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On Blockchain Performance Enhancement: A Systematic Map of Strategies Used

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ABSTRACT

Blockchain technology is one among the recent innovations in the computing industry. Blockchains have gathered a widespread interest in the industry mainly due to their security promise. Despite the anticipated benefits of Blockchains, there are several limitations which make the technology less suitable in large scale applications such as banking, one being low throughput. Several initiatives to improve the throughput of Blockchains are being tried out both in the academia and the business worlds but no systematic classification of the initiatives and the strategies used has been done. This study explores Blockchain performance improvement initiatives and classify the initiatives by the improvement strategy used. This study has found that, out of 365 articles on the area of Blockchain performance, 300 were solution proposals aimed at improving the performance of Blockchains. The most used strategies in these proposals were alternative to PoW, sharding and multi-chain architecture.

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INTRODUCTION

Recent years have seen new computing technologies which form a new wave of innovations in the computing industry. This wave of innovations is referred to by some researchers as the 4th Industrial Revolution (Xu et al., 2018). Some of these technologies include Blockchain, Artificial Intelligence, Machine Learning, and Internet of Things. These technologies are set to introduce new products and services that will completely change the way humans work, communicate and live in general. Blockchains first appeared in an article published by Satoshi Nakamoto in 2008 titled "Bitcoin: A Peer-to-Peer Electronic Cash System". The article proposed a digital currency, Bitcoin (Cao et al., 2017). Blockchains have a potential to disrupt many other industries apart from payments, this includes healthcare, finance and Governments.

A Blockchain is a data structure that stores digital objects and their ownership history in a chronological order. The main characteristics of Blockchain technology are; use of distributed ledger, peer to peer network and use of cryptography. Two features that distinguish Blockchains from other data structures are its immutability and decentralized trust which makes it very secure. Immutability is the difficulty to change data once stored in a Blockchain. De-centralized trust removes the need for a central authority to verify and authorize transactions. Based on these features, Blockchains present an attractive solution in applications where security of the stored data is of high importance, for example the financial industry or health sector.

Apart from the security benefits of Blockchains, one downside of this technology is its low transactions throughput. Blockchain takes longer time to process and verify transactions compared to traditional financial systems. For example, Bitcoin Blockchain (the original Blockchain) takes about 10 minutes to process one block (a block has about 4200 transactions), which is equivalent to 7 transactions per second compared to the 2,000 transactions per second which can be processed by the Visa payment system (Yli-Huumo et al., 2016). This limitation of Blockchains make them less desirable in mainstream financial services such as banking and mobile payments which have to process millions of transactions each day. There exist several initiatives on the ground which try to address the performance limitation of Blockchains. This study reviews the literature on the area of Blockchain performance and creates a systematic map of the initiatives used for performance enhancement based on the strategies being used.

METHODS AND MATERIALS

Systematic mapping research methodology was used in this study. Systematic mapping is a review of literature on a specific area based on already existing primary studies (Kitchenham & Charters, 2007). The main goal of a systematic mapping studies is to provide an overview of a research area, and identify quantity and type of studies available in that area (Petersen et al., 2008). Figure 1 provides a schematic diagram of the systematic mapping process. In this research we used scientific databases as a source of primary studies used throughout the mapping process. Microsoft Excel was used for screening, aggregation, de-duplication, analysis and presentation of data.

Implementation

The mapping process was broken down into five (5) steps following guideline by Petersen et al. (2008). The steps were

i. Definition of research questions
ii. Searching for relevant papers
iii. Screening of papers
iv. Keywording and
v. Classification and mapping.

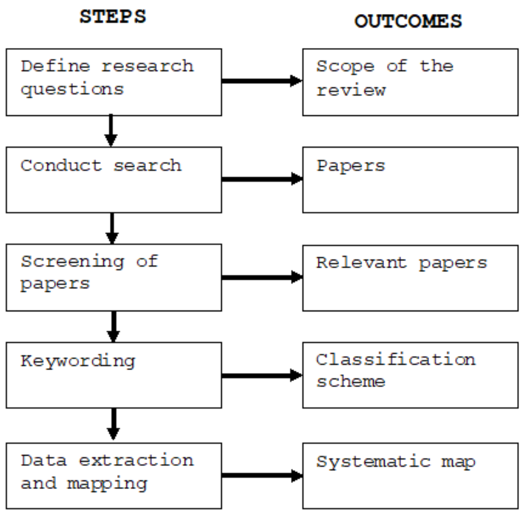

Figure 1: Systematic mapping process (Petersen et al., 2008).

Research questions

Based on the objective of our study, we defined three research questions:

- *RQ1*: What are the existing initiatives aimed at improving the performance of Blockchains?
- *RQ2*: Which strategies are used in these initiatives?
- *RQ3*: What strategies yield better performance?

Search for primary studies

The next step in our study was to search for primary studies on the research area. The primary studies were identified by searching for relevant papers in scientific databases. The search string was created by combining the words Blockchains, performance, throughput, enhancement and improvement. Wild cards were used to improve the search by including possible variations of the same word. Example, the words improve, improving and improvement were accounted for using one word improv*. Synonyms of the words were also considered e.g., improve, enhance and increase. After several searches and fine tuning, the final search string used was "Blockchain AND (Performance OR Throughput OR Speed) AND (Improv* OR Enhance* OR Increas*)". Four scientific databases, IEEE Xplore, Scopus, Web of

Science, and ACM Digital were used for this study as they are reputed to be the best repositories for peer-reviewed studies in computing. A total of 2,705 papers (IEEE Xplore (941), Scopus (482), Web of Science (256), and ACM Digital (1,026)) were retrieved from the search process.

Screening of papers

After searching and retrieval of the papers, the next step was to screen the papers in order to remain with those most relevant to our study. We employed screening method inspired by Dybå and Dingsøyr (2008) which uses inclusion and exclusion criteria to select relevant papers. There was one inclusion criterion which was, the title or abstract of the paper must mention performance, speed or throughput in relation to Blockchains. The exclusion criteria excluded papers that appears repeatedly in more than one database (only one kept), papers that are not in English language, and papers that are referencing Blockchains in other context such as applications. The screening process started with 2,705 papers, at the end of the process we remained with 365 papers which were passed to the next step.

Keywording

Keywording was used to create categories for classifying studies based on the strategies used to enhance performance of Blockchains. Keywording was done in two steps adopting the procedure set out by Petersen et al (2008). In the first step we read the abstract and extracted keywords that are relevant to this research. The second step was to combine the identified keywords to create more broader categories that will be used for classification. For articles whose title and abstracts could not give meaningful keywords, we used the introduction or conclusion sections of the articles. Figure 2 summarizes the key wording process used to create the classification categories also called the classification scheme.

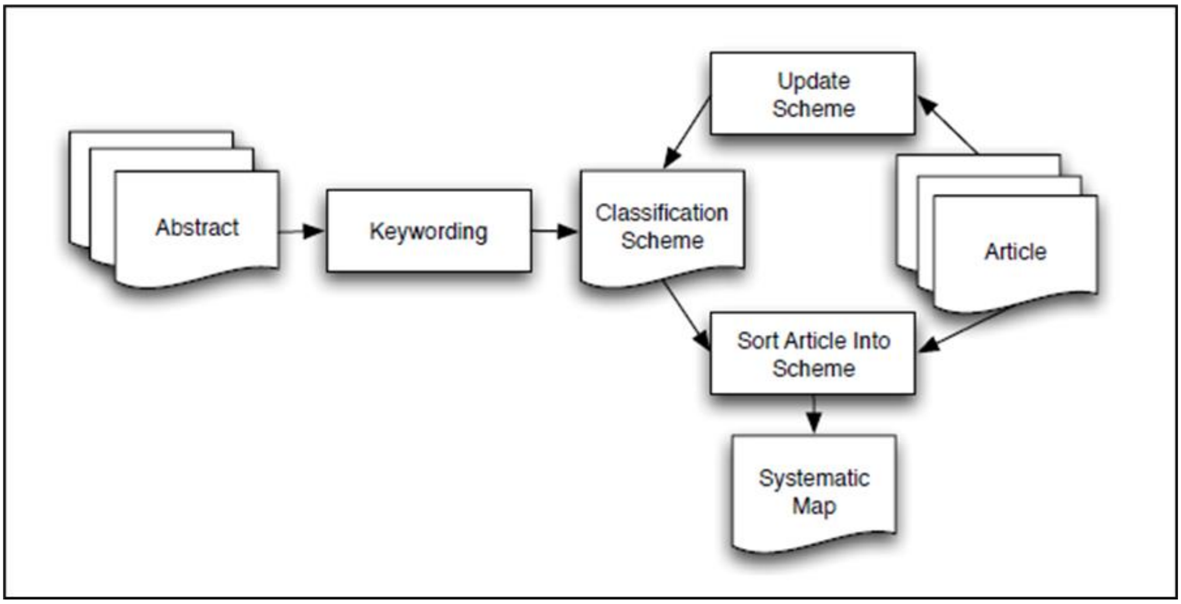

Figure 2: Building classification scheme (Petersen et al., 2008).

The classification process used 365 articles retrieved from the search and screening process. Each paper was assigned a category based on the strategy used to enhance performance in the study.

Data extraction and mapping

Excel spread sheet was used to process and analyze the collected data. The results were presented as a number of publications for each performance improvement strategy. Table 1 summarizes the mapping results.

Table 1: Systematic map

Category	Paper Count
Consensus Algorithm	147
Multiple Chains	41
Performance Evaluation	39
Sharding	30
Technology Analysis	20
Transaction Processing	20
Cryptography	10
Transaction Dissemination	10
Caching	7
Review Paper	6
Transmission Network	6
Block Propagation	5
Architecture Redesign	4
Block Size	4
New Blockchain Development	4
Storage	4
Deep Reinforcement Learning	2
Memory	2
Message Transmission	2
Artificial Intelligence	1
Cloud Computing	1
Total	**365**

FINDINGS AND DISCUSSION

In this section we discuss the results and answer the three main research questions. The limitations of this study are also discussed.

RQ1: What are the existing initiatives aimed at improving the performance of Blockchains?

The results of this mapping study shows that there is quite a number of initiatives aimed at improving the performance of Blockchains, both in the business world and the academia. Using 4 scientific databases, we were able to get 365 peer reviewed articles on the area Blockchain performance. IEEE Explore had most of the articles (184), followed by Scopus (115), Web of Science (14) and ACM Digital (52). Figure 3 summarizes the evidence of literature on Blockchain performance enhancement. Of the retrieved studies, 300 were solution proposals that proposed strategies to improve the performance of Blockchains. The remaining 65 studies did not propose an actual solution but either conducted a performance evaluation on Blockchains or performed analysis of Blockchains as a technology in general.

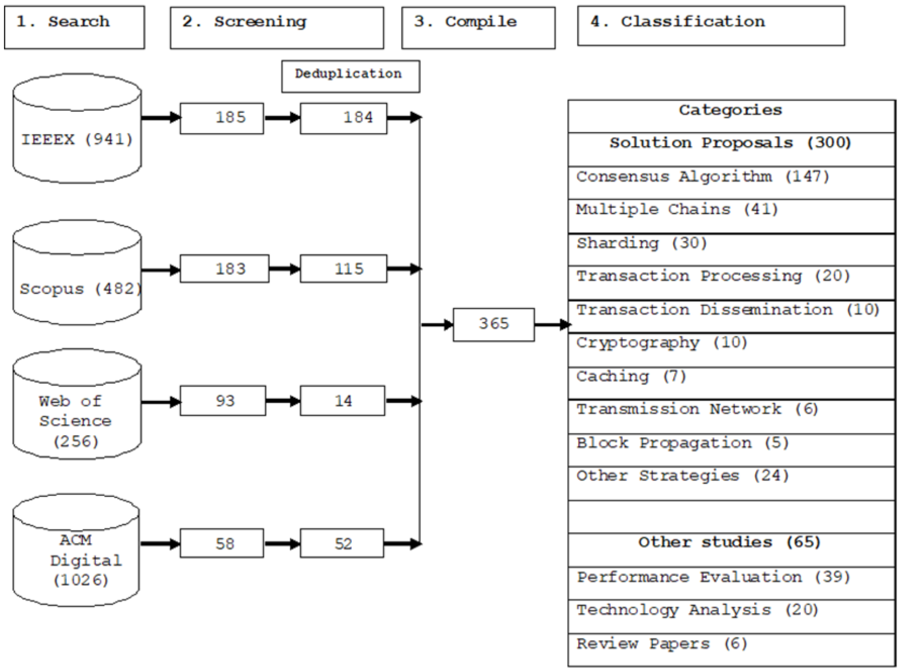

Figure 3: Articles on blockchain performance enhancement

RQ2: Which strategies are used in these initiatives?

Results from the mapping process shows that there are some common strategies used in the enhancement of Blockchains performance. Most of these strategies proposes improvement on the Blockchain architecture specifically on the four major components of the architecture; the database, peer to peer network, consensus algorithm and cryptography. The most common strategy for improvement of Blockchains performance was proposing alternative to PoW (147 articles), followed by use of multiple chains (41), and sharding (30). In most of these studies, a framework, algorithm or a simulation was created to showcase the achieved performance improvement. The next sections describe the most common performance improvement strategies

Alternative to PoW: A consensus algorithm is a procedure through which nodes in the Blockchain network can verify transactions and reach a common agreement on the state of the distributed ledger. The first Blockchain application, Bitcoin, uses proof of work (PoW) as its consensus protocol. This consensus protocol is energy and time-intensive relative to other popular transaction protocols. Therefore, most of the initiatives exploit this limitation and propose alternate consensus protocols. A number of consensus algorithms have been developed since PoW, some of the most popular ones include Proof of Stake (PoS), Proof of Quality Factor (PoQF), Proof of Proximity, Byzantine Fault Tolerance (BFT), Practical Byzantine Fault Tolerance (PBFT), Proof of Value (PoV) and Proof of Event.

Multiple Chains: Most Blockchains are implemented such that blocks of transactions are arranged linearly or in one-dimension. Some of the initiatives to improve Blockchains performance proposes arranging block of transactions in two or more dimensions, that is multiple chains. Multiple chains are expected to reduce transaction verification time hence improves the overall Blockchain performance.

Sharding: Sharding is partitioning of a Blockchain network to limit the computational and storage workload. This prevents nodes from processing the entire network's transactional load but only transactions in its partition, or shard. The information contained in a shard can still be shared among other nodes, which keeps the ledger decentralized. Sharding helps to reduce latency or slowness of Blockchains enabling them to process more transactions per second.

Transaction dissemination: Blockchains use peer-to-peer network architecture, that is all nodes can communicate directly and share data with other nodes without going through an intermediary. Some initiatives propose performance enhancement of Blockchains by improving this node-to-node communications. One example of the proposal is implementation of bandwidth-informed neighbor selection.

Transaction Processing: These are initiatives which proposes to redesign Blockchain architecture in order to reduce inherent delays in transaction processing. Examples include reducing I/O overheads, address checking delays and reducing the size of the broadcast domain.

Cryptography: Blockchains uses cryptography to secure user identities (public/private keys) and secure the transactions (hashing). Some initiatives try to improve the performance of Blockchains by reducing inefficiencies on the cryptography aspect of Blockchains i.e., PKI certificates issuing time and hash quality.

RQ3: What strategies yield better performance?

In this context, the most effective strategy is considered to be the one that resulted to a higher throughput increase on a platform than it originally was. To achieve this objective, we selected several studies in which throughput values before and after intervention were provided. The effectiveness of the strategies was documented and summarized on Table 2.

Table 2: Comparing performance enhancement strategies effectiveness

Initiative/Project	Strategy	System/ Protocol	Improvement
Validating Pairwise Transactions (Dos Santos et al., 2018)	Block size & in memory processing	Bitcoin	52%
K-Bucket (R. Wang et al., 2019)	Consensus algorithm	Raft	41%
Proof of Event and Location (Nurfatih et al., 2020)	Consensus algorithm	Proof of Event	17%
Scalable Byzantine Fault Tolerance (Golan Gueta et al., 2019)	Consensus algorithm	Byzantine Fault Tolerance	100%
Accelerating Blockchain Transfer System Using FPGA-Based NIC (Sakakibara et al., 2018)	Multiple chains	Bitcoin	500%
Batched Chaincode Message (Lee & Sejin, 2020)	Message transmission	Hyper Ledger Fabric	50%
Fair and Efficient Gossip in Hyperledger Fabric (Berendea et al., 2020)	Message transmission	Hyper Ledger Fabric	900%
Secure Off-chain Payment in Consortium Blockchain System (L. Yang et al., 2020)	Multiple chains	Hyper Ledger Fabric	300%
Secure Balance Planning of Off-blockchain Payment Channel Networks (Li et al., 2020)	Multiple chains	Lightning Network	30%
Concurrent Consensus (Dai et al., 2019)	Multiple chains	Hyper Ledger Fabric	300%
CoDAG (S. Yang et al., 2019)	Multiple chains	Ethereum	2500%
OptChain (Nguyen et al., 2019)	Sharding	OmniLedger	50%
Sharding Open Blockchains (Tao et al., 2020)	Sharding	Ethereum	620%
FastChain (K. Wang & Kim, 2019)	Transaction dissemination	Bitcoin	40%
Optimizing Validation Phase (Javaid et al., 2019)	Transaction processing	Hyper Ledger Fabric	100%
ABACUS (T. Wang et al., 2020)	Transaction processing	IOTA	200%
Parallel Hash-Mark-Set on the Ethereum Blockchain (Painter et al., 2020)	Transaction processing	Ethereum	540%
Improvement of Ordering and Endorsement Phase (Kwon & Yu, 2019)	Transaction processing & Consensus algorithms	Hyper Ledger Fabric	20%

From Table 2 it is seen that the performance improvement achievable can go to as high as several hundred percent. The improvement seems to be moderate for the case of alternative to PoW (17 – 100%) and higher for some other strategies example Message Transmission, Sharding (620%) and Caching (500%). These figures cannot be used to conclusively rate the effectiveness of the strategies because other factors such as baseline platform/protocol used plays a role in arriving to the figures. For example, Hyper

Ledger Fabric has a throughput of up to 3,000 TPS, its relatively difficult to get high percentage improvement compared to Ethereum platform with up to 15 TPS. Some studies have used more than one strategy for performance enhancement. In the study by Dos Santos et al (2018), two strategies, one to increase block size and the second to use in memory processing were used. This combined strategy has improved the performance of the Bitcoin Blockchain to 374 TPS. In another study a model was developed which uses self-referencing Directed Acyclic Graph (DAG) structure and voting based PBFT consensus algorithm. This combined strategy has improved the performance of the Bitcoin Blockchain to 1,400 TPS.
It should be noted that the effectiveness comparison of these strategies only considered throughput increase while leaving out other aspects that might have been affected such as security of the platform. This opens a door for an area of future research that will analyze the effectiveness of the performance enhancement strategies in consideration of other factors such as security.

Limitations to the study

This study started with 2,705 papers, after screening and de-duplication these were trimmed down to 365 papers. As this task was done manually, there are chances of inaccuracies being introduced in the selection and classification process. The primary studies used in this research were conducted in different environments, using different settings and different technologies. It is therefore possible that the results were affected by the settings that a study was subjected to.

CONCLUSION

Blockchain technology holds a promise to revolutionize the way data is stored and consumed due to its strong security features. This promise will benefit many industries in which security of data stored is of high importance for example in the financial and health sectors. Besides these potential benefits, Blockchains have several limitations one of them being low throughput. Several initiatives are currently being implemented to improve the performance of Blockchains. This study was set out to explore existing initiatives, improvement strategies used in the initiatives and their contribution to the quest for performance improvement. The study has found that there is a number of ongoing research and projects aiming at improving the performance of Blockchains. Several strategies are used in these initiatives the most common being providing alternative to PoW, followed by sharding and use of multiple chains. The study has also found that there is a need for an in-depth analysis on the effectiveness of these strategies as an area for future research.

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