Trust-Centric Blockchain Framework: A Three-Layered Architecture for Securing Open and Private Systems

Jihen Bennaceur[1,2,a], Wissem Zouaghi[3], Kawouther Thabet[4], Aziza Bennour[1], Roudha Ben Jemaa[4] and Ali Mabrouk[3]

[1] *Mediterranean Institute of Technology, Tunis, Tunisia*

[2] *National School of Computer Science, Manouba, Tunisia*

[3] *SAMA PARTNERS Business Solutions GmbH, Mannheim, Germany*

[4] *Higher Institute of Computer Science and Communication Technologies, University of Sousse, Tunisia*

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Abstract: Cybersecurity threats are becoming increasingly sophisticated, posing significant risks to both open and private architectures. Open architectures, such as open-source ecosystems, collaborative platforms, and information-sharing frameworks, thrive on transparency and accessibility but face challenges in maintaining trust, data integrity, and security. Conversely, private architectures, while operating within controlled environments, are not immune to internal threats or compromised trust mechanisms. Blockchain technology has emerged as a transformative solution to address these challenges by leveraging decentralization, immutability, and transparency. This paper introduces a dual Blockchain-based trust framework tailored to the unique needs of both open and private architectures. For open systems, the framework enhances trust and security through transparent trust modeling, Blockchain-based validation, and tamper-proof accountability mechanisms. For private systems, it strengthens internal trust evaluation and mitigates risks by securing interactions in a closed, permissioned environment. The proposed solution integrates three layers—trust modeling, Blockchain-enabled validation, and adaptive penalty mechanisms—to ensure robust security and participant accountability. Extensive simulations and security validations demonstrate the effectiveness of this approach across diverse open and private architecture scenarios, providing a comprehensive strategy to mitigate threats and reinforce trust in these critical ecosystems.

1 INTRODUCTION

Architectures, whether open or private, serve as foundational frameworks for modern technological ecosystems. Open architectures, such as threat information sharing (TIS) (Mohaisen et al., 2017) frameworks and open-source ecosystems (Gil et al., 2024), foster innovation and collaboration by enabling diverse communities to co-develop adaptable systems and share critical data. However, the very openness that drives their success also introduces vulnerabilities. In TIS, for example, malicious actors can target the integrity of shared data or exploit trust mechanisms to impersonate legitimate participants. Similarly, in open-source environments, vulnerabilities in code or compromised contributors can jeopardize security and reliability.

On the other hand, private architectures operate in controlled, closed environments that restrict access and collaboration to authorized entities. While this design minimizes exposure to external threats, it introduces unique challenges related to trust management within a limited and often hierarchical set of participants. Internal malicious actors or errors in the trust assessment can compromise the architecture, affecting its security and functionality.

Trust and reputation management systems (Bennaceur et al., 2020)(Z. et al., 2018) have become crucial for securing both open and private architectures. These systems aim to evaluate and maintain the trustworthiness of participants, mitigate malicious behavior, and ensure reliable collaboration. However, existing mechanisms face limitations. Attackers can manipulate trust values, elevate their reputation through

[a] https://orcid.org/0000-0001-8584-5253

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falsification, or discredit legitimate contributors, undermining the integrity of the system.

To address these challenges, this paper proposes leveraging blockchain technology (Chowdhury et al., 2016) to enhance trust and reputation management systems. The properties of the blockchain, namely immutability, decentralization, and transparency, make it an ideal solution for both open and private architectures. For open systems, blockchain can secure trust values against tampering, ensure transparency in contributions, and deter malicious behavior with historical accountability. In private systems, blockchain can enforce strict trust policies through immutable records and smart contracts, enhancing internal security and operational reliability.

By designing and implementing tailored blockchain solutions for both open and private architectures, this approach bridges critical gaps in trust management. It addresses the risks posed by malicious actors while enhancing the security and reliability of collaborative systems, whether in dynamic open-source ecosystems, tightly controlled private platforms, or hybrid environments.

1.1 Contributions

The increasing reliance on open and private architectures necessitates robust solutions to secure trust and reputation in both collaborative and controlled environments. The vulnerabilities inherent in open architectures, such as falsified reputation scores and malicious contributions, demand a transparent and tamper-proof trust management mechanism. Private architectures, while inherently more secure, require enhanced trust assessment systems to protect against internal threats and ensure operational reliability. Contributions This work presents the following key innovations:

- Design of a public blockchain architecture to secure trust in open systems, such as open-source platforms.
- Design of a private blockchain architecture to enhance trust in targeted and controlled environments, such as closed-source systems.
- Implementation and validation of both solutions to demonstrate their effectiveness in securing trust and reputation across diverse architectural frameworks.

The structure of this research is indicated in Fig. 1; Section 2 describes the trust model for the open and private architectures. Section 3 indicates the design of blockchain-based trust. Section 4 describes the two Blockchain architectures: Private and Public. Sections 5 and 6 discuss the implementation and analyze the results. Section 6 describes the conclusion of this research work. The abbreviations used in this paper are indicated in Table 1.

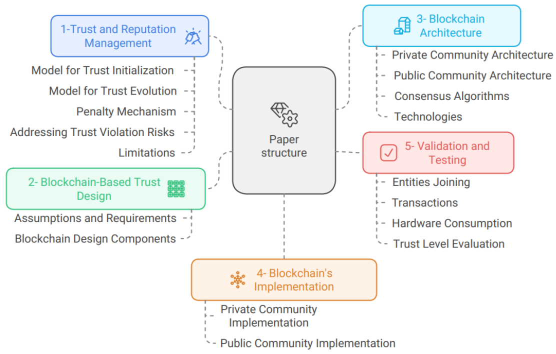


Figure 1: Paper structure.

2 TRUST AND REPUTATION MANAGEMENT FOR OPEN AND PRIVATE ARCHITECTURES

2.1 Model for Trust Initialization

During trust initialization, newly joined entities are assigned a first level of trust, defined as the trust initialization model (Bennaceur et al., 2025). Values are calculated based on the various dimensions specified (see Fig2).

- Pre-trust: In this context, it denotes the initial level of trust attributed to a newly participating entity. This trust rating is determined following the aggregation of recommendations, often referred to as reputation, from existing entities within a specific community. This reputation is then converted into a numerical value within the threat-sharing platform and subsequently forwarded to the Blockchain layer for the initial trust assessment. The magnitude of the pre-trust value assigned to an entity is directly correlated with the quality and quantity of recommendations it receives from the community. In essence, the more favorable recommendations an entity garners from its peers, the higher its pre-trust score will be.
- Community Type: The category of community represents the second dimension in initiating trust, as it significantly influences the trust-building process. In a public community marked by an untrusted environment, trust initiation is determined

using the zero-trust concept as the basis for calculation.

- Legal Contract: Upon becoming a member of the community, participants will enter into a formal contract with the system. This contractual arrangement serves as a safeguard for the rights of both the threat information-sharing platform and the participating entity. It establishes the terms and conditions governing community membership and the utilization of platform benefits. The jurisdiction for the legal contract will align with the location of the participating entity, and its enforceability will be assessed on a scale ranging from low to high, depending on the extent to which the agreement adheres to legal procedures in that particular country.
- Capabilities: The entity's capability will be categorized on a scale from low to high, determined by its expertise and experience in the field of cybersecurity. This factor will significantly influence the level of trust, as the reliability of the shared information will hinge on the extent of the entity's experience in this domain.
- Indirect trust pertains to the geographical context in which participants operate, and it involves the assessment of trustworthiness based on the participant's country of origin. This facet of trust comprises three sub-dimensions:
  1. Data Privacy Regulations: This sub-dimension evaluates the extent to which data privacy laws are upheld in the participant's country and the legal repercussions for any breaches of data privacy.
  2. Copyright Protection: Within this sub-dimension, an assessment is made regarding the level of protection afforded to individual copyrights in the participant's country, along with the legal consequences associated with copyright infringement.
  3. Cyber crimes: These are assessed based on a country's susceptibility to cyberattacks, a sub-dimension that encompasses not only the frequency of attacks but also factors in the country's cybersecurity strength index.

2.2 Model for Trust Evolution

Trust within a system evolves gradually based on the nature and quality of the actions performed by entities, and it is shaped by the specific requirements of the environment—whether public or private. The criteria for establishing trust depend on the type of honest and benign actions necessary within the system.

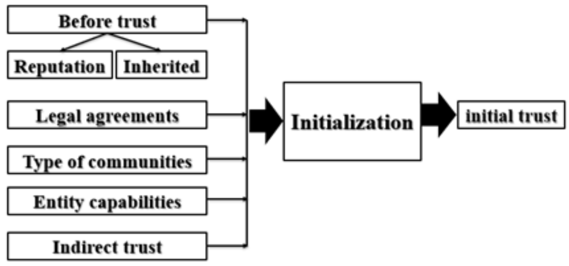


Figure 2: Trust initialization model dimensions.

In private environments, such as threat information-sharing frameworks, trust is calculated based on the quality, relevance, and accuracy of the data shared by entities. Entities are evaluated on their ability to provide actionable insights regarding threats, vulnerabilities, and incidents that enhance the security and resilience of the network. In public environments, such as open-source platforms, trust is determined by the quality, originality, and reliability of the contributions made by entities. Actions such as adhering to coding standards, addressing issues, and improving functionality play a significant role in shaping trust scores. By tailoring the trust evaluation model to the specific actions and contributions required in each environment, this approach ensures that trust evolves naturally and accurately reflects the entity's value within the system.

Consequently, the assessment and adjustment of trust levels hinge on several critical factors tailored to the environment and the type of contributions being evaluated. These factors ensure that the system remains secure, fair, and trustworthy, regardless of whether it operates in a private or public architecture. Key elements include:

- Quality: In both private and public environments, the quality of the shared contributions is crucial. For private systems like threat information sharing, this involves evaluating the accuracy, relevance, and reliability of the shared data. In public systems like open-source platforms, quality pertains to the correctness, originality, and functionality of the submitted code or resources.
- Quantity: The volume of contributions is an important indicator of an entity's activity and willingness to engage with the system. In threat information sharing, this could mean the number of threat reports or vulnerabilities shared. In open-source platforms, it may reflect the frequency of code commits, bug fixes, or feature enhancements.
- Integrity: This dimension ensures that the shared content is honest, accurate, and free from malicious intent. For private systems, it verifies that

threat data is not manipulated or falsified. In public systems, it ensures that code contributions do not introduce vulnerabilities or other malicious elements.

- Intent: The intent behind contributions is critical to maintaining trust within the system. For private architectures, this involves evaluating the motivation behind shared reputation values and detecting any malicious attempts to discredit trustworthy entities. In public systems, intent is assessed by analyzing behavior patterns, such as whether contributions genuinely aim to improve the system or to gain undue advantage.

These trust dimensions ensure that the system adapts to the specific requirements of both private and public architectures, fostering a secure and collaborative environment. Trust evolves dynamically as these metrics are continuously monitored and updated, reflecting the entity's ongoing behavior and contributions.

2.3 Penalty Mechanism

In the process of evaluating contributions and interactions within a system, any entity that raises suspicion—whether in a private or public environment—is flagged for review. The system leverages a collective decision-making process to determine the credibility of the entity, ensuring that trust and integrity are preserved.

- Community Feedback Aggregation: Once an entity is flagged, feedback is collected from all members of the network to evaluate the credibility of the suspicious entity. This collaborative approach ensures transparency and fairness in the decision-making process.

  Two scenarios typically follow:

1. Expulsion from the System: If the community determines, through aggregated feedback and centralized validation, that the flagged entity exhibits malicious behavior or breaches trust, the entity is removed from the system. This decision is then communicated to all users, ensuring that the malicious actor can no longer compromise the system.
2. Affirmation of Trustworthiness: If the investigation concludes that the flagged entity is trustworthy, the centralized entity dismisses the request to expel it and communicates this decision to the community. This ensures that the entity remains engaged in the system without reputational damage. However, an inquiry is conducted with the party that initiated the request to investigate any potential misuse of the reporting mechanism.

This penalty mechanism is essential in both public and private environments to maintain a balance between fostering collaboration and safeguarding the network from malicious or dishonest entities. It ensures that trust is not only established but actively protected against misuse.

Fig 3 summarizes the trust-based model and the penalty mechanism.

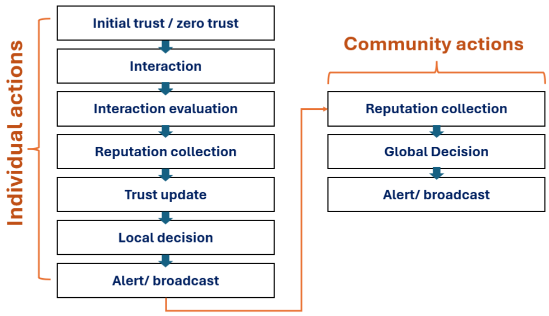


Figure 3: Trust-based models and penalty mechanism.

2.4 Limitations

The trust model, including the penalty mechanism, provides a structured approach to evaluating and managing trust within the system. While effective in many cases, it has inherent limitations that can leave the system vulnerable to manipulation and inaccuracies. Addressing these limitations is essential to ensure the reliability and security of trust and reputation values such as :

- Trust Violations
  1. False Data Injection: Malicious entities may share misleading or deceptive information, disrupting the trust evaluation process and compromising system integrity.
  2. Reputation Manipulation: Entities may exploit vulnerabilities in the model to inflate their trust scores or discredit honest participants by fabricating false claims.
  3. Sybil Attacks: Attackers may create multiple fake identities to manipulate trust calculations and dominate the decision-making process.
- Inaccuracy in Trust Evaluation
  1. Trust scores based on static or predefined thresholds may fail to capture complex behavioral patterns, resulting in delayed or incorrect trust assessments.
  2. Scalability Issues: As the number of entities in the system grows, aggregating feedback and applying penalty mechanisms become

resource-intensive, potentially slowing down the process.

3. Trust Decay and Erosion: Over time, trust values may become outdated or inaccurate without robust mechanisms for continuous verification, leading to potential breaches of trust and reduced system reliability.

To overcome these limitations, blockchain technology can be integrated into the trust model to enhance the security and robustness of trust and reputation management.

1. Immutable Trust Records: Blockchain ensures that all interactions, trust scores, and penalties are recorded on an immutable ledger, making them tamper-proof and verifiable.
2. Decentralized Trust Validation: By distributing the validation process across the network, blockchain reduces reliance on a single point of control, ensuring a fair and transparent evaluation process.
3. Sybil Attack Mitigation: Cryptographic mechanisms within the blockchain enforce unique identity verification, preventing malicious actors from creating multiple identities to manipulate trust values.
4. Dynamic and Automated Trust Management: Smart contracts can automate trust score adjustments and penalty enforcement based on predefined rules, ensuring consistency and reducing human intervention.
5. Scalability and Efficiency: Blockchain's distributed nature allows for efficient handling of trust calculations and penalties, even in large-scale systems, without bottlenecks or performance degradation.

By integrating blockchain as a foundational layer in the trust model, the system gains enhanced resilience against trust manipulation and ensures the integrity of trust and reputation values. This solution not only addresses existing challenges but also establishes a scalable, secure, and transparent framework for trust management in dynamic environments.

3 BLOCKCHAIN-BASED TRUST DESIGN

Blockchain (Bandara et al., 2021)(Zheng et al., 2017) is a distributed and immutable ledger that records transactions in a secure and transparent manner. This technology is leveraged to create trust in various applications (Fathi et al., 2020)(Badsha et al., 2020), including:

- Transaction Security: Blockchain ensures the security and integrity of digital transactions by recording them in a tamper-resistant and time-stamped manner. This builds trust among parties that the transaction history is accurate and cannot be altered.
- Data Transparency: The decentralized nature of blockchain allows multiple parties to have access to the same data in a transparent and synchronized way. This transparency fosters trust by reducing the need for intermediaries and providing a clear view of data and processes.
- Smart Contracts: Smart contracts, which are self-executing contracts with the terms of the agreement written into code, operate on blockchain platforms. These contracts automatically execute actions when predefined conditions are met, eliminating the need for intermediaries and increasing trust in contract enforcement.
- Identity Verification: Blockchain can be used for identity verification and management, allowing individuals to have more control over their personal information and who has access to it. This enhances trust in online interactions and reduces the risk of identity theft.
- Supply Chain Transparency: In supply chain management, blockchain can be used to track the provenance of products from manufacturer to consumer. This transparency builds trust in the authenticity and quality of products.
- Digital Ownership: Blockchain can establish and verify ownership of digital assets such as art, music, or digital collectibles. This ensures that individuals have true ownership of their digital property, fostering trust in digital markets.

The implementation of both public and private architectures, such as Threat Information Sharing (TIS) platforms or open-source systems, offers significant opportunities for collaboration, innovation, and improved decision-making. However, these architectures also raise critical concerns that must be addressed to ensure their effectiveness and security:

- Data Trustworthiness: In both public and private architectures, ensuring the trustworthiness of shared data is a major concern. Companies worry about sensitive information falling into the wrong hands or being manipulated within the system. Establishing a basis for trusting other entities, verifying the authenticity of shared events, and detecting malicious or fabricated data remain ongoing challenges.

- Selective Data Sharing: Public architectures, such as open TIS platforms, allow data and events to be accessible to all members of the community. However, companies often prefer to share data selectively, limiting access to entities that meet specific criteria aligned with their interests and trust levels. Private architectures also face challenges in implementing granular access controls to ensure data reaches only the intended recipients.
- Data Integrity Assurance: Maintaining the integrity of data shared within both public and private architectures is essential. Unauthorized alterations can compromise trust and reliability. While public platforms rely on their creators' security measures, concerns arise regarding the potential for tampering or modifications for political, governmental, or organizational reasons. Similarly, in private systems, ensuring transparency and accountability in data handling is crucial to prevent internal misuse or errors.

These challenges represent the core issues faced by organizations when adopting public or private architectures. Key concerns include the lack of privacy between entities, undefined trustworthiness criteria for participants and data, and the need for enhanced transparency and assurance regarding data integrity beyond the reliance on platform-specific security measures or legal agreements. Addressing these issues requires robust frameworks and technologies to secure trust, integrity, and accountability in both types of architectures.

3.1 Blockchain Design Components

- Entity: The main entity inside a community, either private or public, will be the organizations. These entities will represent the holders of the trust levels of their employees or members. For that, it will affect positively or negatively the level of trustworthiness of its members and vice versa, which means the members will also affect the trust level of the organization by their behavior and information. So we design an organization as the main entity of the system, since later on, the trust level of a user will be the trust level of his organization.
- Users: They are the manipulators of actions inside the system. In other words, they are the individuals interacting within the system, performing actions such as contributing, evaluating, and exchanging trust or recommendations. They operate under the umbrella of their associated entity, and their trust level is often tied to the collective reputation of that entity. This allows for distinguishing users from one another and monitoring their activities in a secure and transparent manner. Every user must belong to an organization and they will be given the same level of trust. For that, compulsory data must be gathered from a user and stored inside the system to distinguish one user from another.
- Administrator: The administrator oversees the proper implementation, maintenance, and security of the blockchain-based system across both public and private architectures. Their responsibilities include developing, deploying, and maintaining self-executing contracts on the blockchain. Additionally, they manage user accounts, permissions, and access to blockchain applications, ensuring compliance with organizational policies. In private architectures, administrators may also negotiate with service providers, manage service-level agreements, and enforce adherence to company policies.
- Records: The user initiates the update process by submitting the changes they want to make. This could involve editing existing information, adding new data, or deleting outdated entries.
- Blockchain: All transactions on the blockchain are recorded and stored in a chronological and immutable ledger. Trust-related transactions, such as changes in trust levels or ratings, are added to this ledger. These transactions serve as a historical record of trust evolution.

4 BLOCKCHAIN ARCHITECTURE

Any architecture can adopt either a public or private design, depending on the use case and target audience:

- Public Design: These architectures are fully open and accessible to a broad audience. Examples include open-source platforms, where code and resources are freely available for collaboration, and public threat information-sharing systems, where organizations share data to collectively combat cyber threats. Public architectures prioritize transparency and community involvement but face unique challenges in ensuring trust and security.
- Private/Targeted Design: These architectures are restricted to a specific group of participants and

prioritize confidentiality, control, and targeted collaboration. Examples include private software supply chains, where organizations securely manage their proprietary software development lifecycle, or private data-sharing frameworks that require strict access control and data integrity.

For each type of architecture—public or private—it is crucial to implement a blockchain framework tailored to its specific requirements. The blockchain must address the unique challenges of the architecture, such as enhancing transparency and trust in public systems or ensuring strict access control and tamper-proof interactions in private systems. This adaptability ensures that the blockchain solution aligns with the design principles and security goals of the respective architecture.

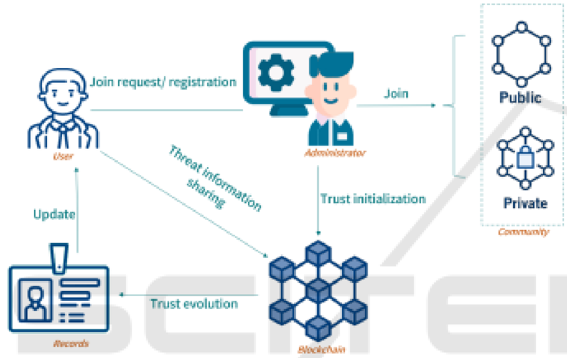


Figure 4: Global architecture.

4.1 Private Community Architecture

In the private community architecture, communication between participants is maintained continuously. When a new entity joins the community, the data is sent to the blockchain. The blockchain layer then verifies the data's validity, and upon confirmation, the server sends a permission token to the demonstrator. Trust initiation is calculated for the new entity, and a wallet is created for them, with their addition to the blockchain as a recognized entity. For trust value updates, the platform sends information consisting of the entity and the updated trust value. The blockchain calculates the difference between the old and new trust values, generating a new block for the transaction. The consensus algorithm validates the creation of this new block.

4.2 Public Community Architecture

The public community (see fig 6) shares some similarities with the private community in terms of its operation. However, there are distinct differences in

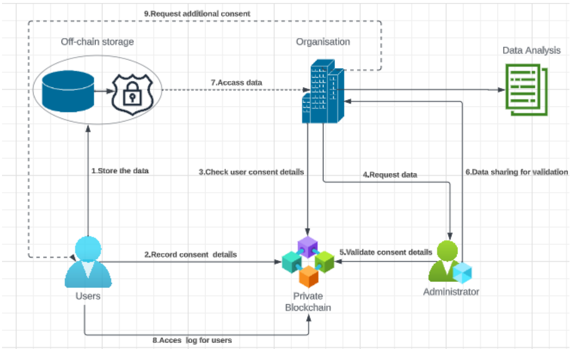


Figure 5: Private Blockchain architecture.

its functioning. Firstly, the public community employs multiple servers distributed globally to address network latency. Additionally, authority nodes play a critical role in validating or reporting newly created blocks. These nodes also have the responsibility of monitoring server statistics and ensuring network availability.

4.3 Consensus Algorithms

The consensus algorithm plays a pivotal role in validating the creation of each newly generated block. Both PoW (Proof of Work) and PoS (Proof of Stake) consensus algorithms may not be the most suitable choices for deployment. This is because relying on miners may not align with the preferred method of block creation. Instead, the concept of authority nodes proves beneficial as trusted nodes can exert influence based on established trust. Another factor influencing the choice of the appropriate consensus algorithm is the verification of entity identities. Ensuring that at least 75 percent of the entities are not malicious is a significant consideration. In light of these factors, the decision has been made to implement two alternative consensus algorithms. Specifically, the Practical Byzantine fault tolerance (PBft) algorithm will be employed for private communities, while the public community will adopt PBft with the validation of authority nodes.

- For private community: The architecture of private communities ensures continuous communication between the demonstrator and its members. When a new entity joins the community, the demonstrator promptly transmits the participant's data. Subsequently, the blockchain layer undertakes the crucial task of validating this data. Once the data is confirmed as valid, the server issues a permission token to the demonstrator. Simultaneously, it computes the initial trust level for the new entity, creates a dedicated wallet for them, and officially registers them on the blockchain as

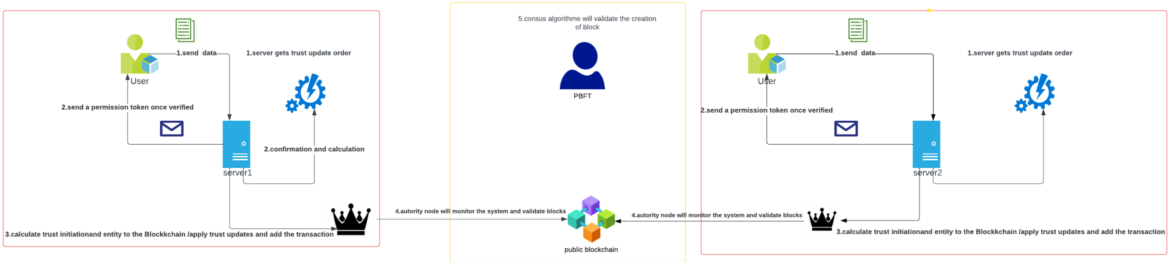


Figure 6: Public Blockchain architecture.

an entity. Regarding trust value updates, the platform is responsible for transmitting relevant information, which includes the entity's identity and the updated trust value. The blockchain layer then calculates the difference between the previous and new trust values, resulting in the generation of a fresh block for this transaction. The final step involves the consensus algorithm's validation of the newly created block.

- Public community: The operation of the public community shares some commonalities with the private community, albeit with notable distinctions. One significant difference is the presence of multiple servers distributed globally to address network latency efficiently. Additionally, the public community introduces the concept of authority nodes responsible for the validation or reporting of newly generated blocks. Furthermore, these authority nodes play a pivotal role in monitoring server statistics and ensuring overall network availability.

4.4 Technologies

Many technologies were investigated and compared, so the final ones were chosen.

4.4.1 Blockchain

Researching blockchain technologies provided many open-source options for the creation of this threat information-sharing system blockchain. For that, multiple technologies were tested and they will be presented in this section and put into a comparative table to decide what is the best choice.

- Hyperledger fabric: IBM's Hyperledger Fabric is a created platform for developing applications or solutions with an architecture based on modules. Hyperledger Fabric is used for blockchain creation and component customization, like consensus and smart contracts, to be plug-and-play. Its design satisfies a broad range of industrial use cases. It offers a singular approach to consensus that permits performance at scale while preserving scalability and efficiency.
- Hyperledger Sawtooth: IBM's Hyperledger Sawtooth enables a flexible and module-based architecture that separates the core system from the application domain. So that the smart contracts can detail the business rules for the applications without the need to know the hosted design of the core system. By default, a variety of consensus algorithms are implemented in Hyperledger Sawtooth, including Practical Byzantine Fault Tolerance (PBft) and Proof of Elapsed Time (PoET).
- Hyperledger Besu: IBM's Hyperledger Besu is an Ethereum platform that designates a client to be friendly for enterprises that are used for both public and private permissioned networks. It can also be deployed on test networks such as Rinkey, and Görli. Hyperledger Besu includes many consensus algorithms such as Proof of Work, and Proof of Authority (IBFT, IBFT 2.0, Etherhash, and Clique).

Based on the comparison between the technologies illustrated in Table 1, Hyperledger Sawtooth was the chosen technology to be implemented in the threat information sharing system since it provides an implemented Bit consensus algorithm by default, supports permissioned public and private blockchains and can be developed in multiple languages.

Table 1: Comparison of Blockchain Technologies.

Technology	PBFT	Permissions	Communities	Language
Fabric	Unsupported	Permissioned	Public/Private	js / java / goLang / python
Besu	Unsupported	Permissionless	Public	Solid (Ethereum)
Sawtooth	Supported	Permissioned	Public/Private	Python/java / goLang / rust/cxx / js

4.4.2 Cryptography

For creating the ledger and securing the information inside wallets and blockchains. It is necessary to choose convenient cryptographic algorithms to ensure these features. For ledger creation, MD5 hashing will be used for data encryption. It might be changed to

SHA-512 or SHA-256 if it does not prove its efficiency after the simulations. For token creation, the system will generate JWT tokens for permissions and access. And for the blockchain blocks that need to remain non-plain texts. Base 64 cryptography will encrypt the payloads. And finally, RSA public and private keys will be the keys to participating as a node inside the blockchain.

4.4.3 Scripting

Since Hyperledger Sawtooth supports multiple languages, Python represents a suitable solution for developing the blockchain in the Hyperledger Sawtooth, for creating both the needed scripts for functionality deployment and the back-end of the authority engine and for developing the simulation scripts. Python is the simplest language in terms of syntax since it provides multiple modules that will be needed inside the threat information-sharing system such as cryptography, HTTP servers, and mathematical tools. The Authority engine front-end, on the other hand, will be developed using Angular, which is an open-source TypeScript-based web application framework created by Google Inc. Angular is chosen for the Authority engine front-end.

5 BLOCKCHAIN'S IMPLEMENTATION

5.1 Private Community

Private communities (Hou and Jansen, 2023) will operate as on-demand blockchains. Any entity within the blockchain network has the capability to request the demonstrator to establish a new private community and define the entry criteria. This request undergoes a thorough assessment by the threat information system, and once it is determined to be suitable for deployment, the demonstrator initiates the process of creating the new private community within the host system.

As previously mentioned, the steps necessary for setting up a new blockchain will be repeated; however, this time, the process will be automated. Special scripts will be employed to generate a new Docker file in a pristine directory, configure rules and specifications, and subsequently deploy this blockchain onto the host machine.

5.2 Public Community

The initial function within the communication layer is the "joining" function. To start, this function initiates a listener to capture the incoming data from newly joined entities. It performs several checks, such as ensuring the data's validation and uniqueness, including parameters like pre-trust value, geolocation, and capabilities. A Python function has been implemented to verify the correctness of these incoming requests.

Subsequently, the function employs the previously mentioned trust initiation script. This script computes the initial trust value within the trust model utilized by the threat information-sharing system, based on the data provided by the newly joined entity. Upon calculating the trust initiation, the script generates a JSON wallet containing the user's details, including their trust value. Additionally, it creates a new node within the blockchain, associating it with the user's username and trust value.

Upon successful entry into the community, the script generates a permission token designed for the public community. This token is generated using PYjwt, a Python module for creating JWT tokens. The token is then transmitted back to the threat information-sharing demonstrator for delivery to the user.

After successfully sending the response, the script proceeds to hash the newly created wallet and add it to verification ledgers. To verify this process, blockchain logs are examined. It is observed that each time a joining request is submitted, the Hyperledger Sawtooth validator generates a public and private key for the new user. Additionally, it creates a new block containing the user's trust value along with their public key. Verification can also be confirmed by visiting the rest-API address with the "state," where a new batch containing the newly created user's public key and associated trust value, encrypted using the base-64 cryptography algorithm, is evident.

6 VALIDATION AND TESTING

The testing results of the simulation will be illustrated in this section. Six simulations were put to the test to prove the work of the simulation scripts in the first place and see the allure of the growth functions in the second place. The graphs illustrated do not show real values due to company data confidentiality.

6.1 Entities Joining

This section presents the analysis of three graphs generated by blockchain entity joining simulation scripts. The results provide valuable insights into the behavior and performance of the blockchain system under varying conditions.

***Data Size Per Node**

The first graph (Fig 7. a) demonstrates the relationship between the number of nodes and the size of wallets (in bytes). The results exhibit a clear linear trend, where each node contributes a predictable amount of data to the system:

- At 1 node, the size of wallets is approximately 400 bytes.
- At 3 nodes, the size increases to around 1000 bytes.
- At 6 nodes, the size reaches approximately 1800 bytes.

This linear behavior indicates that the system is scalable with respect to wallet data storage, as the data size grows proportionally with the number of nodes.

***Blockchain Growth**

The second graph (Fig 7. b) illustrates the total size of the blockchain (in bytes) as new nodes are created. Similar to the wallet size, the blockchain size also grows linearly with the number of nodes:

- At 1 node, the blockchain size starts at around 5600 bytes.
- By 3 nodes, the size increases to approximately 5900 bytes.
- At 6 nodes, the blockchain size grows to about 6200 bytes.

This trend highlights the system's ability to handle continuous node creation without exponential growth in data storage requirements, which is critical for scalability and long-term maintenance.

***Node Creation Delay**

The third graph (Fig 7. c) examines the delay associated with node creation. Unlike the previous two metrics, the delay exhibits fluctuations influenced by external factors such as system load and network latency:

- At 1 node, the delay is approximately 2.66 seconds.
- At 2 nodes, it decreases slightly to 2.64 seconds.
- At 3 nodes, it increases to around 2.70 seconds before fluctuating in subsequent nodes.

These variations suggest that node creation time is not constant and depends on the system's state and external conditions. This unpredictability could impact performance in real-world applications, necessitating further optimization to reduce delays and improve reliability.

The simulation results highlight the following:

- Scalability: The wallet size and blockchain growth exhibit linear trends, confirming that the system is scalable in terms of data storage as nodes are added.
- Performance Challenges: The fluctuations in node creation delay reveal potential challenges in system performance, influenced by factors such as network latency and processing efficiency. Addressing the variability in node creation delay through optimization strategies can enhance the overall reliability and responsiveness of the blockchain system.

6.2 Transactions

This section presents an analysis of three performance graphs generated by blockchain transaction simulation scripts, offering insights into transaction delays and data scalability.

***Transaction Creation Delays**

The first graph (Fig 8. a) illustrates the delays associated with the creation of individual transactions. These delays are influenced by random transaction amounts and data sizes. Key observations include:

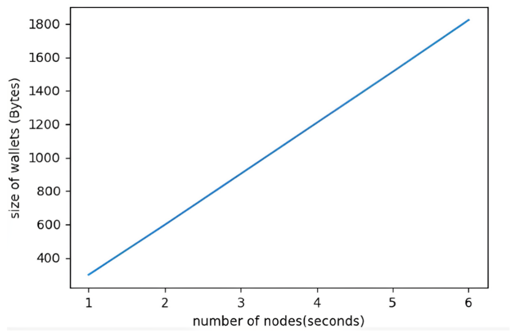
- For a small number of transactions (e.g., 1 to 2 transactions), the delay is relatively low, approximately 2.64 seconds.
- At 3 transactions, the delay peaks at around 2.70 seconds, before fluctuating as more transactions are added.
- The delay function demonstrates non-linearity, with unpredictable spikes and dips caused by factors such as network latency, hardware conditions, and the dynamic state of the system.

This variability highlights the challenges in predicting transaction creation times in real-world scenarios, emphasizing the need to account for underlying infrastructure when designing blockchain systems.

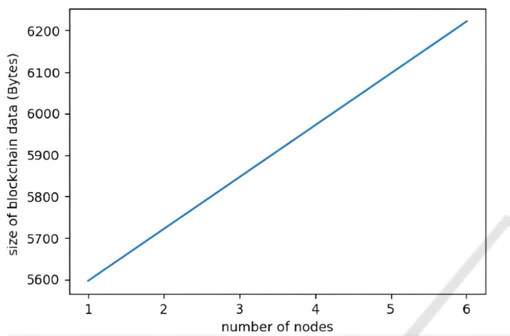
***Simultaneous Transaction Creation Delays**

The second graph (Fig 8. b) examines delays in simultaneous transaction creation, where multiple transactions are processed concurrently. Similar to the previous graph:

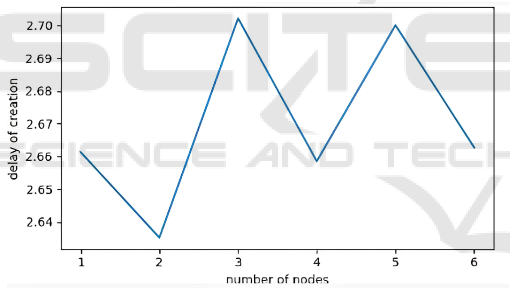
- Delays range between 2.64 seconds and 2.70 seconds, depending on the number of transactions.
- The graph shows irregular trends, reflecting the impact of system congestion, network conditions,



(a) Size of Wallets vs Number of Nodes.



(b) Size of Blockchain Data vs Number of Nodes.



(c) Creation Delay vs Number of Nodes.

Figure 7: Analysis of blockchain performance metrics: (a) Size of wallets, (b) Size of blockchain data, (c) Delay in creation.

and the computational overhead of simultaneous operations.

Both the first and second graphs reveal that transaction delay metrics exhibit non-linear behavior, underscoring the need for further optimization in blockchain implementations to reduce delay variability and enhance performance.

***Transaction Data Size**

The third graph (Fig 8. c) depicts the total size of transactions as the number of nodes increases. Unlike the delay metrics, this graph follows a clear linear trend:

- For 1 transaction, the data size starts at approximately 400 bytes.
- At 3 transactions, the size grows to around 1000 bytes, and by 6 transactions, it reaches approximately 1800 bytes.

This linearity indicates that the blockchain system efficiently manages transaction data growth, maintaining predictable storage requirements as the number of transactions increases. Such scalability is critical for ensuring the system's ability to handle larger transaction volumes over time.

***Interpretation**

The results from the simulation highlight key characteristics of blockchain performance:

- Delay Metrics: Both individual and simultaneous transaction creation delays exhibit non-linear behavior, influenced by external factors like network latency and system state. This unpredictability may impact system responsiveness and reliability, calling for strategies to optimize performance.
- Scalability: The linear growth of transaction data size demonstrates the system's scalability, ensuring predictable and manageable storage requirements even as transaction volumes increase.

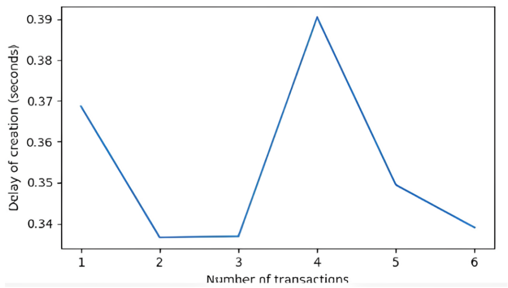
These findings provide a comprehensive understanding of the blockchain system's behavior, identifying areas for improvement in delay predictability while affirming its scalability for future growth. This analysis serves as a foundation for optimizing blockchain performance in diverse applications.

6.3 Trust Level Evaluation

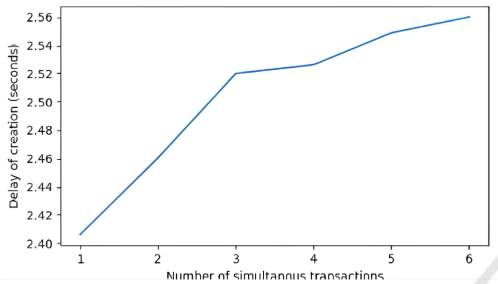
- Power consumption: According to information from the Ehow.com website, the power consumption of a server typically ranges from 500 to 1,200 watts per hour. This averages out to around 850 watts per hour. When considering a full day of operation (24 hours), this equates to 20,400 watts per day or 20.4 kilowatts (kW). Over the course of a year (365 days), this amounts to 7,446 kWh, based on data from the US Energy Information Administration.

  Taking into account the average commercial electricity cost in Germany, which is 0.0683 Euros per kWh, the annual cost to power the server would be approximately 542.94 Euros.

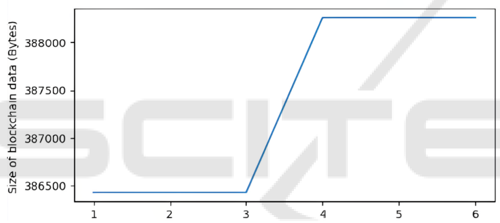
  To make informed decisions about where to host the threat information sharing system and minimize power consumption costs, an investigation was conducted by comparing the host server's power consumption to the typical usage of a server. These statistics will guide the corporation in choosing the most cost-effective hosting location.



(a) Wallet Size (bytes) vs Transaction Numbers.



(b) Blockchain Size (bytes) vs Transaction Numbers.



(c) Node Creation Delay (seconds) vs Transaction Numbers.

Figure 8: Performance analysis of blockchain metrics: (a) Wallet size, (b) Blockchain size, (c) Node creation delay, all as a function of transaction numbers.

- Scalability investigations: To gain a comprehensive understanding of the scalability challenges faced by blockchain systems, it's instructive to delve into the early days of Bitcoin's operation. Bitcoin, while a relatively simple blockchain with a specific use case—sending and receiving digital currency—experienced scalability issues right from its inception. The core problem revolved around ensuring that this decentralized network could effectively manage a continually increasing user base. This challenge can be likened to a fundamental computer networking dilemma: the available bandwidth to process transactions is finite. Furthermore, each user must validate transactions by referencing the blockchain records, a process that demands a certain amount of storage space.

  To address this, simulations were conducted to scale up the number of system entities and transaction volumes by deploying millions of them. This simulated state represents the potential condition of this trust-based blockchain in the years to come. Subsequently, the system was set into motion, and all prior simulations were rerun to calculate updated statistics and observe the blockchain's performance on a larger scale. The aim of this simulation is to provide the organization with valuable insights into what can be anticipated after years of blockchain growth. These insights will enable the organization to formulate an effective strategy to preemptively address any impending challenges.

- Trust and reputation management model investigation: The trust model, which is currently under development and not in its final form, will undergo a series of simulations to assess its functionality comprehensively. These simulations will rigorously test all aspects and values related to trust. To ensure robustness, organizations involved will identify potential attacks that could impact the trust and reputation management system and subsequently simulate these scenarios once the system is deployed. The outcome of these simulations will inform the refinement of mathematical formulas and weightings within the trust model of the threat information-sharing system. This phase is deemed the most critical simulation within the entire project, and the organization has determined that it warrants a separate, dedicated project for its execution.

7 DISCUSSION

This study sheds light on the challenges and limitations associated with integrating a blockchain-based trust architecture into threat information-sharing platforms. While the proposed system demonstrates promise in addressing key issues such as trust management and data integrity, several limitations were identified during simulations and security assessments. One significant limitation is the vulnerability of the system when the proportion of malicious entities within the network exceeds 50

Another challenge lies in the computational and storage overhead associated with the implementation. Blockchain inherently requires significant resources to maintain an immutable ledger, which becomes increasingly demanding as the system scales. This limitation could hinder its deployment in environments with limited infrastructure or when handling large volumes of transactions and data. Furthermore, latency issues observed in the simulations indicate that the system may face delays during peak operational periods, which could affect its responsiveness and usability in real-world scenarios. The trust model, while effective in many cases, also requires refinement to address sophisticated attacks that attempt to manipulate reputation scores or exploit vulnerabilities in the penalty mechanisms.

Despite these limitations, the system represents a robust framework for enhancing trust and security in both private and public architectures. By combining blockchain with trust modeling and penalty mechanisms, the architecture provides a comprehensive solution for managing and securing shared information. However, addressing the identified shortcomings is essential to ensure its effectiveness and scalability in diverse operational environments.

8 CONCLUSION AND PERSPECTIVES

This paper presents an emergent approach to addressing the growing challenges of cybersecurity by introducing a blockchain-based trust architecture for public and private architectures. The study builds upon the inherent strengths of blockchain, such as decentralization and immutability, and combines them with a trust model and penalty mechanisms to create a multi-dimensional security solution. The proposed system effectively addresses the needs of both private and public architectures, ensuring trust and accountability among participants while maintaining data integrity and resilience.

The work highlights the pressing need for robust cybersecurity solutions in the face of increasingly sophisticated threats. By leveraging blockchain and trust modeling, the proposed architecture represents a significant step forward in securing shared threat information. Extensive simulations and security evaluations confirm its potential to enhance system reliability and scalability.

In our future work, to continue advancing this field and addressing the ever-evolving cybersecurity landscape, we will explore methods to improve the scalability and performance of blockchain networks for handling large volumes of threat information while maintaining efficiency. Future work in these areas can contribute to the ongoing improvement and effectiveness of blockchain-based trust and reputation systems for threat information sharing, ultimately strengthening cybersecurity defenses and reducing the impact of cyberattacks on organizations and society as a whole.

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