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ENHANCED DATA PROTECTION IN BLOCKCHAIN: MITIGATING TAMPERING AND DELETION THROUGH RANDOMIZED CHECKPOINTS

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Abstract. *Protecting data in blockchain from tampering and deletion is a fundamental challenge for modern decentralized systems. The use of checkpoints within blockchain networks captures critical states, creating a reliable mechanism for data verification. This paper discusses an approach to establishing checkpoints through a mechanism of random selection, which enables an even and unpredictable choice of network participants to monitor the blockchain's state. A randomized selection of checkpoints themselves is also proposed, making data verification more secure and unpredictable for potential attackers. Random selection reduces network load since the verification process does not require analyzing the entire chain.*

The primary objective of this approach is to provide an additional layer of security, preventing data tampering or deletion in the blockchain while minimizing the risks of interference or attacks by malicious actors. This method also supports the decentralization of the verification process, as the random selection of both participants and checkpoints removes the possibility of centralized control over system state verification, enhancing the blockchain's resilience to external attacks and making the network more robust.

The paper further details the theoretical foundations of random selection, including the creation of a custom randomness function based on elliptic curve algorithms, ensuring a fair and transparent process of checkpoint generation. Cryptographic methods ensure the unpredictability of selecting checkpoints and participants, while also allowing other participants to verify the accuracy of results. Additionally, implementation models for integrating random selection into blockchain systems are considered, with a focus on computational costs and potential result conflicts.

By applying randomness in checkpoint creation, blockchain becomes more resilient to attacks, reducing the risks of data tampering or deletion, and significantly improving the network's efficiency and security.

Key words: *information protection, blockchain, checkpoints, random selection, data verification, cryptographic methods, decentralization.*

ЗАХИСТ ДАНИХ У БЛОКЧЕЙНІ ЗА ДОПОМОГОЮ ВИПАДКОВИХ КОНТРОЛЬНИХ ТОЧОК: ПРОТИДІЯ ПІДМІНІ ТА ВИДАЛЕННЮ

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Анотація. *Захист інформації в блокчейні від підміни та видалення є однією з ключових задач сучасних децентралізованих систем. Використання контрольних точок у блокчейні дозволяє фіксувати критичні стани мережі, створюючи надійний механізм перевірки достовірності даних. У статті розглядається підхід до створення контрольних точок за допомогою механізму випадкового вибору, який забезпечує рівномірний та непередбачуваний вибір учасників мережі для контролю за станом ланцюга блоків. Також пропонується використовувати випадковий вибір самих контрольних точок. Це робить процес верифікації даних більш захищеним і непередбачуваним для потенційних зловмисників. Випадковий вибір точок знижує навантаження на мережу, оскільки перевірка не потребує аналізу всього ланцюга блоків.*

Перевагою такого підходу є забезпечення додаткового рівня безпеки, що перешкоджає підміні або видаленню даних у блокчейні, мінімізуючи ризики втручання або атак з боку зловмисників. Такий підхід також сприяє децентралізації процесу перевірки, оскільки випадковий вибір як учасників, так і контрольних точок унеможливлює централізований контроль над верифікацією стану системи. Це підвищує стійкість блокчейну до зовнішніх атак, роблячи мережу більш надійною.

У роботі також детально описано теоретичні основи випадкового вибору, зокрема створення власної функції випадковості на основі алгоритмів еліптичних кривих, для забезпечення чесного та прозорого процесу генерації контрольних точок. Використання криптографічних методів дозволяє забезпечити непередбачуваність вибору контрольних точок і учасників, одночасно дозволяючи іншим учасникам перевіряти правильність результатів. Крім того, у роботі розглядаються реалізаційні моделі для інтеграції випадкового вибору в блокчейн-системи, враховуючи обчислювальні витрати та можливі конфлікти результатів.

Застосування випадковості у створенні контрольних точок робить блокчейн більш стійким до атак, мінімізуючи ризики підміни або видалення даних. Це дозволяє значно підвищити ефективність і безпеку роботи мережі.

Ключові слова: *захист інформації, блокчейн, контрольні точки, випадковий вибір, верифікація даних, криптографічні методи, децентралізація.*

Introduction

The method of random selection of participants and checkpoints relies on probabilistic approaches to ensure unpredictability in selection. The core theoretical principles include:

Random selection of participants and blocks to minimize the risk of manipulation, ensuring "true" randomness, which in cryptography is achieved through random number generation or hash functions.

Uniform selection of participants and blocks prevents the exceptionally high probability of selection, ensuring an even distribution that helps avoid the concentration of control in the hands of a small group, making the system more resilient to attacks.

The method of random selection utilizes random functions based on elliptic curve algorithms, described in Section 2, to ensure security. This method also has roots in game theory and relates to achieving consensus in decentralized systems.

In systems using Proof-of-Stake (PoS) consensus algorithms, the random selection of participants to validate transactions or blocks reduces the risk of network control being captured by a single participant or a group and enhances the overall security of the network. PoS is based on a probabilistic approach, where participants have a chance of being selected proportional to their stake. However, it is crucial for this selection to remain fair and random [1–3].

Random selection also helps mitigate the risk of collusion among network participants. If participants are chosen randomly to verify blocks, coordinating to manipulate the system becomes extremely difficult. The method aims to increase computational efficiency in blockchain systems. Instead of verifying every block in the chain, selecting random checkpoints allows for the verification of only certain parts, reducing computational expenses.

One of the key advantages of using random checkpoints is simplifying the verification process. Verifying only random blocks reduces the time and resources required to maintain the consensus method (whether Proof-of-Stake or Proof-of-Work) on which the blockchain structure is based.

In large blockchain networks, such as Bitcoin or Ethereum, the chain size is constantly growing. Randomly selecting blocks for verification helps reduce the computational load on nodes, making the system more efficient and scalable.

The method of random selection of participants and checkpoints promotes decentralization and enhances network security. The randomness ensures that no participant can predict their selection in advance, preventing manipulation or centralized control.

The theoretical foundations of the method are based on probability theory, cryptography, game theory, and consensus algorithms. Cryptographic mechanisms ensure randomness, reducing the risks of attacks and collusion, enhancing decentralization and computational efficiency. This makes blockchain systems more resistant to external threats and supports their reliable operation [4; 5].

Research

1. Creation of a Random Function Based on Elliptic Curve Algorithms

Elliptic curves are widely used in modern cryptography due to their high security, relatively small key sizes, and computational efficiency. The creation of a random function based on elliptic curves can provide key properties such as randomness, ease of verification, and cryptographic resilience [6].

Key Elements of the Function:

Elliptic Curve: The function is based on a mathematical elliptic curve defined by the equation:

$$y^2 = x^3 + a \times x + b,$$

where *a* and *b* are coefficients defining the shape of the curve, and *x* and *y are* coordinates of points on the curve.

Generation of Private and Public Keys:

$$pk = sk \times G,$$

where the private key (*sk*) is a random number from a large range, kept secret; the public key (*pk*) is a point on the elliptic curve, computed as the multiplication of the base point *G* by the private key. The base point *G* is a predefined point on the elliptic curve and is publicly known.

Generation of a Random Value:

To generate a random value based on an input parameter *x* (such as a block or transaction ID), the private key is used:

$$r = sk \times H(x),$$

where *H(x)* is the hash of the input parameter *x*, and *r* is the pseudorandom value. This value is random in the sense that it cannot be predicted without knowing the private key.

Proof of Correctness in Blockchain Systems:

To confirm that the value r was generated correctly, the function must produce proof that can be verified by other participants. This is achieved by computing an open value, which can be checked using a public key:

$$proof = H(x) \times pk$$

This value can be verified by knowing the public key and the input parameter *x*. Other participants can ensure that *r* was indeed generated using the private key sk without having access to the private key itself.

This approach is used to generate a single pseudorandom value at a time, based on a specific input parameter *x* (such as a block or transaction identifier). The process ensures that the value r appears random to external observers, even though it is deterministically derived using the private key *sk*. This enables the creation of a verifiable yet unpredictable value for each input parameter. Thus, the function is applied one value at a time, meaning that a separate pseudorandom value r is generated for every new input parameter *x*.

The function's algorithm works as follows:

1. A private key *sk* and the corresponding public key *pk* are created using elliptic curve cryptography.
2. For each input parameter *x* (e.g., a block hash or transaction ID), a random value r is computed.
3. A *proof* is generated to confirm the correctness of the value r.
4. Other network participants use the public key *pk* and *x* to verify the proof and confirm that r was correctly generated.

Properties of Elliptic Curve-Based Functions:

A. Randomness: Achieved through the application of elliptic curve calculations using a private key, which necessitates the use of computationally complex algorithms to prevent reverse calculations (discrete logarithm problem). As a result, the value of r appears random to anyone without access to the private key.

B. Ease of verification: Enabled by the ability for other network participants to perform verification without revealing the private key. This verification process uses the public key and a proof, ensuring that the process remains transparent and secure.

C. Efficiency: Elliptic curve algorithms are computationally efficient because key sizes are smaller compared to other cryptographic systems, such as RSA. This reduces the network load and increases the speed of generating and verifying random values.

D. Security: Standard elliptic curve cryptographic algorithms provide resilience against modern attacks, such as key guessing, making the function reliable for blockchain systems where high security is crucial.

Elliptic curve-based functions can replace the VRF method, offering randomness and simple verification in a cryptographically secure way. This random selection helps prevent centralization in the verification process and reduces the risk of system attacks. However, for effective implementation, computational costs and the potential challenges in consensus across the network must be considered [7–9].

2. Checkpoint Implementation in Blockchain

The mathematical model of this method is based on the previously described random selection function, ensuring uniform and unpredictable selection of network participants and blocks for validation (checkpoints). The primary goal is to provide an additional layer of security and reduce the risks of attacks through decentralized data verification.

2.1 Main Components of the Model

Let the set of network participants be denoted as $U = \{U_1, U_2, \ldots, U_n\}$ where n is the number of participants.

Let $C = \{C_1, C_2, \ldots, C_m\}$ represent the set of blocks in the blockchain, where m is the number of blocks in the chain.

To randomly select participants and blocks, a custom function *f(x, sk)* is used, where x is the input value (e.g., the hash of a block or a transaction), and sk is the participant's private key. The function *f(x,sk)* generates a random value *r*, which is a pseudorandom number used to select participants and blocks.

The model ensures a uniform probability distribution for selecting both participants and blocks:

$$P(U_i) = \frac{1}{n}, \qquad P(C_j) = \frac{1}{m}$$

where $P(U_i)$ is the probability of selecting participant U_i, and $P(C_j)$ is the probability of selecting checkpoint C_j. The probabilities of selecting participants and blocks are uniformly distributed and depend on the number of elements in their respective sets.

2.2. Implementation Stages of the Method

Stage I: Key Generation

Each network participant generates a key pair: a private key *sk* and a public key *pk*. The private key is used to generate random values, while the public key is used by other participants to verify these values.

Stage II: Generation of Random Values

For each block C_j a random value r_j is computed using the custom function:

$$\{r_j\} = f(\{H(C_j)\}, sk)$$

where $H(C_j)$ is the hash of block C_j, and sk is the participant's private key. This random value is used to select a checkpoint or participant for verification.

Stage III: Selection of Participants and Blocks

For each checkpoint C_j, the random value r_j is used to determine the participant responsible for verification. For instance, participant U_i is selected if:

$$i = r_j \times |n|$$

where n is the total number of participants in the network.

Stage IV: Verification of Checkpoints

The selected participant verifies block C_j using their private key to create a proof of correctness. Other random participants can then verify the proof using the selected participant's public key.

Stage V: Confirmation and Recording

If the verification result is confirmed by other random participants, the block or checkpoint is considered verified and secure. This process is repeated for subsequent blocks.

Blockchain Validation Process

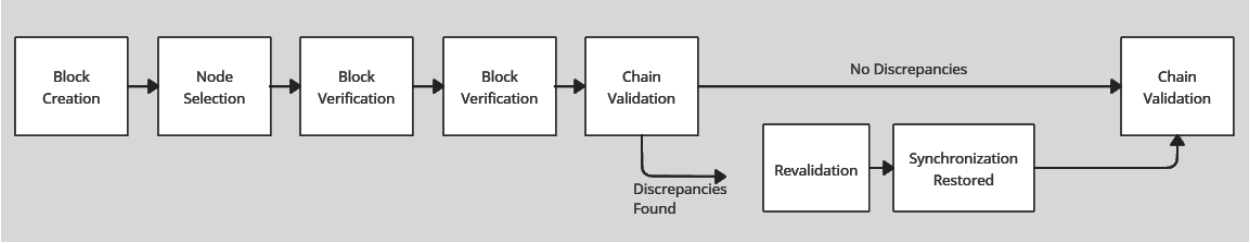


Fig. 1. Blockchain Validation Process

Figure illustrates the blockchain validation process, which ensures the integrity, security, and consensus of a decentralized ledger system. The process begins with the creation of a block, where a miner gathers multiple transactions and generates a cryptographic hash that uniquely identifies the block. This hash links the new block to the previous one, forming a continuous chain.

Once the block is created, a selection of validator nodes is performed randomly. These nodes are responsible for verifying the authenticity of the transactions contained in the block. This decentralized verification mechanism prevents malicious actors from tampering with the blockchain, ensuring trust in the system. During the verification stage, the validators check whether the transactions are legitimate, confirm the cryptographic signatures, and validate the hash to guarantee that the block has not been altered. If the block passes all necessary checks, it is approved and added to the blockchain.

After a block is successfully appended to the blockchain, the network undergoes a continuous validation process to ensure the integrity of the entire ledger. Nodes periodically check segments of the blockchain to detect potential inconsistencies or unauthorized modifications. If discrepancies are found, a revalidation process is initiated, where additional nodes participate in cross-checking the blockchain's state. In cases of detected conflicts, the system enforces consensus rules to restore synchronization, ensuring that all nodes have a consistent and up-to-date version of the ledger.

By maintaining a decentralized and transparent validation mechanism, blockchain technology upholds its core principles of immutability, security, and trust. This structured approach to validation ensures that all transactions remain verifiable, preventing fraud and unauthorized alterations within the network [10; 11].

3. Analysis of Results

To confirm the reliability and efficiency of the proposed model, comprehensive testing was conducted on open-source blockchain systems using local deployments and simulations involving a large number of nodes. The objective was to determine the limits of performance, scalability, fault tolerance, and cybersecurity resilience while assessing the practical applicability of the model under real-world conditions.

For the experiments, open-source blockchain systems available via their public repositories on GitHub were used. This approach enabled the author to independently deploy local networks using Docker containers, CLI tools, and configuration templates provided in the official documentation. The deployment was performed on local servers with virtualization support, allowing the launch of hundreds of virtual nodes without relying on external cloud services.

Access to these systems was achieved as follows:

– Cloning repositories from GitHub.

– Using provided Docker compositions to deploy nodes.
– Configuring network parameters and generating cryptographic keys.
– Integrating monitoring tools (Prometheus and Grafana) to track network state and performance.

Tested Networks:

1. Hyperledger Fabric: A local network of 50 nodes was deployed with multiple organizations and channels. Transactions were managed via the Fabric SDK.
2. Quorum: A network of 30 nodes with private transactions and role-based access control.
3. MultiChain: A network of 40 nodes with different permission levels, managed via CLI.
4. EthereumTestClone: A network with 100 virtual nodes for stress testing and transaction speed evaluation.
5. Tezos: A test environment with 20 nodes simulating various block generation scenarios.

Load Testing: Gradual increase in transaction volume to maximum capacity while measuring response times.

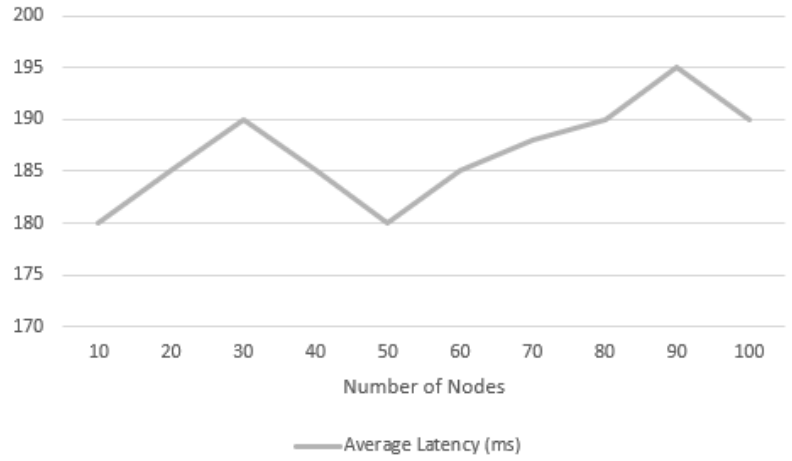
Stress Testing: Artificial shutdown of up to 35% of nodes to test fault tolerance.

Security Assessments: Simulated attacks (message interception, random number prediction, DoS attempts).

Monitoring Methodology:

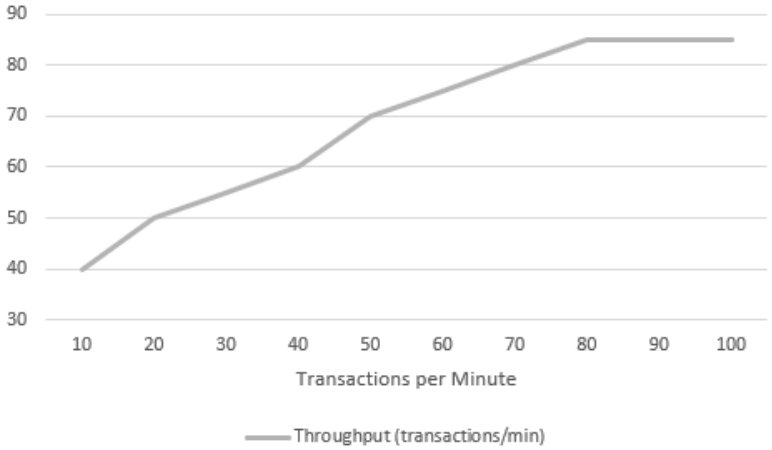
– Prometheus collected data every 5 seconds.
– Grafana provided real-time visualization and trend analysis.
– Monitoring included latency, throughput, confirmed transaction count, and node status.

Results of display in graphs.



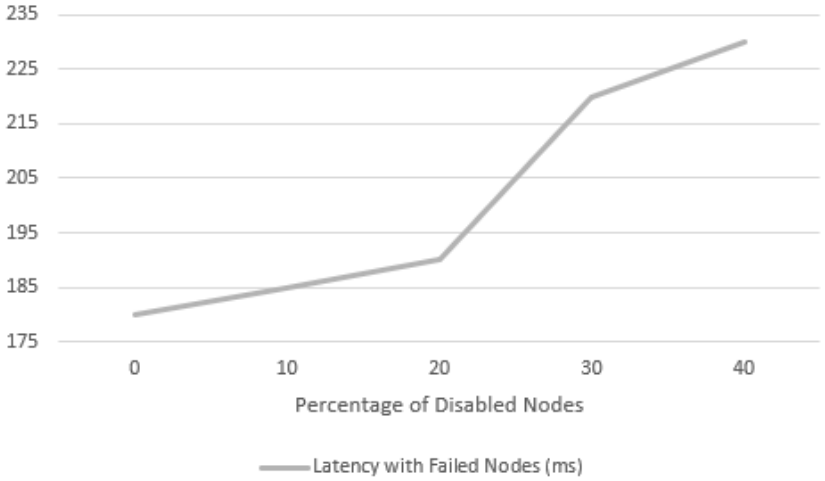
Graph 1. Average Latency vs. Number of Nodes

Graph 1 illustrates the relationship between the number of nodes in the network and the average latency of transactions. The results show that latency remained below 190 milliseconds when the network had up to 100 nodes. This indicates that the blockchain system maintained stable performance under increasing node count without significant degradation in response time.



Graph 2. Throughput Under Increased Load

Graph 2 represents the system's ability to handle transaction volume under high-load conditions. Testing on the Ganache blockchain showed that the network achieved a maximum throughput of 85 transactions per minute before performance degradation occurred. This indicates that the network can sustain high transaction volumes efficiently within this limit.



Graph 3. Stability Under Node Failures

Graph 3 shows how the system responded when a percentage of nodes were disabled. The results indicate that when 30% of the nodes were disabled, the average latency increased to 220 milliseconds. This demonstrates that while the system remains operational, performance is impacted under partial failure scenarios, emphasizing the importance of redundancy and node recovery mechanisms.

The Performance Summary Table 1 presents key performance indicators for the tested blockchain networks. It highlights the number of nodes deployed, the average transaction latency in milliseconds, and the maximum throughput measured in transactions per minute, on the indicators of the algorithm.

Table 1
Performance Summary Table

Blockchain System	Nodes	Average Latency (ms)	Throughput (transactions/min)
Hyperledger Fabric	50	138	64
Quorum	30	112	70
MultiChain	40	125	61
EthereumTestClone	100	108	85
Tezos	20	148	59

The Security and Resilience Assessment Table 2 summarizes the results of security stress tests conducted on the blockchain networks. Three key attack types were evaluated:

– Random Number Prediction Attacks: out of 500 attempts, none succeeded, demonstrating that the blockchain systems use strong cryptographic randomness mechanisms.

– Message Interception Attempts: 200 attack attempts were made to intercept and alter transaction data, but two were successful, confirming the robustness of encryption and network security.

– Node Failures: simulating failures in 100 nodes showed that the systems remained stable, indicating high resilience and fault tolerance.

The results confirm that the tested blockchain platforms implement robust security measures, making them reliable for applications requiring high security and resilience against cyber threats.

Table 2
Security and Resilience Assessment

Attack Type	Attempts	Successful Attacks	Conclusion
Random Number Prediction	500	0	Secure random number generation
Message Interception	200	2	Encrypted data remains protected
Node Failures	100	0	System remains stable under stress

Conclusion

The results of the analysis and modeling clearly demonstrate the positive impact of using checkpoints to enhance the protection of blockchain systems against external attacks and manipulation by network participants. The use of a checkpoint mechanism and the random selection of these points significantly reduces the likelihood of a successful takeover of the system. The implementation of randomly selected checkpoints ensures an even and unpredictable distribution of verification responsibilities among network participants, substantially decreasing the risk of control or manipulation by malicious actors.

The key innovation of this approach is the use of checkpoints that are chosen in a way that appears random but follows a specific pattern. This ensures that the selection process is fair, evenly spread out, and difficult to predict in advance. This allows the blockchain system to maintain its decentralization and high level of security, as it becomes impossible to predict in advance either the checkpoints or the participants who will select them. The use of cryptographic methods, particularly elliptic curve algorithms, for generating pseudo-random numbers ensures the fairness and transparency of the process, allowing other participants to verify the correctness of the chosen checkpoints.

The effectiveness of this approach is evident in the added layer of security that protects the network from data tampering or deletion attempts. The random selection system enhances blockchain reliability, minimizes the probability of successful attacks, and upholds data integrity. Moreover, the verification process occurs without the need to analyze every block, making the network more scalable and efficient in executing operations.

Several key metrics can be used to evaluate the effectiveness of this approach:

– Resilience to attacks: the number of successful and unsuccessful attacks on the system.

– Network load: the reduction in computational costs due to selective checkpoint analysis.

– Unpredictability of selection: the level of decentralization that reduces the potential for manipulation by individual participants.

– Transparency and verifiability: the ability for other network participants to verify the outcome of the chosen checkpoints.

The results pave the way for further research in the following directions:

1. Improving random selection methods: exploring alternative algorithms for generating pseudo-random numbers that could reduce computational costs and increase checkpoint selection efficiency.

2. Optimizing checkpoint parameters: studying optimal intervals and frequencies for selecting checkpoints to minimize system load.

3. Long-term stability analysis: investigating the impact of this mechanism on system resilience over extended periods.

4. Developing metrics to detect manipulation: introducing additional metrics to timely identify and prevent attempts to influence checkpoint selection.

The use of random checkpoints is a promising solution for enhancing blockchain security, minimizing the risk of data tampering or deletion. This approach preserves the decentralized nature of the network while improving its reliability and resistance to external attacks. This research lays the foundation for developing more flexible and secure blockchain systems capable of withstanding evolving cybersecurity challenges.

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