Bulletin of Electrical Engineering and Informatics
Vol. 14, No. 3, June 2025, pp. 2380~2392
ISSN: 2302-9285, DOI: 10.11591/eei.v14i3.9219

Comparative analysis of PoS and PoA consensus in Ethereum environment for blockchain based academic transcript systems

Palguno Wicaksono, Puspanda Hatta, Yusfia Hafid Aristyagama
Department of Informatics Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia

Article Info

Article history:

Received Sep 1, 2024
Revised Dec 21, 2024
Accepted Mar 25, 2025

Keywords:

Blockchain
Ethereum
Performance comparison
Proof of authority
Proof of stake

ABSTRACT

Many educational institutions worldwide now use blockchain to verify electronic document, often relying on Ethereum 1.0, which uses proof of work (PoW) or proof of authority (PoA). However, Ethereum 2.0, launched in 2022 by Ethereum Foundation operates on proof of stake (PoS). This study provides comparative analysis of PoS and PoA consensus in Ethereum environment specifically focusing on performance and scalability in the context of academic transcript databases. To demonstrate this, a student academic reputation information system was developed using two different blockchain technologies: Ethereum 1.0 with PoA and Ethereum 2.0 with PoS. This setup was used to obtain comparative analysis data for the two blockchain systems by measuring the throughput and latency. We observed how these platforms responded to an increasing number and frequency of transactions with Hyperledger Caliper. Results indicates that in performance testing, both consensus mechanisms exhibited. Scalability tests revealed that both consensus mechanisms experienced increased latency with higher loads. However, PoA system was superior in average throughput and latency than PoS system except in high transaction of data addition. The experiment result show that PoA system better than PoS system in context of academic transcript databases, making it more suitable to be implemented on that context.

Corresponding Author:

Puspanda Hatta
Department of Informatics Education, Faculty of Teacher Training and Education
Universitas Sebelas Maret
Ir. Sutami Street 36A, Kentingan, Jebres, Surakarta, Indonesia
Email: hatta.puspanda@staff.uns.ac.id

1. INTRODUCTION

The process of globalization, the transition to a digital economy, and the industrial revolution 4.0 affect the transition to a digital society, especially in the field of education. The COVID-19 pandemic has also stimulated the digital transition process by forcing everyone to do work using digital devices: learning online, working from home, and so on [1]. The digital transition causes a change in the form of publishing files or documents from paper-based to electronic documents. As a result, new issues arise concerning the legality and validity of issued documents. Proper document legalization and validation are essential for ensuring the authenticity of these documents. One common method of electronic document legalization is to include a digital signature, often represented as an image in files (such as PDFs). However, PDF files can be extracted using various tools [2], which means that signature images can be easily obtained and potentially misused by unauthorized parties. While digital signatures have been implemented in certain sectors like banking, there remains a misconception that they are merely images affixed to electronic documents, as illustrated in the previous example. This limited understanding of digital signatures can lead to legal challenges [3].

To address these issues, several educational institutions worldwide have started issuing electronic documents using advanced technology to verify their legality and validity. For example, the Massachusetts Institute of Technology (MIT) uses a system called Blockcerts for issuing electronic diplomas. Blockcerts leverages blockchain technology developed by MIT, combined with machine learning [4]. Similarly, the University of Rome Tor Vergata also employs Blockcerts, but operates on the Bitcoin blockchain. This system goes beyond just issuing diplomas; it has evolved into a comprehensive tool for recording a student's entire academic career. This approach aims to simplify bureaucratic procedures related to course repetitions or advancing to higher levels, thereby enhancing the ease and efficiency of academic record management. This situation is detailed in Table 1.

Table 1. Blockchain implementation in educational institution [5]

System name	Institution	Blockchain	Network type	Consensus	Consensus type
Certiblok	UNIR	Ethereum	Public	PoW	PoW (51%)
OpenDCert	UOC	Rinkeby	Public	PoW	PoW (51%)
Blockchain for Education	Franhoufer, University of Luxembourg	Ethereum	Permitted private	-	-
Blockcert	MIT, University of Nicosia, University of Rome, and University of Fernando Pessoa	Ethereum, Hyperledger, Bitcoin	Public, permitted private	PoA	-
BeCertify	IEBS Bussiness Schools	Europe chain	Permitted private	PoW	PoW (51%)
CRUE	Jaen Univ, and Extremadura Univ	BLUE	Permitted private	-	-
SmartCert	University of Al-Zaytoonah	Ethereum	Public	-	-
Smartdegrees	Carlos III Univ	Quorum	Permitted private	QuorumChain	Red T: QuorumChain Red B: PoW, PoA, eIBFT

The previously mentioned implementations have some limitations, primarily because many blockchain technology applications still use Ethereum 1.0, which is based on proof of work (PoW) [6] or Proof of authority (PoA). However, as of 2022, the Ethereum Foundation has launched Ethereum 2.0, which operates on proof of stake (PoS). This upgrade presents an opportunity to enhance blockchain-based systems by leveraging of PoS consensus, reducing the weakness of PoW consensus (transaction speed, transaction cost, and energy consumption) [7], [8].

By constructing and evaluating a decentralized application (dApp) for managing student academic records, this study conducts a comparative analysis of PoA and PoS consensus focusing on key performance metrics such as throughput and latency in the context of academic transcript databases. The findings aim to determine which consensus mechanism is better, contributing to the advancement of blockchain-based digital academic record management. This paper main contributions are summarized as follows: proposing blockchain technology as databases for academic transcript and shows comparative analysis of PoS and PoA consensus in Ethereum environment in the context of academic transcript databases using robust methodologies and metrics.

This paper will be structured as follows: section 2 reviews related works, highlighting key contributions and identifying gaps in the existing literature, section 3 introduces the Ethereum platform, explaining its core concepts and mechanisms. Section 4 details the design choices made in the implementation of the proposed system, including outlines the testing scenarios and parameters used to evaluate performance, section 5 presents the results of the testing, followed by an analysis of the findings, and section 6 concludes the paper with a discussion on the implications of the results and suggestions for future research.

2. RELATED WORKS

Research on the application of blockchain technology in the field of education has been explored in several studies. For example, Ouyang and Huang [9] designed an educational evaluation system utilizing their proposed blockchain-system, demonstrating reduced storage load compared to traditional systems. Similarly, Rahman *et al.* [10] developed a feedback system for faculty services that prioritizes user anonymity by implementing Ethereum in Goerli test network (using PoA consensus) and comparing with conventional database driven feedback system, resulting high levels of satisfaction of students chosen to use the system. Abdelsalam *et al.* [11] research improving reliability of online exam result using Ethereum (Ganache). Compared with normal system, the proposed system increases the level of transparency and reduce chance of failure.

Other studies focused on using blockchain for the authentication, verification, and validation of diplomas. Reddy *et al.* [12], Sakhipov *et al.* [13] created systems for securely and quickly storing and verifying diploma authenticity through a blockchain consortium involving universities and stakeholders. Another relevant study by Maestre *et al.* [5] used the BeCertify platform for certifying student skills. Kistaubayev *et al.* [1] building a decentralized apps for storing student achievement documents and high education registry using Ethereum, finding the operating costs of proposed system like gas fees and storage usage. Zheng [14] proposed e-portofolio evaluation system and evaluate the proposed system by implementing the system with Practical Byzantine fault tolerance (PBFT) and Raft consensus with variance of scenario test. The result is showing the variations of network throughputs with the change in the number requests. Chaniago [15] conducted research addressing the problem of fake academic credentials, utilized Ethereum blockchain technology to store transaction data as part of its development research methodology. From the results of the study, it was found that the transaction speed of the system built was 1 second for each transaction and if there was damage to the file, it led to the difference in the hash of the damaged file with the hash that had been stored in the blockchain. Unfortunately, Ethereum 2.0 research not widely done, especially in education field. We only found research in another field by Edgar *et al.* [16] implemented in SepoliaETH network (PoS consensus) for NFT land transaction, finding performance testing by observing transaction times of minting process.

A review of existing studies revealed that, many blockchain implementation in the field of education lack of evaluations on performance and scalability. Then, there is no comparative analysis of PoS and PoA consensus in Ethereum environment. This study fills a gap in the literature by evaluating the performance of PoS (Ethereum 2.0) and PoA (Ethereum 1.0) consensus mechanisms specifically in the context of academic transcript databases. Previous works have not provided a direct comparison of these two mechanisms within this specific application area, which this research aims to address.

3. ETHEREUM CONCEPT

The concept of blockchains and consensus protocols was introduced in 1982 and became popular with the advent of Bitcoin in 2009 [17]. The features that caused blockchain technology to become popular are as follows: incorruptibility and transparent [18], [19]. Ethereum, introduced by Vitalik Buterin, began as a decentralized computing platform allowing users to create, store, and execute smart contracts (known as dApp) [20]. Initially, Ethereum used PoW consensus, and PoA was used for testnets. All transactions are processed and stored on the Ethereum virtual machine (EVM), a virtual computer [21]. On the EVM, programs known as Ethereum smart contracts can be executed. These contracts are public and immutable, meaning their code cannot be updated. Smart contracts built on Ethereum are typically written in Solidity, a programming language specifically designed for writing smart contracts that run on the Ethereum network [22]. PoW consensus need high energy consumption because this protocol is based on the PoW of solving complex computational problems [23]. Computational problem solving requires huge energy consumption [24].

Ethereum 2.0, also known as Eth2 or Serenity, is a significant upgrade from Ethereum 1.0, designed to enhance scalability, security, and energy efficiency. This evolution involves transitioning from the PoW consensus mechanism of Ethereum 1.0 to PoS and introduces various architectural improvements to address previous limitations [20]. In PoS consensus, users are chosen to add new blocks to the blockchain based on the number of tokens they have staked and the duration of their stake, meaning those with more tokens and longer staking periods have a higher chance of being selected [25]. In Ethereum 2.0, stakers commit their Ethereum holdings into smart contracts as stake. If a staker fails to meet their validation responsibilities whether accidentally or maliciously they risk losing their staked Ethereum. Ethereum 2.0 introduces a new layer known as the consensus layer, implemented as the beacon chain. The beacon chain manages validator registration and organizes them into committees of at least 128 validators per epoch. Each committee includes attesters and attestation aggregators. Additionally, one validator is randomly chosen as the block proposer for each slot, with role assignments determined through the RANDAO process [20].

4. METHOD

Figure 1 shows the research framework for comparing the performance of PoA and PoS consensus. The process begins with the creation of a virtual machine (VM) on DigitalOcean to host blockchain nodes for both ecosystems. Smart contracts are deployed and tested on each network, and Hyperledger Caliper is used to generate and apply workload modules that simulate real-world transactions. Key performance metrics such as latency and throughput are measured for both ecosystems. The results are then analyzed to assess the comparative performance of PoS and PoA under the same testing conditions, providing insights into the scalability and efficiency of each consensus mechanism, detailed as follows:

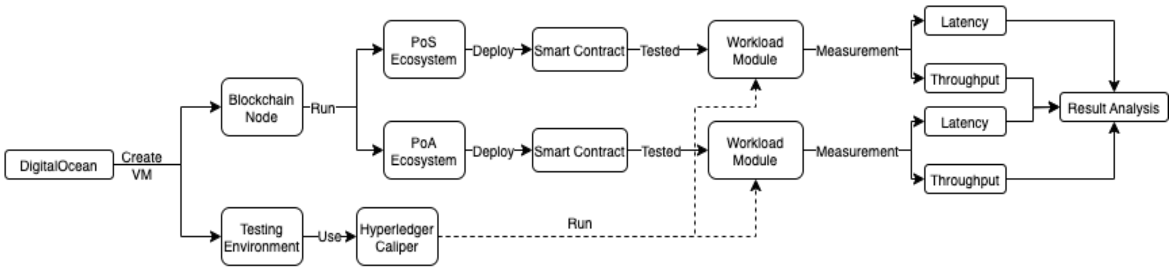

Figure 1. Research framework

4.1. System and network architecture

The network design is simulated using VM, facilitated by virtual private servers from the DigitalOcean cloud provider. Figure 2 is the design for the blockchain network to be constructed in this study. In this network, there are 5 (five) nodes acting as miners (authority holders) responsible for creating blocks and 1 (one) VM as testing environment. These 5 (five) mining nodes are connected in a peer-to-peer (P2P) connection. We assign identities to the nodes based on geographic locations—Kentingan, Pabelan, Manahan, Kleco, and Kebumen—to represent distinct network entities in this study. Although the testing is performed on a VM hosted by DigitalOcean, the node identities provide a real-world analogy to geographic locations. The identities and specifications of each node are described at Table 2.

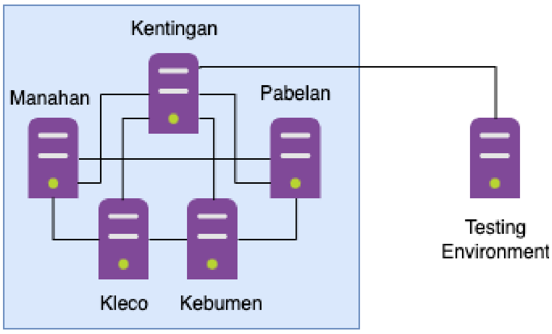

Figure 2. Network architecture

Table 2. Specification of nodes

Variable	Nodes					
	Kentingan	Pabelan	Manahan	Kleco	Kebumen	Testing environment
CPU (vCPU)	4	2	2	2	2	2
RAM (GB)	8	4	4	4	4	4
Storage (GB)	160	80	80	80	80	80
Location	NYC 3	NYC 3	NYC 3	NYC 3	SFO 3	NYC 1

The system architecture of each node shown in Figure 3. One VM functions as one node. Each VM is running the Debian 12 GNU/Linux operating system. Inside Debian 12 GNU/Linux, the Docker Engine is installed to create an isolated environment for running the blockchain software. For this research, geth used as the Ethereum 1.0 platform also as Ethereum 2.0 execution layer, and lighthouse is deployed as the beacon chain and validator platform. Because of different architecture, different configuration must be adjusted to ensure a balance between two system, shown at Table 3.

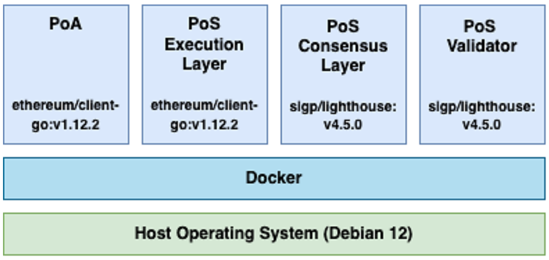

Figure 3. System architecture

Table 3. Configuration adjustment between PoS and PoA system

PoS configuration	PoA configuration	Value
Number of validators	Number of sealers	1 per node
Nodes	Nodes	5 nodes
Slot duration	Block period	5 second
Gas limit	Gas limit	30,000,000 wei

4.2. Use-case scenario: academic reputational system

The student academic reputation information system displays student achievement records and requires two access rights: admin, who can perform create, read, and update (CRU) operations on student identities, course lists and grades, internship history, and project history; and guest, who can verify student information without using their identity. For supporting the use-case scenario, smart contract must be developed and deployed at blockchain system. The list smart contract method can be seen at Table 4 and the smart contract code can be accessed on https://github.com/icaksh/smart-contract-PP2712801.

Table 4. Smart contract methods

Method		
Create	Update	Read
addStudent (P0)	setStudent (P4)	getStudentAcademicReputation (getSAR) (P8)
addCourseReport (P1)	setCourseReport (P5)	getSARForPublic (P9)
addInternExp (P2)	setInternExp (P6)	
addProject (P3)	setProject (P7)	

4.3. Parameter

In this study, performance of the system is based on two metrics of transaction: throughput and latency. Same metrics has been used by Ucbas *et al.* [26] for performance and scalability analysis of Ethereum and Hyperledger Fabric. Throughput and latency described as [26], [27]:

4.3.1. Throughput

Throughput is defined as T in (1) as the average number of successful transactions n_c inserted into the blockchain with t_f being the final test time and t_i being the initial test time when the performance test is conducted.

$$T = \frac{n_c}{(t_f - t_i)} \quad (1)$$

4.3.2. Latency

Latency is defined as L in (2) as the duration of time required to validate and record a transaction to the blockchain with t_c being the time the transaction is confirmed and t_s being the time the transaction is submitted.

$$L = t_s - t_c \quad (2)$$

4.4. Testing scenario

Testing blockchain systems is typically conducted using the benchmark test method. The benchmark test was conducted using a blockchain benchmarking application, Hyperledger Caliper.

Figure 4 shows the diagram of testing architecture of this study. Hyperledger Caliper installed on testing environment VM. Within the Caliper application, a single worker is assigned to act as a user of the system, responsible for executing transactions on the blockchain with a workload. In this study, the artificial workload, or input parameters, are derived from the Universitas Sebelas Maret (UNS) executive information system (EIS) for student numbers and the UNS open course ware (OCW) for course information.

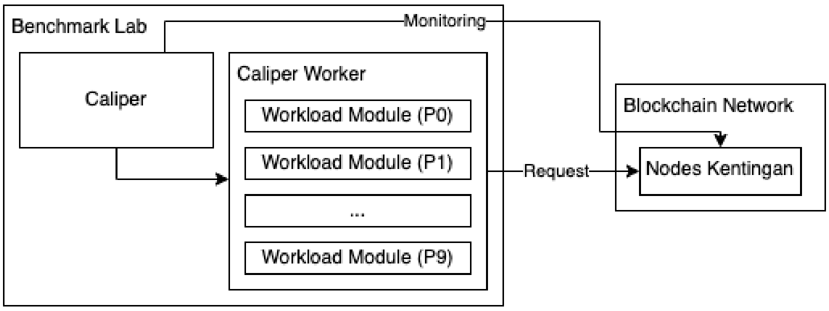

Figure 4. Diagram of testing architecture

4.4.1. Performance test

The performance test involves executing 100 transactions simultaneously for each smart contract method (Table 3) to be tested, using identical input parameters for both systems. The choice of 100 transactions is based on findings from a pilot test, which revealed that the maximum number of transactions in a single Ethereum block typically varies between 125 and 150 (calculated by gasLimit/(gasFee for 1 transactions)). The similar approach has been carried out by Christyono *et al.* [28] which shows that the average value of transactions that can be stored in one block is 113.3 transactions. It is important to note that in performance testing reliant on the internet network, network conditions may fluctuate, potentially impacting the results [26]. To prevent misleading conclusions from the data collected, each smart contract method is tested 5 (five) times to ensure the accuracy and reliability of the results.

4.4.2. Scalability test

The scalability test evaluates the system's performance as loads or transactions increase. This test involves creating 10 transaction sessions for each smart contract method (Table 3). In each session, the transaction volume is incrementally increased from 100 to 1,000, with an increment of 100 for each session. To prevent rejection transaction from Ethereum, we determine that send rate of transaction in scalability test is 100 per second. By gradually increasing the transaction volume, the ability of the blockchain to handle congestion and process transactions efficiently as the load grows can be assessed. Like performance testing, scalability testing is repeated 5 (five) times for each method session. The results are obtained by averaging the data from these repetitions. The final data for the scalability test includes the average throughput value and the average latency value for each session.

5. RESULT

5.1. Performance test

Based on Figure 5, in data addition operations, PoS has an average throughput that stabilizes between 12.84 and 12.94 transactions per second (TPS) across all methods, while PoA shows a variable average throughput ranging from 17.52 to 30.72 TPS. Additionally, PoS generally has higher latency compared to PoA. Overall, PoA performs better than PoS in handling data addition operations, both in terms of average latency and average throughput. In data alteration operations, PoS exhibits a stable average throughput ranging from 12.86 to 13.04 TPS. In contrast, PoA shows variable average throughput, ranging from 21.56 to 25.68 TPS. Similarly, PoS generally has higher latency compared to PoA. Thus, PoA outperforms PoS in handling data alteration operations.

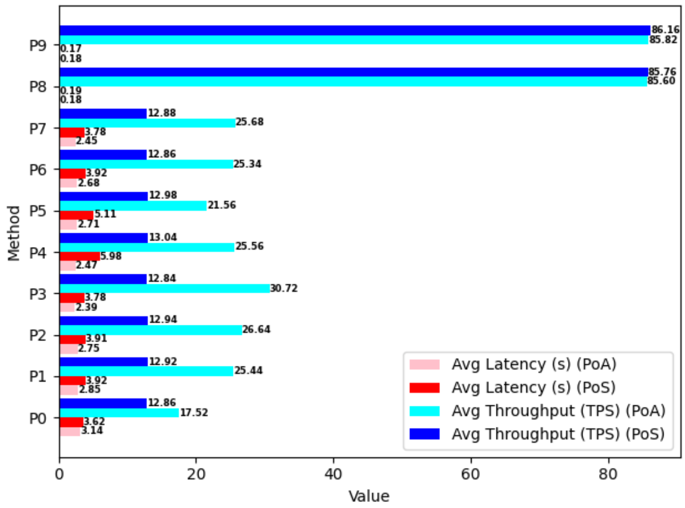

Figure 5. Performance test result

5.2. Scalability test

5.2.1. Data addition

Figure 6 is the result of scalability test in data addition for addStudent and addCourseReport method. In the addStudent method, the average latency value of the PoS consensus system rises from 6.08 at 100 transactions to 16.97 seconds for 1,000 transactions. In contrast, the average latency value of the PoA consensus system tends to vary, ranging from 4.70 at 100 transactions to 29.62 seconds for 1,000 transactions. Both systems show varying average throughput values with 13.66 TPS at 100 transactions to 25.38 TPS at 1,000 transactions for the PoS consensus system and 13.24 TPS at 100 transactions to 17.50 at 700 transactions for the PoA consensus system. In the addCourseReport method, the average latency value of the PoS consensus system increased from 5.95 at 100 transactions to 17.64 seconds for 1,000 transactions. The average latency value of the PoA consensus system also shows an increase, ranging from 3.36 at 100 transactions to 24.42 seconds for 1,000 transactions. Both systems show varying average throughput values with 13.66 TPS at 100 transactions to 24.64 TPS at 1,000 transactions for the PoS consensus system and 13.46 TPS at 100 transactions to 22.66 at 700 transactions for the PoA consensus system.

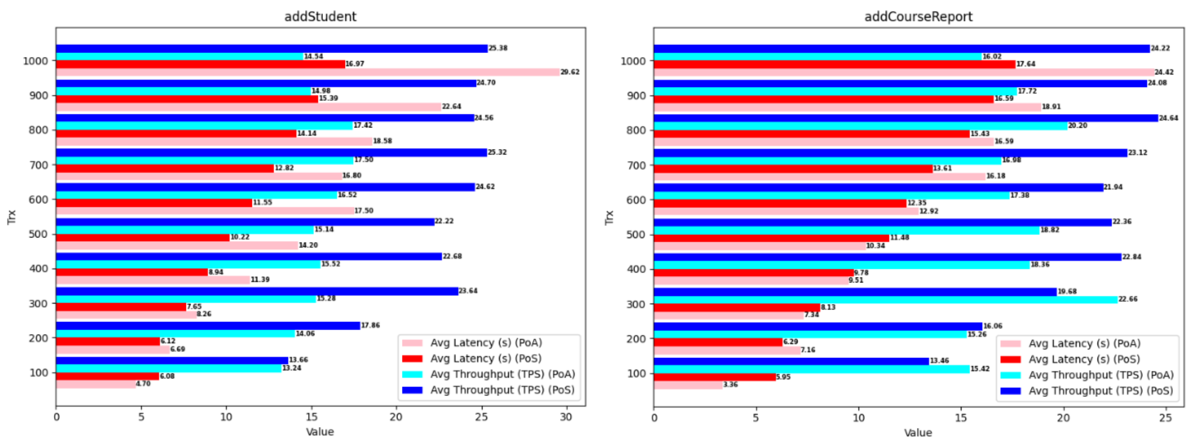

Figure 6. Result of scalability test (addInternshipExperience and addProject method)

Figure 7 is the result of scalability test in data addition for addInternshipExperience and addProject method. In the addInternshipExperience method, the average latency value of the PoS consensus system increases from 5.71 at 100 transactions to 16.77 seconds for 1,000 transactions. The average latency value of the PoA consensus system also shows an increase, ranging from 3.56 at 100 transactions to 19.98 seconds for

1,000 transactions. Both systems show varying average throughput values with 13.66 TPS at 100 transactions to 26.84 TPS at 1,000 transactions for the PoS consensus system and 13.58 TPS at 100 transactions to 26.02 at 500 transactions for the PoA consensus system. In the addProject method, the average latency value of the PoS consensus system increases from 4.55 at 100 transactions to 10.02 seconds for 1,000 transactions. The average latency value of the PoA consensus system also shows an increase, ranging from 3.49 at 100 transactions to 9.20 seconds for 1,000 transactions. Both systems show varying average throughput values with 13.10 TPS at 100 transactions to 44.00 TPS at 1,000 transactions for the PoS consensus system and 17.64 TPS at 100 transactions to 44.28 at 500 transactions for the PoA consensus system.

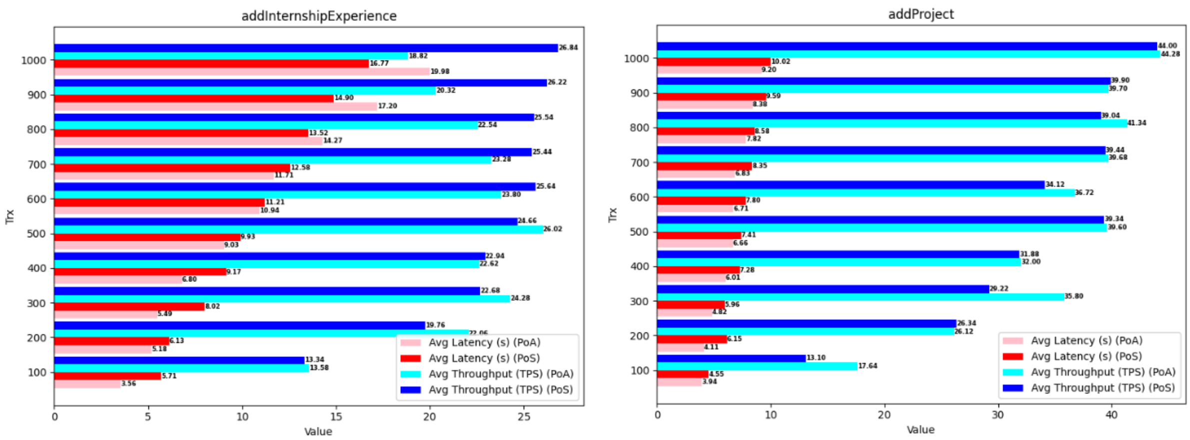

Figure 7. Result of scalability test (addInternshipExperience and addProject method)

5.2.2. Data alteration

Figure 8 is the result of scalability test in data addition for setStudent and setCourseReport method. In the setStudent method, the average latency value of the PoS consensus system varies from 5.42 for 100 transactions to 6.47 seconds for 1,000 transactions. The average latency value of the PoA consensus system also shows the same thing, with variations ranging from 3.69 at 100 transactions to 5.56 seconds for 1,000 transactions. Both systems show average throughput values that vary with 13.30 TPS at 100 transactions to 63.66 TPS at 800 transactions for the PoS consensus system and 21.30 TPS at 100 transactions to 64.04 TPS at 800 transactions for the PoA consensus system. In the setCourseReport method, the average latency value of the PoS consensus system varies from 5.86 at 300 transactions to 6.82 seconds for 100 transactions. The average latency value of the PoA consensus system also shows the same thing, which varies from 3.18 at 100 transactions to 6.22 seconds for 1,000 transactions. Both systems showed average throughput values that varied from 13.58 TPS for 100 transactions to 57.62 TPS for 1,000 transactions for the PoS consensus system and 18.06 TPS for 100 transactions to 57.04 TPS for 1,000 transactions for the PoA consensus system.

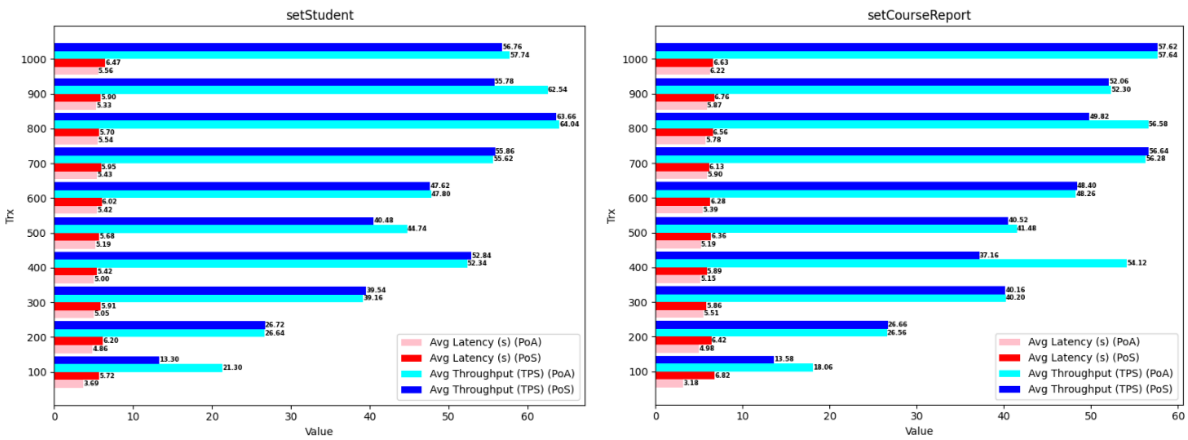

Figure 8. Result of scalability test (setStudent and setCourseReport method)

Figure 9 is the result of scalability test in data addition for setInternshipExperience and setProject method. In the setInternshipExperience method, the average latency value of the PoS consensus system varies from 5.60 at 400 transactions to 6.69 seconds at 100 transactions. The average latency value of the PoA consensus system also shows the same thing, which varies from 3.31 at 100 transactions to 5.54 seconds for 1,000 transactions. Both systems show average throughput values that vary from 13.54 TPS at 100 transactions to 60.76 TPS at 800 transactions for the PoS consensus system and 18.46 TPS at 100 transactions to 63.16 TPS at 800 transactions for the PoA consensus system. In the setProject method, the average latency value of the PoS consensus system varies from 5.53 at 400 transactions to 6.61 seconds at 100 transactions. The average latency value of the PoA consensus system also shows the same thing, which varies from 3.34 at 100 transactions to 5.04 seconds for 300 transactions. Both systems show average throughput values that vary with 13.32 TPS at 100 transactions to 67.22 TPS at 900 transactions for the PoS consensus system and 17.96 TPS at 100 transactions to 74.66 TPS at 800 transactions for the PoA consensus system.

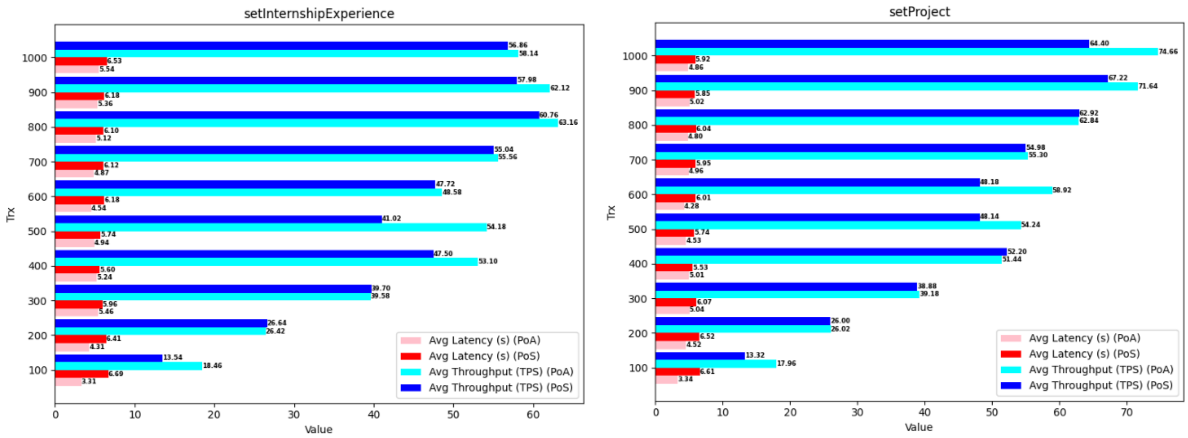

Figure 9. Result of scalability test (setInternshipExperience and setProject method)

5.2.3. Data read

Figure 10 shown the result of scalability test for data read from the system. There is no significant difference between PoS and PoA for handling read operations. However, during scalability testing, the average throughput of the PoS consensus blockchain system for getStudentAcademicReputation decreased to 91.10 TPS in 900 transactions, and a similar decrease was observed for getStudentAcademicReputationForPublic with 1,000 transactions.

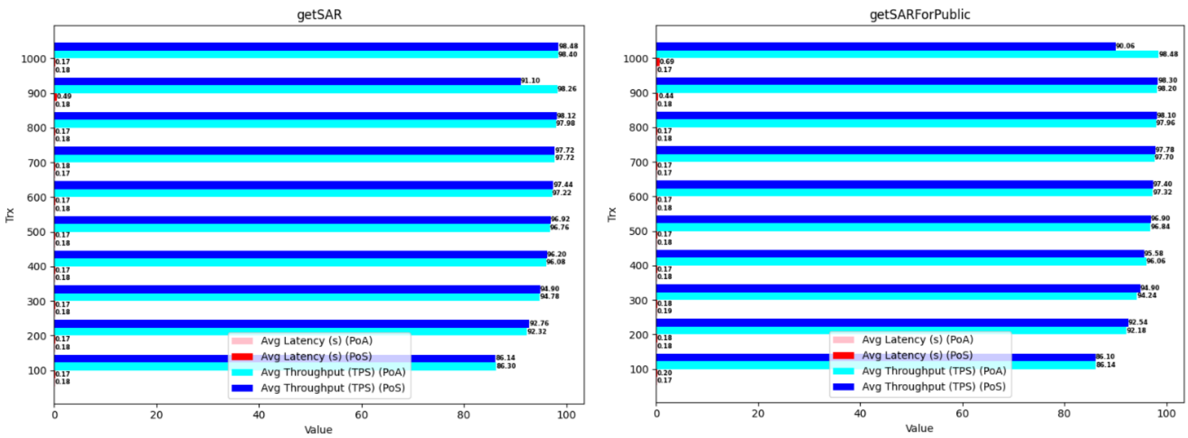

Figure 10. Result of scalability test (getSAR and getSARForPublic)

From the data analysis of the scalability test results, it can be summarized that the latency values for both PoS and PoA blockchain systems increase with the load. In the case of adding data to the blockchain, the increase in average latency is linear and stable. Conversely, when altering data on the blockchain, average latency varies with the number of transactions. Similarly, average throughput increases linearly and stably with data addition, while it varies with data alteration. We found that the increase of throughput and latency correlates with the study done by Gupta *et al.* [29] which comparing Ethereum PoW and PoA, Ucbas *et al.* [26] which comparing Hyperledger Fabric and Ethereum, and Zheng [14] which directly comparing the consensus of PBFT and Raft show the similar result that average throughput and latencies increases linearly and stably with data addition.

From the scalability test for the case of adding data to the blockchain, both consensus systems experience an increase in latency value due to the increasing transaction load. The PoA consensus system is better than the PoS consensus system when handling the addition of data with a low number of transactions, shown when transactions are low (100-500 transactions), the PoA throughput value tends to be higher than PoS. Conversely, the throughput value of the PoS consensus system is higher during high transactions (600-1,000 transactions) compared to the PoA consensus system. However, this does not apply to the addProject method where the average throughput value of the PoS consensus system is lower than that of the PoA consensus system. In data alteration, the PoA consensus blockchain system is better to the PoS consensus system when handling low-transaction and high-transaction.

Our findings indicate that the differences in average throughput and latency are influenced by the architectural complexity and consensus mechanisms of the two systems. In Figure 11, PoS consensus system requires a beacon chain for transaction validation, which need additional time while the PoA consensus blockchain system uses predefined sealers or validators [30]. Research by Asaithambi *et al.* [31] also indicates that PoS has higher block creation times compared to PoA, leading to increased latency and affecting throughput. In terms of data addition, the PoS consensus system exhibits better average latency compared to the PoA consensus system, largely due to the application of the sharding strategy in the PoS system [30]. From the experiment result, it can summarize that PoA system is better than the PoS system in the context of the academic transcript database, making suitable to be implemented in that context.

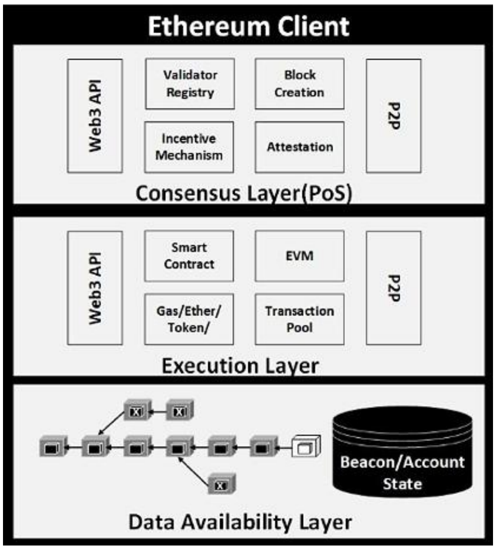

Figure 11. Architecture of Ethereum 2.0 [20]

6. CONCLUSION

This study aimed to evaluate and compare the PoS and PoA consensus mechanisms in the context of academic transcript databases within the Ethereum environment, determine which consensus mechanism is better. The evaluation was based on performance and scalability indicators, particularly focusing on average throughput and latency, which were tested across different transaction scenarios. The indicators conducted by examining the average of throughput and latency based on the number of transactions in testing scenario.

The results of this study show that, in terms of performance, the PoA consensus mechanism consistently achieves higher average throughput and lower average latency compared to the PoS mechanism, suggesting that PoA is more efficient at handling transactions under lower to moderate loads. In the scalability test, PoA consensus system showing the similar result, except in high load transaction for data addition. When tested under high transaction loads, particularly during data addition, the PoS system better than PoA. In these high-volume transaction scenarios, PoS showing higher throughput and lower latency than PoA. This difference arises because PoS, despite being more complex, able to process larger transaction volumes more efficiently, leading to lower latency.

Overall, while PoA performs better under low to moderate transaction load conditions, PoS proves more effective in scenarios with high transaction volumes, where it can process transactions more efficiently with lower latency. Therefore, the choice between PoA and PoS depends on the specific requirements of the system, requiring a balance between transaction speed and the ability to handle high transaction loads. However, to validate these findings further, additional research is needed, particularly to explore scalability under different conditions. This study only tested a single worker, which does not simulate real-world conditions where multiple requests are made simultaneously by multiple workers. Future research should consider varying the number of workers and send rate to obtain a more comprehensive and reliable understanding of the scalability and performance of both consensus mechanisms. Future research may use different the number of workers and different of send rate.

FUNDING INFORMATION

We would like to express our gratitude to the Institute for Research and Community Service at Sebelas Maret University for their generous funding support for this research (Research Contract Number: 194.2/UN27.22/PT.01.03/2024). We also appreciate the provision of essential resources that made this research possible.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Palguno Wicaksono	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Puspanda Hatta	✓	✓		✓		✓	✓	✓	✓	✓		✓	✓	✓
Yusfia Hafid Aristyagama		✓		✓			✓	✓	✓	✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY

The derived data that support the findings of this study can be obtained from the corresponding author, Puspanda Hatta, upon reasonable request.

REFERENCES

[1] Y. Kistaubayev, G. Mutanov, M. Mansurova, Z. Saxenbayeva, and Y. Shakan, "Ethereum-Based Information System for Digital Higher Education Registry and Verification of Student Achievement Documents," *Future Internet*, vol. 15, no. 1, Jan. 2023, doi: 10.3390/fi15010003.

[2] K. Wiechork and A. S. Charão, "Automated Data Extraction from PDF Documents: Application to Large Sets of Educational Tests," in *International Conference on Enterprise Information Systems, ICEIS - Proceedings*, Science and Technology Publications, Lda, 2021, pp. 359–366, doi: 10.5220/0010524503590366.

[3] M. N. Haikal and S. Mahmudah, "Implementation, advantages and barriers and legal protection against the use of electronic signatures," *Journal of Social Research*, vol. 3, no. 6, pp. 1179–1195, 2024.

[4] F. Vidal, F. Gouveia, and C. Soares, "Analysis of blockchain technology for higher education," in *Proceedings - 2019 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery, CyberC 2019*, Institute of Electrical and Electronics Engineers Inc., Oct. 2019, pp. 28–33, doi: 10.1109/CyberC.2019.00015.
[5] R. J. Maestre, J. Bermejo Higuera, N. Gámez Gómez, J. R. Bermejo Higuera, J. A. Sicilia Montalvo, and L. Orcos Palma, "The application of blockchain algorithms to the management of education certificates," *Evolutionary Intelligence*, vol. 16, no. 6, pp. 1967–1984, Dec. 2023, doi: 10.1007/s12065-022-00812-0.
[6] V. Sagar and P. Kaushik, "Ethereum 2.0 Blockchain in Healthcare and Healthcare Based Internet-of-Things Devices," in *Proceedings of the International Conference on Paradigms of Computing, Communication and Data Sciences*, Singapore: Springer Singapore, 2021, pp. 225–233.
[7] M. Chen, "Comparison on Proof of Work Versus Proof of Stake and Analysis on Why Ethereum Converted to Proof of Stake," *Advances in Economics, Management and Political Sciences*, vol. 12, no. 1, pp. 200–204, Sep. 2023, doi: 10.54254/2754-1169/12/20230624.
[8] Z. Hussein, M. A. Salama, and S. A. El-Rahman, "Evolution of blockchain consensus algorithms: a review on the latest milestones of blockchain consensus algorithms," *Cybersecurity*, vol. 6, no. 1, 2023, doi: 10.1186/s42400-023-00163-y.
[9] S. Ouyang and X. Huang, "Education Evaluation Management Based on Blockchain Technology," *Mobile Information Systems*, vol. 2022, pp. 1-6, 2022, doi: 10.1155/2022/7513365.
[10] M. M. Rahman, K. Saha, S. Islam, and S. Akhter, "Blockchain-based Teaching Evaluation System for Ensuring Data Integrity and Anonymity," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 10, pp. 783-789, 2023.
[11] M. Abdelsalam, A. M. Idrees, and M. Shokry, "A Proposed Model for Improving the Reliability of Online Exam Results Using Blockchain," *IEEE Access*, vol. 12, pp. 7719-7733, 2024, doi: 10.1109/ACCESS.2023.3304995.
[12] T. R. Reddy, P. V. G. D. R. P. Reddy, R. Srinivas, C. V. Raghavendran, R. V. S. Lalitha, and B. Annapurna, "Proposing a reliable method of securing and verifying the credentials of graduates through blockchain," *EURASIP Journal on Information Security*, vol. 2021, no. 1, Dec. 2021, doi: 10.1186/s13635-021-00122-5.
[13] A. Sakhipov, T. Baidildinov, M. Yermaganbetova, and N. Ualiyev, "Design of an Educational Platform for Professional Development of Teachers with Elements of Blockchain Technology," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 14, no. 7, 2023, doi: 10.14569/IJACSA.2023.0140757.
[14] Y. Zheng, "Design of a Blockchain-Based e-Portfolio Evaluation System to Assess the Education and Teaching Process," *International Journal of Emerging Technologies in Learning*, vol. 16, no. 5, pp. 261–280, 2021, doi: 10.3991/ijet.v16i05.21081.
[15] N. Chaniago, P. Sukarno, and A. A. Wardana, "Electronic document authenticity verification of diploma and transcript using smart contract on ethereum blockchain," *Register: Jurnal Ilmiah Teknologi Sistem Informasi*, vol. 7, no. 2, pp. 149–163, 2021, doi: 10.26594/REGISTER.V7I2.1959.
[16] S. Edgard, T. A. Napitupulu, and G. Wang, "Revolutionizing Land Administration in Indonesia: An Exploration of Ethereum-Based Private Blockchain for Transparent and Efficient NFT Land Transactions," *Journal of System and Management Sciences*, vol. 14, no. 10, pp. 350-363, 2024, doi: 10.33168/jsms.2024.1020.
[17] S. Joshi, "Feasibility of Proof of Authority as a Consensus Protocol Model," *arXiv*, Aug. 2021, doi: 10.48550/arXiv.2109.02480.
[18] M. A. Manolache, S. Manolache, and N. Tapus, "Decision Making using the Blockchain Proof of Authority Consensus," in *Procedia Computer Science*, vol. 199, pp. 580–588, 2021, doi: 10.1016/j.procs.2022.01.071.
[19] A. S. Mustafa, M. A. Al-Mashhadani, S. A. Jasim, A. M. Shantaf, and M. M. Hamdi, "Blockchain in fifth-generation network and beyond: a survey," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 3, pp. 1399–1408, 2022, doi: 10.11591/eei.v11i3.3209.
[20] X. Wu, Z. Zhou, and D. Song, *Learn Ethereum: A practical guide to help developers set up and run decentralized applications with Ethereum 2.0*. Birmingham: Packt Publishing, 2023.
[21] C. N. Samuel, S. Glock, F. Verdier, and P. Guitton-Ouhamou, "Choice of ethereum clients for private blockchain: Assessment from proof of authority perspective," *2021 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*, Sydney, Australia, 2021, pp. 1-5, doi: 10.1109/ICBC51069.2021.9461085.
[22] S. Crafa, M. Di Pirro, and E. Zucca, "Is Solidity solid enough?" *Financial Cryptography and Data Security*, Mar. 2020, pp 138–153, doi: 10.1007/978-3-030-43725-1_11.
[23] M. Wendl, M. H. Doan, and R. Sassen, "The environmental impact of cryptocurrencies using proof of work and proof of stake consensus algorithms: A systematic review," *Journal of Environmental Management*, vol. 326, Jan. 2023, doi: 10.1016/j.jenvman.2022.116530.
[24] N. Lasla, L. Al-Sahan, M. Abdallah, and M. Younis, "Green-PoW: An energy-efficient blockchain Proof-of-Work consensus algorithm," *Computer Networks*, vol. 214, Sep. 2022, doi: 10.1016/j.comnet.2022.109118.
[25] B. Lashkari and P. Musilek, "A Comprehensive Review of Blockchain Consensus Mechanisms," *IEEE Access*, vol. 9, pp. 43620-43652, 2021, doi: 10.1109/ACCESS.2021.3065880.
[26] Y. Ucbas, A. Eleyan, M. Hammoudeh, and M. Alohaly, "Performance and Scalability Analysis of Ethereum and Hyperledger Fabric," *IEEE Access*, vol. 11, pp. 67156–67167, 2023, doi: 10.1109/ACCESS.2023.3291618.
[27] G. Wang *et al.*, "BlockLoader: A Comprehensive Evaluation Framework for Blockchain Performance Under Various Workload Patterns," *Mathematics*, vol. 12, no. 21, Nov. 2024, doi: 10.3390/math12213403.
[28] B. B. A. Christyono, M. Widjaja, and A. Wicaksana, "Go-Ethereum for electronic voting system using clique as proof-of-authority," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 19, no. 5, pp. 1565–1572, 2021, doi: 10.12928/TELKOMNIKA.v19i5.20415.
[29] M. K. Gupta, R. K. Dwivedi, A. Sharma, M. Farooq, and B. R. S, "Performance Evaluation of Blockchain Platforms," in *2023 International Conference on IoT, Communication and Automation Technology (ICICAT)*, 2023, pp. 1–6, doi: 10.1109/ICICAT57735.2023.10263700.
[30] S. Fahim, S. Katibur Rahman, and S. Mahmood, "Blockchain: A Comparative Study of Consensus Algorithms PoW, PoS, PoA, PoV," *International Journal of Mathematical Sciences and Computing*, vol. 9, no. 3, pp. 46–57, Aug. 2023, doi: 10.5815/ijmsc.2023.03.04.
[31] S. Asaithambi, L. Ravi, M. Devarajan, A. S. Almazyad, G. Xiong, and A. W. Mohamed, "Enhancing enterprises trust mechanism through integrating blockchain technology into e-commerce platform for SMEs," *Egyptian Informatics Journal*, vol. 25, Mar. 2024, doi: 10.1016/j.eij.2024.100444.

BIOGRAPHIES OF AUTHORS

Palguno Wicaksono obtained his Bachelor of Education in Informatics Education's candidate at the Department of Informatics Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia. He can be contacted at email: pwicaksono@student.uns.ac.id or hello@icaksh.my.id.

Puspanda Hatta is a Senior Lecturer at the Department of Informatics Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia. Hatta received Bachelor of Computer Science from Universitas Sebelas Maret, Surakarta, Indonesia and Master of Engineering in Informatics System from Universitas Gadjah Mada, Yogyakarta, Indonesia. His research interests are primarily in computer network and cybersecurity. He can be contacted at email: hatta.puspanda@staff.uns.ac.id.

Yusfia Hafid Aristyagama is a Lecturer at the Department of Informatics Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia. He received Bachelor's degree in Informatics Engineering from Telkom University, Bandung, Indonesia and received Master of Electrical Engineering in Digital Media and Game from Institut Teknologi Bandung, Bandung, Indonesia. His research interests are primarily in computer graphics and computer vision. He can be contacted at email: yusfia.hafid@staff.uns.ac.id.