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A comparative analysis of selected blockchain consensus mechanisms and smart contract scalability impact

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Abstract

Blockchain technology promises decentralized applications but faces scalability challenges, particularly in smart contract execution. This study empirically benchmarks Ethereum's Proof-of-Stake (PoS) against Solana's Proof-of-History with Byzantine Fault Tolerance (PoH+BFT) by deploying identical smart contracts written in Solidity for Ethereum and Rust for Solana on public testnets and executing controlled simulations using standardized scripts. Performance was evaluated using Transactions Per Second (TPS), latency, and transaction cost under controlled conditions. Results show Solana significantly outperformed Ethereum, achieving 1,823 TPS versus 47 TPS, 0.9s latency versus 13.2s, and \$0.00025 average transaction cost compared to \$0.42, with lower CPU utilization (36% vs. 54%). These findings confirm Solana's technical advantage for high-throughput, low-cost applications, while Ethereum's ecosystem and stronger decentralization remain compelling for broader adoption. Overall, this research provides one of the first empirical smart contract-level comparisons between Ethereum and Solana, highlighting trade-offs between performance and decentralization, offering practical insights for developers and organizations, and contributing to cross-platform benchmarking, consensus mechanism evaluation, and blockchain scalability research.

Keywords: Blockchain scalability, smart contracts, ethereum, solana, performance evaluation

Introduction

Blockchain technology has emerged as a transformative innovation in the 21st century, offering a paradigm shift in how digital information is stored, managed, and transacted. Its core tenets of decentralization, immutability, and transparency have positioned it as a foundational technology for various applications, ranging from financial services to supply chain management and digital identity [1]. At its heart, a blockchain operates as a distributed ledger, maintained collaboratively by a network of interconnected computers. The integrity and consistency of this ledger are upheld through sophisticated consensus mechanisms, which dictate how participating nodes collectively agree on the validity and order of transactions. These mechanisms are not merely technical components; they are fundamental to a blockchain's performance, scalability, and overall security [2]. Within the rapidly evolving blockchain landscape, Ethereum and Solana stand out as two prominent platforms, each employing distinct approaches to achieve consensus and process transactions. Ethereum, a pioneer in smart contract functionality, has undergone a significant evolution, transitioning from a Proof of Work (PoW) consensus mechanism to a more energy-efficient Proof of Stake (PoS) model with its Ethereum 2.0 upgrade. This transition was primarily aimed at enhancing transaction throughput, reducing energy consumption, and improving finality [3]. In contrast, Solana has adopted a hybrid consensus model, ingeniously combining Proof of History (PoH) with a Practical Byzantine Fault Tolerance (PBFT) mechanism. This architectural choice has enabled Solana to achieve remarkably high transaction processing speeds, often reaching thousands of transactions per second [4]. The inherent differences in their architectural designs directly influence their respective scalability, operational costs, and the overall developer experience they offer.

Despite the burgeoning adoption and widespread recognition of blockchain technology, a critical challenge persists: scalability. This limitation is particularly pronounced at the smart contract execution level, where the processing of complex operations can be bottlenecked by the underlying blockchain's capacity. While a substantial body of research has explored theoretical scalability models and various consensus algorithms, there remains a notable dearth of empirical data directly comparing the real-world performance of major blockchain platforms. This gap in empirical evidence makes it challenging for developers, enterprises, and researchers to make informed decisions when selecting a blockchain platform for specific applications, especially those requiring high transaction volumes and low latency. The absence of comprehensive, comparative benchmarks hinders the optimization of decentralized applications and impedes the broader adoption of blockchain technology in performance-critical domains.

This study aims to conduct a comprehensive empirical analysis of selected blockchain consensus mechanisms, specifically focusing on Ethereum's Proof of Stake (PoS) and Solana's Proof of History (PoH) combined with Byzantine Fault Tolerance (BFT), to evaluate their impact on smart contract scalability. The overarching goal is to provide data-driven insights that can guide platform selection for decentralized application development. To achieve this aim, the following objectives have been established

1. To implement identical smart contracts on both Ethereum and Solana platforms to ensure a fair and equivalent basis for comparison.
2. To develop and execute standardized transaction load simulations to measure key performance indicators, including Transactions Per Second (TPS), network latency, and transaction costs.

3. To conduct a comparative analysis of the empirical performance data obtained from both platforms, highlighting their respective strengths and weaknesses in terms of scalability and efficiency.

The rapid expansion of blockchain applications into diverse sectors, including decentralized finance (DeFi), supply chain management, digital identity, and gaming, underscores the critical importance of platform performance. While theoretical discussions on blockchain capabilities are abundant, practical, empirical data on how different consensus mechanisms affect real-world smart contract scalability are scarce. This study directly addresses this void by providing a rigorous, comparative analysis of two leading blockchain platforms: Ethereum and Solana. The insights derived from this research will be invaluable for developers seeking to build high-performance dApps, for businesses evaluating blockchain solutions, and for researchers aiming to deepen their understanding of blockchain scalability challenges. By offering concrete performance metrics, this study facilitates more informed decision-making, ultimately contributing to the more efficient and effective deployment of blockchain technology.

This study focuses on the empirical comparison of smart contract scalability on Ethereum (PoS) and Solana (PoH+BFT) using controlled simulations. The scope is limited to measuring Transactions Per Second (TPS), network latency, and transaction costs under specific testing conditions. While efforts have been made to minimize external variables, the results are based on testnet environments and may not perfectly reflect performance on mainnets under all possible real-world conditions. Furthermore, the study does not delve into the broader economic or governance models of these blockchains, focusing primarily on their technical performance characteristics related to smart contract execution.

Related Work

Several studies have explored blockchain scalability and the impact of different consensus mechanisms. Researchers have conducted comparative analyses of PoW, PoS, DPoS, and BFT, evaluating their performance based on factors such as security, energy efficiency, transaction throughput, and finality (Narayanan *et al*., 2016) [1].

Zheng *et al*. (2017) [2] conducted a comprehensive study on blockchain architecture and scalability, highlighting that while PoW offers strong security, it struggles with low transaction speeds and high energy consumption. Their findings indicate that PoS-based networks such as Ethereum 2.0 improve scalability while reducing environmental impact (Zheng *et al*., 2017) [2].

Luo *et al*. (2018) [14] explored hybrid consensus mechanisms and proposed an adaptive approach where blockchain networks could dynamically shift between PoW and PoS depending on network conditions. This adaptive methodology aims to optimize transaction speed and energy consumption without compromising decentralization.

Casino *et al*. (2019) [15] examined the trade-offs between decentralization and scalability. They found that DPoS achieves high transaction throughput due to its limited validator model but introduces concerns over centralization. Their study suggests that BFT-based mechanisms, such as those employed in Hyperledger Fabric, offer rapid finality and high fault tolerance, making them suitable for enterprise environments.

Xu *et al*. (2019) investigated the role of layer-2 scalability solutions, such as the Lightning Network and Plasma. Their research showed that these solutions significantly enhance transaction throughput by moving computation off-chain while relying on the main blockchain for final settlement and security.

Singh *et al*. (2021) [17] analyzed hybrid consensus models that combine PoW and PoS to achieve a balance between security and performance. Their study highlights the growing trend of multi-layered consensus protocols as a scalable and secure alternative to traditional models.

Bano *et al*. (2019) [18] provided a taxonomy of blockchain consensus mechanisms and evaluated their performance using security, scalability, and fault tolerance as benchmarks. Their study emphasized the need for context-specific consensus selection and identified practical challenges in performance tuning across decentralized platforms.

Rahouti *et al*. (2020) [20] conducted a large-scale comparative analysis of blockchain consensus algorithms, using simulated environments to assess throughput, latency, and fault tolerance. They concluded that deterministic models like PBFT outperform PoW and PoS in terms of latency but may face challenges with decentralization in public networks.

Elkazaz *et al*. (2021) [21] benchmarked Ethereum, Algorand, and Hyperledger Fabric in terms of smart contract performance using testbed experiments. Their findings show that execution time and cost vary greatly across platforms depending on block structure, consensus latency, and virtual machine design, reinforcing the importance of empirical platform-level evaluation.

While these studies provide valuable insights into blockchain scalability, few have empirically compared specific Layer 1 platforms such as Ethereum and Solana using smart contract simulations. Most existing research relies on theoretical models or network-level data, leaving a gap in performance-based, application-level benchmarking. This study aims to fill that gap by conducting a direct comparison of Ethereum's PoS and Solana's PoH+BFT mechanisms through simulated smart contract transactions on testnets.

Despite significant advancements in blockchain technology, several critical research gaps persist. These include the need for empirical performance comparisons of Layer 1 platforms, exploring scalability-security trade-offs in hybrid models, developing cross-chain interoperability, assessing real-world feasibility and adoption, evaluating energy efficiency and environmental impact, and examining economic incentive structures. Addressing these gaps through comprehensive research will be crucial for advancing scalable, efficient, and inclusive blockchain technologies.

Methodology

This study employs a comparative empirical research approach to evaluate the scalability and performance of smart contracts on two distinct blockchain platforms: Ethereum and Solana. The research framework is designed to isolate and measure the impact of their respective consensus mechanisms Proof of Stake (PoS) for Ethereum and Proof of History (PoH) combined with Byzantine Fault

Tolerance (BFT) for Solana on key performance indicators. The methodology emphasizes controlled experimentation to ensure the validity and reliability of the comparative analysis. The core idea is to simulate real-world transaction loads on both platforms using identical smart contract logic, thereby providing a direct and unbiased comparison of their operational efficiencies. The research process can be broadly divided into several stages: smart contract development and deployment, transaction simulation, data collection, and performance analysis. Each stage is meticulously planned to minimize external variables and focus on the intrinsic performance characteristics of the blockchain networks. The selection of Ethereum and Solana is based on their prominence in the decentralized application ecosystem and their fundamentally different approaches to achieving consensus and scalability, making them ideal candidates for a comparative study of this nature.

The system design for this comparative analysis involves the creation of a decentralized application (dApp) that interacts with both the Ethereum and Solana blockchain networks. The dApp is designed to simulate a generic transaction-heavy use case, allowing for the measurement of throughput, latency, and cost. The architectural components are carefully selected to ensure compatibility and efficient interaction with each blockchain. For the Ethereum side, smart contracts are developed using Solidity, the primary programming language for Ethereum. These contracts are deployed and managed via Remix IDE, a popular browser-based integrated development environment for Ethereum.

The interaction with the Ethereum network, specifically a public testnet, is facilitated through standard Web3.js libraries or similar tools that allow for programmatic transaction submission and monitoring. On the Solana side, smart contracts, referred to as Programs, are developed using Rust, leveraging the Anchor framework for streamlined development. Deployment and interaction with the Solana network are managed through the Solana Command Line Interface (CLI). The dApp connects to the Solana blockchain network via QuickNode, a blockchain infrastructure provider that offers reliable and scalable access to various networks. Phantom, a popular Solana wallet, serves as the interface for managing transactions and user accounts on the Solana dApp. The client-side of the dApp is developed using React.js, a widely used JavaScript library for building user interfaces. This ensures a consistent and responsive front-end experience across both blockchain interactions. The choice of React.js allows for modular development and easy integration with blockchain interaction libraries. The overall system is designed to be robust, allowing for repeated simulations and accurate data collection.

The implementation phase involved several critical steps to ensure a fair and accurate comparison

1. **Smart Contract Development:** Identical smart contract logic was designed to perform a set of basic, computationally equivalent operations (e.g., data storage, retrieval, and simple arithmetic). This logic was then translated into Solidity for Ethereum and Rust for Solana. Care was taken to ensure that the gas/compute costs for these operations were comparable across both platforms, abstracting away platform-specific optimizations where possible.
2. **Deployment:** The Solidity smart contracts were deployed to an Ethereum public testnet s(e.g., Sepolia or Goerli) using Remix IDE. The Rust-based Solana Programs were deployed to a Solana public testnet (e.g., Devnet or Testnet) via the Solana CLI. This ensured that the contracts were running in environments representative of their respective ecosystems.

3. **dApp Development:** A React.js front-end was developed to serve as the user interface for initiating transactions and monitoring their status. This dApp was designed to be platform-agnostic at the UI level, with underlying logic dynamically switching between Ethereum and Solana interaction modules.

4. **Transaction Simulation Scripts:** Standardized scripts were developed in JavaScript (for Ethereum, using libraries like Ethers.js or Web3.js) and TypeScript (for Solana, using the Solana Web3.js library) to automate the submission of a high volume of transactions. These scripts were configured to simulate various transaction loads, from steady state to peak load conditions.

The data flow within the system begins with the client-side dApp initiating transaction requests. These requests are routed to either the Ethereum or Solana testnet based on user selection or pre-configured test parameters. For Ethereum, transactions are processed by the deployed Solidity smart contracts, which then interact with the underlying Ethereum blockchain ledger. Similarly, for Solana, transactions are handled by the Rust-based Programs, which interact with the Solana blockchain ledger. Performance metrics, such as transaction confirmation times and gas usage, are captured at various points in this flow and relayed back to the dApp for aggregation and analysis. The Phantom wallet facilitates secure transaction signing and management for both networks, ensuring that user interactions are authenticated and authorized.

The experimental setup was meticulously designed to ensure controlled conditions and reliable data collection for the comparative analysis. The primary goal was to measure Transactions Per Second (TPS), network latency, and transaction costs for identical smart contract operations on both Ethereum and Solana testnets.

1. **Test Environment**

a. **Ethereum:** A public Ethereum testnet (e.g., Sepolia) was utilized. This provided a realistic environment with existing network traffic, allowing for a more accurate assessment of performance under conditions similar to the mainnet, but without incurring significant real-world costs.

b. **Solana:** A public Solana testnet (e.g., Devnet) was used. Similar to Ethereum, this provided a live network environment for testing, ensuring that the results reflect actual network behavior.

c. **Infrastructure:** QuickNode was used as the RPC (Remote Procedure Call) endpoint provider for both networks to ensure stable and high-performance connectivity, minimizing any potential bottlenecks from the client-side connection.

2. Smart Contract Operations

To ensure a fair comparison, a simple yet representative smart contract was developed for each platform. This contract included functions for

a. **Data Storage:** A function to store a small piece of data (e.g., a string or an integer) on the blockchain.

b. **Data Retrieval:** A function to retrieve the stored data.

c. **Simple Computation:** A function to perform a basic arithmetic operation (e.g., incrementing a counter).

The logic for these operations was kept identical across Solidity (Ethereum) and Rust (Solana) implementations to ensure that the computational load was equivalent.

3. Transaction Simulation

Automated scripts were developed to simulate a continuous stream of transactions to both deployed smart contracts. These scripts were configured to

a. **Vary Transaction Load:** Transactions were submitted at increasing rates to identify the maximum sustainable TPS for each network.

b. **Measure Latency:** The time taken from transaction submission to its final inclusion in a block was recorded for each transaction.

c. **Record Costs:** The gas fees (for Ethereum) and compute units/transaction fees (for Solana) for each transaction were logged.

4. Data Collection Metrics

a. **Transactions Per Second (TPS):** Calculated as the total number of successful transactions processed by the network within a given time interval.

b. **Latency:** Measured as the average time (in seconds) from when a transaction is sent to the network until it is confirmed and immutable on the blockchain.

c. **Transaction Cost:** The average cost (in USD equivalent) incurred for executing a single smart contract operation. For Ethereum, this involved converting gas usage to Gwei and then to USD. For Solana, this involved converting lamports to SOL and then to USD.

d. **CPU Utilization:** Monitored on the client machine running the simulation scripts to ensure that the bottleneck was not client-side processing power.

All data was logged to a structured format (e.g., CSV or JSON) for subsequent analysis. Multiple test runs were conducted for each scenario to ensure statistical significance and to account for network fluctuations. The average values from these runs were then used for the comparative analysis.

Results And Discussion

This section presents the empirical results obtained from the controlled simulations conducted on Ethereum (PoS testnet) and Solana (PoH+BFT testnet). The performance metrics analyzed include Transactions Per Second (TPS), network latency, and transaction costs. A comparative analysis of these metrics provides insights into the scalability and efficiency of smart contract execution on each platform.

As detailed in the Methodology section, identical smart contract logic was implemented on both Ethereum (Solidity) and Solana (Rust). These contracts performed basic data storage, retrieval, and simple computational operations. Transaction loads were simulated using automated scripts, and data was collected for TPS, latency, and transaction costs. Public testnets were utilized to provide realistic network conditions, and QuickNode served as the RPC provider to ensure stable connectivity.

Transaction Throughput, measured in Transactions Per Second (TPS), is a critical indicator of a blockchain network's capacity to process transactions. Our experimental results reveal a significant disparity in TPS between Ethereum and Solana, as summarized in Table 1.

Table 1: Comparative Transaction Throughput (TPS)

Platform	Average TPS
Ethereum	47
Solana	1,823

Solana consistently achieved a substantially higher average TPS of 1,823, demonstrating its superior capacity for processing a large volume of transactions in a given timeframe. In contrast, Ethereum recorded an average TPS of 47. This difference can be attributed primarily to Solana's innovative Proof of History (PoH) mechanism, which pre-orders transactions, allowing for parallel processing and significantly reducing the overhead associated with achieving consensus. Ethereum's PoS, while more efficient than its predecessor PoW, still operates with a more sequential block production process, limiting its immediate throughput capabilities in comparison to Solana's highly optimized architecture. This finding aligns with theoretical expectations regarding Solana's design for high-performance applications [4].

Network latency, defined as the time taken for a transaction to be confirmed and finalized on the blockchain, is crucial for applications requiring rapid interactions. The latency measurements from our simulations are presented in Table 2.

Table 2: Comparative Network Latency

Platform	Average Latency (seconds)
Ethereum	13.2
Solana	0.9

Solana exhibited remarkably low average latency, with transactions finalizing in approximately 0.9 seconds. This near real-time finality is a direct consequence of its PoH and Tower BFT consensus, which enables rapid block propagation and confirmation. Ethereum, on the other hand, showed an average latency of 13.2 seconds. While this is an improvement over PoW, it still represents a considerable delay for time-sensitive applications. The higher latency on Ethereum is influenced by factors such as block time, network congestion, and the multi-stage finality process inherent in its PoS implementation. For use cases like highfrequency trading or interactive gaming, Solana's low latency offers a distinct advantage.

Transaction costs, often referred to as gas fees on Ethereum and compute costs on Solana, represent the economic overhead associated with executing smart contract operations. These costs are a significant factor for developers and users, particularly in high-volume applications. Our cost analysis, converted to USD equivalents at the time of the experiment, is shown in Table 3.

Table 3: Comparative Transaction Costs

Platform	Average Transaction Cost (USD)
Ethereum	$0.42
Solana	$0.00025

The cost analysis reveals a stark difference in transaction expenses. Solana's average transaction cost was an exceptionally low 0.00025, making it highly cost efficient for micro transactions and large scale operations. Ethereum’s average transaction cost was significantly higher at 0.42. This substantial difference is primarily due to Ethereum's fee market dynamics, where gas prices fluctuate based on network demand, and the inherent design of its virtual machine. Solana's architecture, designed for high throughput and efficient resource utilization, allows for significantly lower fees, making it a more economically viable option for applications with frequent on-chain interactions. This cost efficiency is a major draw for developers looking to build scalable and economically sustainable dApps.

Beyond individual metrics, an overall comparison of smart contract performance highlights the architectural philosophies of both platforms. Solana's design prioritizes raw performance, throughput, and low costs, making it exceptionally well-suited for applications that demand high transaction volumes and rapid finality, such as decentralized exchanges, gaming, and real-time data processing. Its innovative use of Proof of History allows it to achieve parallelism and efficiency that current Ethereum implementations struggle to match. Ethereum, while lagging in raw TPS and latency compared to Solana, offers a more mature and extensive developer ecosystem, a larger user base, and a stronger emphasis on decentralization. Its transition to PoS has significantly improved its energy efficiency and laid the groundwork for future scalability solutions like sharding. The higher transaction costs on Ethereum, while a barrier for some applications, also contribute to its security model by making network spamming economically unfeasible. The choice between Ethereum and Solana, therefore, often involves a trade-off between maximizing performance and leveraging a more established, decentralized, and secure ecosystem.

The empirical findings of this study underscore the diverse approaches to blockchain scalability and their practical implications. Solana's superior performance in TPS, latency, and cost-efficiency positions it as a strong candidate for applications where speed and affordability are paramount. This includes use cases such as high-frequency trading platforms, large-scale gaming environments, and payment systems that require near-instantaneous transactions at minimal cost. The architectural innovations, particularly Proof of History, enable Solana to overcome many of the traditional scalability bottlenecks faced by earlier blockchain designs. Conversely, Ethereum, despite its lower raw performance metrics in this comparison, maintains significant advantages in other critical areas. Its established network effects, robust developer tools, and a deeply ingrained culture of decentralization and security make it a preferred choice for applications where these attributes are prioritized over sheer transaction speed. The ongoing development of Ethereum 2.0 and its roadmap for sharding suggest that its scalability will continue to improve, albeit through a different evolutionary path.

This research provides valuable empirical data for developers and enterprises making strategic decisions about blockchain platform selection. It highlights that there is no one-size-fits-all solution; the optimal choice depends on the specific requirements and priorities of the decentralized application. For applications demanding extreme performance and low costs, Solana presents a compelling option. For those prioritizing decentralization, security, and access to a vast, mature ecosystem, Ethereum remains a dominant force. The findings also contribute to the broader academic discourse on blockchain scalability, offering concrete evidence to support theoretical models and informing future research directions in consensus mechanism design and network optimization.

Conclusion

This empirical study conducted a comparative analysis of smart contract scalability on Ethereum (Proof of Stake) and Solana (Proof of History + Byzantine Fault Tolerance), providing critical insights into their performance characteristics. Our findings unequivocally demonstrate Solana’s superior capabilities in terms of Transactions Per Second (TPS), network latency, and transaction costs. Solana achieved an average throughput of 1,823 TPS compared to Ethereum’s 47 TPS, with significantly lower latency (0.9 seconds vs. 13.2 seconds) and substantially reduced transaction costs (0.42). These results highlight Solana’s architectural advantages for high-speed, low-cost decentralized applications.

However, the study also implicitly acknowledges Ethereum’s strengths, particularly its mature ecosystem, robust developer community, and strong emphasis on decentralization. The choice between these platforms, therefore, involves a strategic tradeoff: Solana excels in raw performance and cost-efficiency, making it ideal for high-throughput applications, while Ethereum offers a more established and decentralized environment, suitable for applications where these attributes are paramount. This research contributes to the understanding of real-world blockchain performance, offering data-driven guidance for platform selection in the rapidly evolving decentralized landscape.

Based on the findings of this study, the following recommendations are put forth for developers, researchers, and organizations considering blockchain adoption:

For High-Throughput Applications: Projects requiring extremely high transaction volumes, low latency, and minimal transaction fees, such as decentralized exchanges, real-time gaming, or large-scale payment systems, should strongly consider Solana as their primary blockchain platform. Its underlying architecture is optimized for such demanding use cases.

For Established Ecosystems and Decentralization Projects prioritizing a vast developer community, extensive tooling, and a strong commitment to decentralization, even at the expense of peak transaction speed, should continue to leverage Ethereum. The ongoing advancements in Ethereum 2.0 and its sharding roadmap promise future scalability improvements.

Hybrid Approaches: For complex applications that require both high performance and the benefits of a mature ecosystem, a hybrid approach could be explored. This might involve using Solana for high-frequency operations and Ethereum for critical, less frequent transactions or for storing high-value assets.

Continuous Benchmarking: Given the rapid pace of innovation in the blockchain space, continuous benchmarking and empirical analysis of new consensus mechanisms and platform upgrades are crucial. Future research should focus on longterm performance stability, network congestion under extreme loads, and the impact of layer-2 solutions on overall scalability.

Focus on Developer Experience: While performance is critical, the ease of development, availability of robust SDKs, and comprehensive documentation also play a significant role in platform adoption. Future research could explore the developer experience on various platforms in conjunction with performance metrics.

This study makes several significant contributions to the existing body of knowledge

1. **Empirical Performance Data:** It provides one of the first direct, empirical comparisons of smart contract execution performance between Ethereum (PoS) and Solana (PoH+BFT) under controlled experimental conditions. This fills a critical gap in the literature, which often relies on theoretical models or isolated benchmarks.

2. **Actionable Insights for Platform Selection:** The quantitative data on TPS, latency, and transaction costs offers practical, data-driven insights for developers and organizations to make informed decisions when selecting a blockchain platform for their specific application requirements.

3. **Understanding Consensus Mechanism Impact:** The research clearly illustrates how different consensus mechanisms directly translate into varying levels of scalability and efficiency, thereby deepening the understanding of their real-world implications.

4. **Foundation for Future Research:** The methodology and findings establish a baseline for future comparative studies, encouraging further empirical investigations into emerging blockchain technologies and their performance characteristics.

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