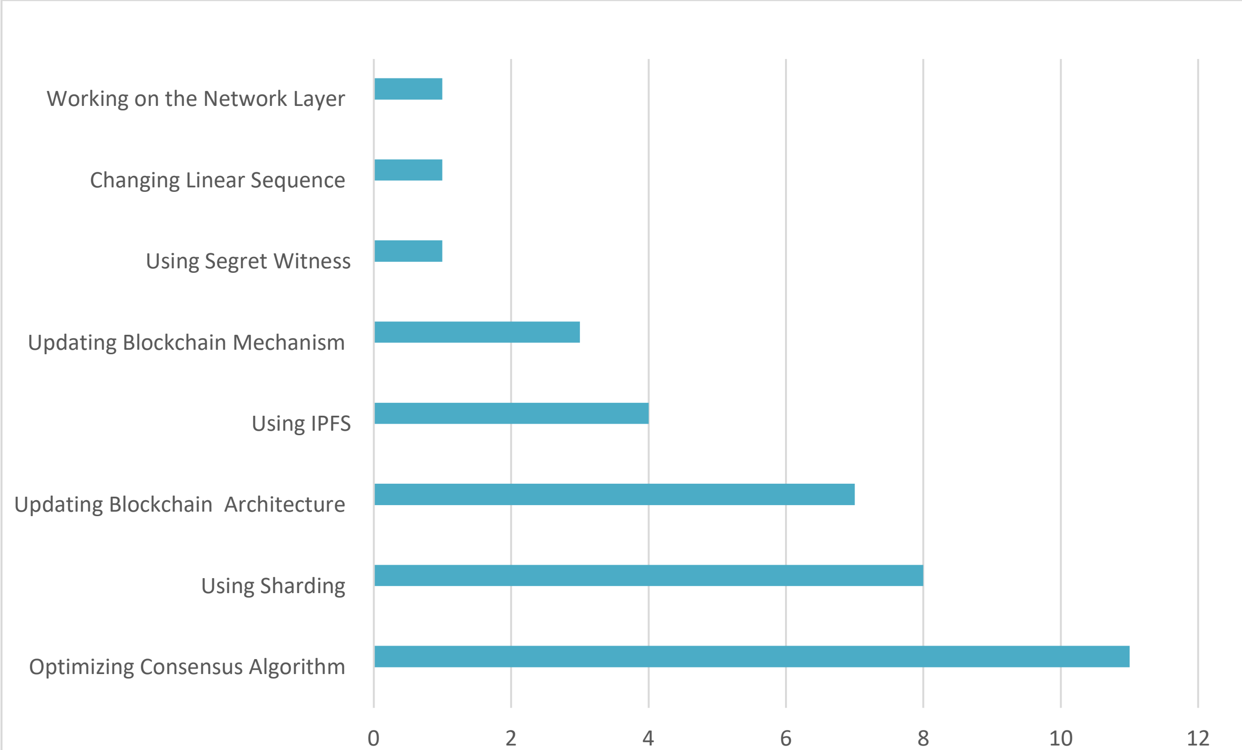

Fig. 7. The distribution of the proposed solution.

TABLE III. MAJOR SOLUTIONS BASED ON CONSENSUS ALGORITHM

Ref	Year	Protocol	Improve scalability by	Goal	Implementation	Results
[17]	2022	Byzantine Group Algorithm	Reducing the communication complexity	reducing complexity from $\boldsymbol{O(n^2)\ to\ O(n_2^3)}$	-	-
[25]	2019	Byzantine Fault Tolerant	Randomly select root	Selecting root randomly will reduce the mining time.	-	Providing constant latency
[18]	2021	Dynamic Proof of Work (PoW)	mining Scaling according to the IoT traffic	Checkpoint mechanism for mining that	NA	
[26]	2019	Byzantine Fault Tolerant	Reduce communication on each node	Cloud service integrated with the blockchain	-	-
[27]	2018	Delegate Proof of Stake (PoS)	Randomize delegated		-	-
[28]	2021	Hybrid protocol (Pow) and (PoS)	Transactions from external sources can be processed through this protocol, which then sends the final outcomes back to the main layer for storage in the distributed ledger.	The Hybrid Lightning Protocol can scale blockchain networks to handle more transactions.	√	maximized the throughput to 1,668,000 Transactions per second
[29]	2019	Distributed Time-Based consensus algorithm	Proposed algorithm that could minimize the processing overhead	To minimize the confirmation time	√	Successfully decreasing the processing time

TABLE IV. SUMMARY OF SHARDING-BASED SOLUTIONS

Ref.	Idea	Improve scalability by	Goal	Implementation	Results
[30]	Muti level sharding	Providing architecture for multi-level sharding and proposed a mechanism for interacting between sub-nodes	Enabling efficient cross-chain transactions in high scalability and extensibility.	NA	NA
[31]	Reducing the inter shard communication	Dividing the assignments, validation, verification, & storage responsibilities between nodes	Minimizing the need for inter-shard communication	NA	NA
[32]	Using the Verification Random Function	Utilizing a sharding strategy to share the random values created by participating nodes within a smaller group of nodes rather than directly among all node	Decreasing the computation and communication overhead	NA	NA
[20]	The scheme simultaneously achieves linear scaling in throughput, storage efficiency, & security.	Each node stores and computes in a coded shard of the same size that is generated by linearly mixing uncoded shards.	Achieving throughput efficiency as well as improving security.	Simulation	performing better than both uncoded Sharding and complete replication in throughput, storage optimization, and security.

3) Changing the structure of blockchain: The architecture of blockchain has a high computational complexity and needs a considerable amount of computing and storage space. These characteristics make it difficult to scale up. From that angle, many research studies proposed solutions to redesigning blockchain, like using a sub-chain [24]. Additionally, other researchers defined three types of blocks, and according to these types, block generation and consensus were updated [33]. However, this review observation shows that this solution has received relatively fewer citations. Therefore, we recommend conducting further studies soon to explore and investigate this area deeply.

4) Improving the scalability from the second network layer: Working on the network layer is an effective scaling option for blockchain. However, as it is an off-chain solution, it lacks the fundamental features of blockchain technology [22]. It became obvious how much scalability could be increased by using second-layer state channels [34]. The second layer channel works as an extra channel that can increase transactions per second and improve blockchain scalability by bypassing the consensus process.

5) Updating the blockchain mechanism: The suggested mechanism and solution focused on the activity inside the blockchain network, such as message passing between nodes. This reduced the amount of data held in each block and improved its scalability [35]. One way to achieve this is by altering the method of selecting the neighboring block [26]. The evaluation of these solutions shows better scalability in terms of reducing the time of confirmation.

6) Changing the linear sequence of the blockchain: Previous solutions have considered factors such as block size, block generation, and consensus. These solutions operate within the linear sequence of the blockchain network. Alternatively, altering the order of the block sequence may improve scalability [9]. Researchers suggested using a Directed Acyclic Graph-based blockchain model, which could enhance the scalability of large-scale networks [9]. A single solution was found in this review as a suggestion for enhancing the scalability. Furthermore, due to the limited amount of published experimental findings and open-source implementations, this solution needs more investigation in the future.

B. Related to Block Storage Capacity

One of the main factors affecting blockchain's scalability is the block storage capacity. This problem has been addressed with several proposals that try to expand the space available within blocks and permit more transactions. Here are some significant solutions that were discovered in this SLR:

1) Using Segregated Witness (SEGwit): Adding more space to the block allows more transactions to be done as SEGwit [36]. The concept involves restructuring transactions through forking, resulting in a four-fold increase in block size. Additionally, the block signature will be kept separate from the block, allowing for improved scalability and increased transaction capacity.

2) Using Interplanetary File System (IPFS): Many proposed solutions use InterPlanetary File System (IPFS) for storing data [37], while others use it for storing transactions [38]. One way to improve scalability is by using IPFS, which reduces the amount of data stored in a block by only including the hash value while the actual data is stored in IPFS. According to the analysis, this technology could play a significant role in scaling blockchain without affecting the core mechanism of blockchain [39].

RQ3: How did the proposed solutions succeed in achieving scalability?

This review found that the available studies have improved scalability by analyzing the factors that caused this obstacle. These factors were the block storage capacity and the mechanism of the blockchain. Most of the studies that suggested solutions could enhance scalability by dealing with these factors. Furthermore, some studies' initial results show incremental scalability improvement in throughput and latency. The studies contributed to enhancing scalability by analyzing the factors and providing theoretical-based solutions. The available solutions can serve as a roadmap for achieving improved scalability. Most of the studies still prove the concept, lacking implementation in real scenarios. Scalability bottlenecks in blockchain still need further investigation. Table V summarizes all the research articles included in this SLR.

TABLE V. SUMMARY OF THE SELECTED STUDIES

Library	Ref.	Aspect	Simulation	Implementation	Improve scalability idea	Domain
ACM	[40]	Scalable consensus algorithm (BFT) and integration blockchain into cloud-based services	√	×	reducing the intra-plant communication complexity from O(n2) to O(n).	Industrial Plant
	[17]	The new consensus algorithm for reducing the complexity	√	×	reducing the communication complexity from O(n2) to O(n32)	Commercial Blockchain
	[38]	Using IPFS	√	×	A theoretical manner for distributing transactions between on-chain and off-chain. Only the hash address is stored in the block, and using IPFS for storing the transactions.	Blockchain-base crypto computing
	[41]	New architecture	×	×	The maximum workload that may be handled varies with the number of nodes which increases the scalability by preventing broadcast in all cases	NA
	[9]	The DAG-based model includes greater scalability and lower transaction fees	×	×	Improving linear sequence and Separating the workload into a different level	NA
	[42]	New consensus algorithm : Proof of Property	×	×	Allowing participants to validate the transaction without downloading the complete blockchain which enhances the storage.	NA
	[21]	Using Sharding + enhancing consensus algorithm	√	√	The consensus protocol in each shard has been improved to achieve more than 3,000 transactions per second, resulting in increased effectiveness. This has been implemented across multiple shards.	NA
	[27]	Using randomize consensus algorithm for subchains	×	×	By using subchain technology, scalability is enhanced as it allows for additional blockchain nodes to become block producers and receive rewards.	NA
IEEE	[30]	Sharding	×	×	By facilitating efficient cross-chain transactions, multi-level sharding can be enabled to achieve high scalability and extensibility.	NA
	[43]	Using New architecture	√	×	Integrating with cloud storage for storing transactions to solve storage	NA
	[37]	Using IPFS	×	×	Improving scalability by utilizing IPFS to store patient records outside of the blockchain.	Medical Records
	[32]	Randomness protocol via sharding	×	×	Eliminating the use of heavy cryptography	Large-scale IoT applications
	[18]	Using new consensus algorithm	√	×	Using dynamic Proof Of Work consensus with checkpoint mechanism for mining Scaling according to the IoT traffic	Indusrtial Internet of Things
	[26]	Algorithm for choosing the block's neighbor	×	√	Reducing propagation time by 20-40%	NA
	[35]	using the data compression scheme	×	√	Reducing the data on the block by compression. Scalability improved by reducing the creation time .	Trading Platforms
	[33]	New Blockchain Architecture	×	√	Reducing the consensus complexity will lead to better scalability.	NA
	[20]	Sharding with Lagrange-Coded Computing	×	×	We are enabling scaling without increasing the number of nodes by reducing the node's storage workload and increasing the verification outside the system.	NA
	[44]	Blockchain Architecture	×	√	They are reducing the resource	Massive devices of

					utilization by updating the architecture for better scalability rate.	IoT
	[45]	Blockchain Architecture focuses on all layers	×	√	Reducing the storage need which operates via DHT	NA
	[25]	Consensus algorithm	×	√	Randomly selecting committees to improve on the quadratic message complexity	
	[46]	New Blockchain System	×	√	Reducing transaction storing by enabling SQL with Hadoop	Big Data
	[47]	Randomize the method for generation nodes by using master node technology	×	×	Raising the number of TP/S	Distributed Apps
	[24]	Scheme with the algorithm for node classification	√	×	Improving the way of nodes production	Information Blockchain
	[19]	Architecture for horizontal scalability	×	√	Delaying the transaction verification to increase the throughput by using checkpoint blocks which increase the number of created nodes.	NA
	[22]	Sharding	×	×	Enhancing the Sharding process by to be more effective and secure	NA
	[48]	Sharding with plasma	√	×	Increasing scalability by making the transactions process parallelly.	NA
	[34]	Second layer Network	×	×	Eliminating some of the transactions from the consensus process by passing their registration in the general ledger	NA
	[39]	IPFS	×	×	Decreasing the storing bloating issue by using IPFS	NA
	[31]	Sharding	×	√	Reducing Inter-shard communication	IoT
Science Direct	[28]	Hybrid consensus algorithm	×	×	Increasing scalability by doing validation and all transaction stored in the second layer and only the final transaction recorded in the first layer to raise throughput to 1,668,000 TP/S	NA
	[29]	Distributed Time Consensus algorithm	√	×	Reducing the mining time	IoT – smart home
	[49]	IPFS	×	√	Storing only the hash data in the block instead of the data itself	Medical Records
	[50]	Sharding + Microservice architecture	×	√	Increasing the throughput by decreasing the communication overhead	Big Data
	[51]	Architecture	√	×	Increasing throughput by splitting and payment to multiple channels.	Cryptocurrencies
	[52]	IPFS	×	×	Decreasing the propagation time	Electronic Health Records

VII. CONCLUSION

In this paper, a systematic review was conducted to define the state of the art on blockchain scalability issues. The researchers attempted to analyze the studies through the literature extracted from the three databases. Introducing a solution for blockchain scalability bottleneck is not a simple process due to the complexity of the blockchain architecture and the distributed nature. Thus, proposed solutions must provide a trade-off between keeping the blockchain scaling and keeping its robust features like the decentralization and security. The consensus algorithm is the most critical component developed by researchers. Moreover, the Proposed solutions show improved scalability regarding throughput and latency. Additionally, sharding techniques come second as a critical solution that could significantly enhance scalability. Finally, most of the solutions are still proof of concept, and the recommendation is to apply these solutions in real scenarios for the best investigation and analysis. Blockchain's scalability problem is a major obstacle to its widespread adoption. More research and better solutions must be developed to make widespread use of blockchain possible.

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