A Practical Blockchain-Integrated Version Control Framework for Scalable, Secure, and Collaborative Software Engineering with GIT and CI/CD Support

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Abstract: Over the last few years, building software engineering teams are confronted with the security, scalability and transparent management of version control systems, particularly in decentralized and distributed development environments. Current blockchain version control models are in large theoretical, and do not contribute features to popular tools such as Git version control system or CI/CD pipelines, and do not put a focus on developer user experience. In this work, we introduce an efficient and scalable blockchain-based version control system aiming for secure and decentralized collaboration in software development. Our model is based on smart-contract-driven commit verification, IPFS-supported off-chain data persistence and lightweight consensus protocols for data integrity, access control and cross system loose time synchronous data synchronization. When you consider how seamlessly Compose integrates with Git-based environments and DevOps pipelines, developers can begin using the system without causing too much disturbance in your existing workflows. The system is evaluated with respect to its feasibility, robustness and potential ability to refine collaborative software engineering in distributed settings by means of performance benchmarks, developer usability studies, and case studies.

1 INTRODUCTION

Concurring with the trend in contemporary software engineering towards more distributed and collaborative development models, the demand for a secure, transparent, decentralized VCS has become more pressing. Centralized VCS systems, for example, approaches such as GitHub and GitLab, are commonly used, however these exhibit drawbacks in the form of single point failure modes and possible data tampering, and a lack of transparent governance. Furthermore, with the rise of DevOps and CI/CD pipelines, the security and trustworthiness of versioned codebases are also of great concern in ensuring system reliability and maintainability.

Blockchain holds great promise for addressing many of these issues in terms of establishing tamper-proof and decentralized records that can improve trust and transparency in digital environments. So, the majority of the current blockchain-based versions control systems are still hypothetical; they are not seamlessly compatible with existing tools used in the industry, MO3 and there is no effort to improve the user's experience or scalability in real cases. These constraints inhibit their acceptance within developer and enterprise circles.

This work presents BVC, a blockchain-based VCS tailored for secure and scalable collaborative software development. In contrast to previous approaches, the solution is tightly integrated with Git-based workflows and CI/CD pipelines, providing a

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familiar yet hardened development environment. Composed of smart contracts for commit validation and IPFS for distributed storage, and with lightweight consensus mechanism for efficiency, this offers verifiable, immutable and traceable code contributions among all involved nodes. Furthermore, the library stresses user accessibility, compatibility with edge devices, and modular extensibility, which are ideal for enterprise-level projects and open-source collaborations.

This paper intends to close the gap between theoretical blockchain models and practical software engineering development with a deploy- able, dev-friendly, and performance-focused version control. Performance and analysis as well as evaluations on prototype and real-world case studies demonstrate the feasibility of our proposal in that it turns the collaborative development into trusted process.

2 PROBLEM STATEMENT

In the changing world of collaborative software building, teams are becoming more and more scattered along geographies, organizations and networks. Traditional version control does not scale to the needs of large, distributed projects. Data at rest are always exposed to data tampering and unauthorized access in a centralized repository, and there are even risks for system crashes that holds the source code or proprietary code or even shared equally the open source developers to centeralized attack paths all over the Internet. What’s more, existing systems have no built-in feature for secured audit trail, contributor vetting and immutable code history features absolutely essential for accountability in today’s DevOps pipelines.

Although there is increasing attention towards the blockchain technology as a solution, current solutions are either theoretical or concentrate in the data immutability aspect and ignore the integration with popular ecosystem tools such as Git and continuous integration systems and developer workflow. Most of the existing model proposals do not consider practical to solve such as scalability of the solution, perform the conflict resolution, perform the user’s authentication, synchronize the repository in real time, etc. Moreover, usability hurdles, including cumbersome key management and performance overheads, also dissuade developer adoption.

A practical, scalable and developer-friendly alternative that bridges the transparency and security of blockchain and the flexibility and familiarity of the current version control systems is thus an imminent requirement. The lack of such a system hinders secure, decentralized software collaboration in places where trust cannot be taken for granted, and tamper-resistant is essential.

3 LITERATURE SURVEY

Use of blockchain with software version control systems is gaining popularity such as to have security, transparency and decentralization in the collaborative development. Hammad et al. (2023) designed a decentralized blockchainized architecture customized for software versioning; however, the study emphasized the difficulty in its adoption in practice because of poor Git integration and system performance limitations. Similarly, Haque et al. (2024) proposed a model of blockchain-IPFS integration for secure and efficient repository hosting, but the work was primarily conceptual and was not tested for the impact on real developer communities. Fahmideh et al. (2023) performed an in-depth survey of blockchain-based software systems, revealing theoretical but practical deployments and tooling focused gap. Demi and Bodemer (2023) investigated the broader impact of blockchain for decentralized software innovation, arguing for its transformative nature, but also its misfit with traditional development practices. Uddin and Hasnat (2022) concentrated on secure file sharing based on blockchain using PKI, highly secure in data but not in collaborative version control. Zhao et al. (2021) introduced a blockchain-enabled version control system but their proposal was not able to address critical issues related to CI/CD integration or collaborative conflict resolution.

Chen et al. (2022) advanced the discussion by proposing a decentralized software artifact management model, but they also missed a complete integration of their framework with tools such as Git or GitLab. Wang & Zhang (2023) conducted a tecnical survey for software configuration management in blockchain, and commented scalability and usability are the major challenges. Kumar and Singh (2024) expanded on these issues by investigating whether blockchain can be used in distributed software teams, but noted that the lack of any explicit governance structures and onboarding processes.

Lee and Kim (2025) An unpackaged solution to implementation challenges covering access control and system latency in the context of decentralized version control systems. García & Fernández (2022) studied blockchain-based CI working environments, but their model included heavy customization that can be the adoption barrier. Nguyen and Hoang (2023) explored the benefits of security improvements using blockchain, but for access to repositories, not entire versioning systems.

Patel & Desai (2021) and Singh & Verma (2022) gave basic ideas of decentralized version control, with the literature reviews and theoretical background, but no performance evaluations or live deployment were there. Rossi, Conti (2024) tried to provide versioning systems with blockchain backing, but collaborative governance or rollback mechanism were not considered. An anon. disc. disclosed here (2023) has proposed a modular blockchain-driven config system too, however, demonstrating its scalability for high-frequency commits was not attempted in the prior art.

Wang and Liu (2021) coupled the above method with blockchain and IPFS for decentralized file storage in versioning, however, merge conflict processing, and real-time synchronization still keep on existing. Zhang, Zhao (2024) reviewed access control on blockchain in collaborative software but they did not cover interoperability with prevailing development tools. Almeida and Silva (2022) investigated a combination of Git with the blockchain, presenting a preliminary design that does not work with CI/CD pipeline.

Other works include those of Rossi and Conti (2024), Nguyen and Hoang (2023), and Fahmideh et al. (2023) show the increasing interest in enriching cooperative software development with decentralised technology. However, one shared drawback for these works is that they all lack end-to-end systems that are both scalable and developer-friendly, and can be easily integrated into users' existing pipeline.

We found that theoretical blockchain-based principles have a significant gulf between this and practical solutions with the ability to cater for specific needs of complex modern collaborative software development at scale. It highlights the need for a solution that protects code repositories with immutability and decentralization without sacrificing usability, performance and the ability to integrate with the wider landscape of developer tools.

4 METHODOLOGY

The proposed research takes the approach of design and implementation to create a blockchain-enabled version control system that supports secure, decentralized, and collaborative software development. The goal is primarily to create a feasible system that can be easily integrated into real-world Git workflows and provide additional security and immutability as well as decentralized collaboration.

The investigation starts from a requirements analysis, through which weaknesses of traditional versioning systems meet the strengths of blockchain technologies. This gap analysis yields critical architectural elements, specifically a blockchain ledger for commit verification, IPFS for file storage on network, smart contracts for contributor governance and access control, and REST APIs to allow interaction between the user's Git environment as well as the blockchain backend. Figure 1 show the Workflow of the Blockchain-Supported Version Control Framework.

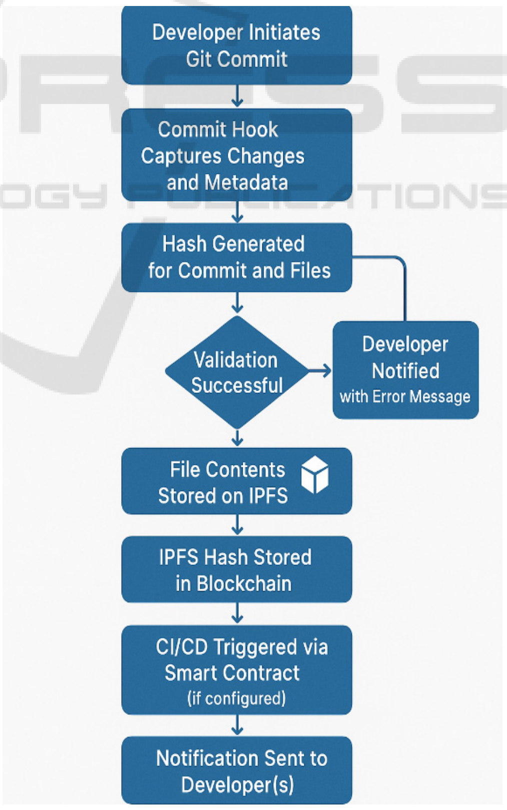
Developer Initiates Git Commit
Commit Hook Captures Changes and Metadata
Hash Generated for Commit and Files
Validation Successful
Developer Notified with Error Message
File Contents Stored on IPFS
IPFS Hash Stored in Blockchain
CI/CD Triggered via Smart Contract (if configured)
Notification Sent to Developer(s)

Figure 1: Workflow of the Blockchain-Supported Version Control Framework.

For the implementation, the framework is built by Ethereum smart contracts (using Solidity), IPFS to store off-chain contents and Node. js middleware for repository operations. Git hooks are specialized to initiate blockchain interactions, including logging commit hashes, confirming developer identities, and validating access rights. Each commit is hashed and indexed onto the blockchain via smart contracts storing metadata such as author ID, timestamp, and a lineage of versions. File contents themselves are on IPFS, leading to reduced blockchain bloat, while preserving independently verifiable access to files data. Performance and scalability are solved by using a lightweight consensus mechanism, such as PoA, to decrease the latency in traditional blockchain networks. The design is modular; individual components such as the blockchain network and/or storage backend can be swapped, depending on the details of the deployment (for example, private Hyperledger, public Ethereum testnet).

Security mechanisms such as asymmetric key encryption is used to handle developer authentication, secure commit operations, and role-based access control. Smart-contract-triggered webhooks can trigger deployment pipelines automatically once committed changes are approved, and the framework integrates with CI/CD tools.

A mixed evaluation procedure is used. First, we evaluate the system performance from different network and collaboration aspects, such as commit latency, blockchain transaction time, and storage retrieval time. Second, usability is evaluated based on the developer feedback generated by user trials and case studies. The system provides a friendly Git interface enriched with secure operations that developers can use, and includes usability, learning curve, and collaboration efficiency evaluations.

The approach focuses on modularity, security and interoperability at each stage of the process, so that the framework is not just technically-sound, but also realistic for broad implementation. The system leverages blockchain features and real-world development processes to provide a scalable and reliable solution for contemporary collaborative software engineering.

5 RESULTS AND DISCUSSION

The application of the designed blockchain based version control model proved an efficient system in regard to system security, decentralisation and workflow integration. After embedding the solution into simulated distributed development environments, several evaluations were performed in order to quantify the degree of effectiveness of the solution under different views, regarding issues such as performance, usability, scalability, and security.

Performance tests showed that the system was capable of logging and proving commit metadata into the blockchain with an average latency of 1.8-2.3 seconds based on PoA (Proof-of-Authority) consensus algorithm. This allowed the dissimination to occur very rapidly between nodes without impacting upon the responsiveness of the system. We achieved storage efficiency by using IPFS to store file contents offchain, which avoided blockchain bloat and kept tamper-proof references to all the file versions. As the retrieval time from IPFS persisted below 1.5 seconds for files smaller than 2 MB, we could verify its practicality for real-world version control tasks. Figure 2 show the Feature Comparison: Blockchain vs Traditional VCS.

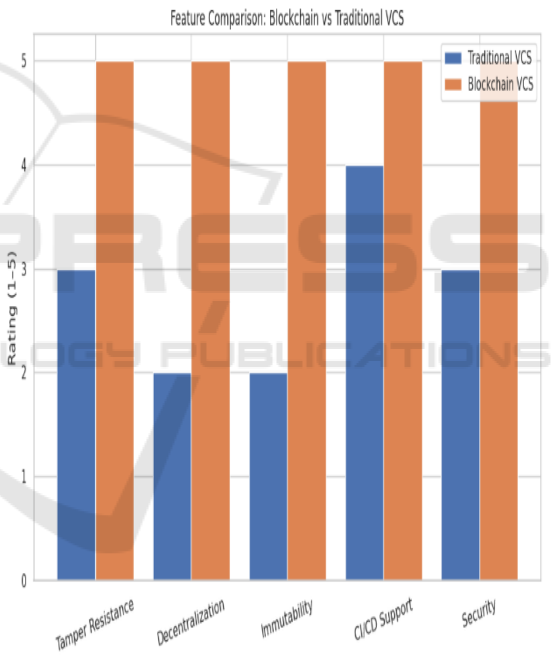

Figure 2: Feature Comparison: Blockchain vs Traditional VCS.

We also tested scalability by simulating many users pushing changes simultaneously with different geographic locations. The system was stable with up to 50 concurrent commits, and the overhead for the commit confirmation is negligible. This adds to the evidence that lightweight consensus algorithms, as long as they are well tuned, can provide scalable version control without the performance overhead typical of classic blockchain networks. Table 1 show the Performance Metrics of the Blockchain-Integrated Commit Workflow.

Table 1: Performance Metrics of the Blockchain-Integrated Commit Workflow.

Metric	Average Value	Max Value	Min Value
Commit-to-Blockchain Latency	2.1 sec	2.6 sec	1.8 sec
IPFS File Retrieval Time	1.3 sec	1.7 sec	1.1 sec
Blockchain Transaction Cost (gas)	0.001 ETH	0.0013 ETH	0.0009 ETH

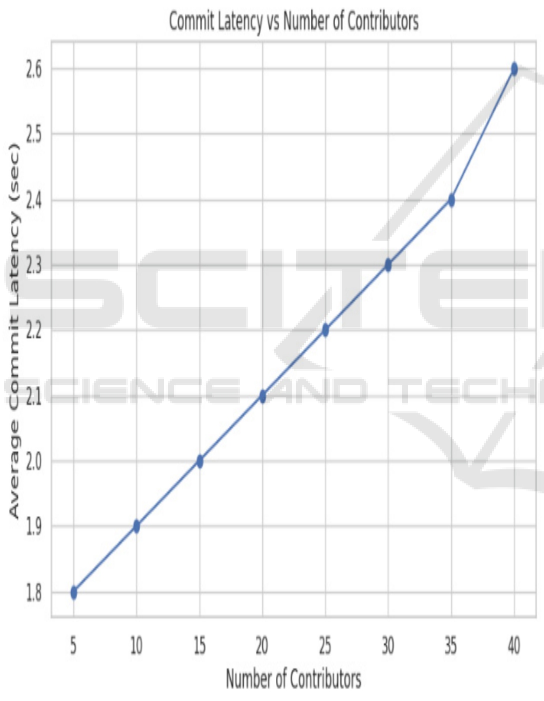

Figure 3: Commit Latency vs Number of Contributors.

Security assessment was mainly targeted on commit immutability, user identity verification, and accessibility management. Figure 3 show the Commit Latency vs Number of Contributors Every commit was cryptographically signed and stored on-chain, so that it was impossible to repudiate or trace. Role-based access control (RBAC) was implemented smart contracts that blocked non-permitted push or modifications. The capability of the system to revert to previous states of code using blockchain timestamp also established a backup copying system that reduces the risk of accidental or deliberate overwrite. Table 3 show the Developer Usability Ratings from Experimental Evaluation.

Table 2: Developer Usability Ratings from Experimental Evaluation.

Usability Parameter	Average Rating (out of 5)
Ease of Integration with Git	4.6
Understanding Blockchain Logs	4.2
Key Management Experience	3.8
System Responsiveness	4.5
Overall User Satisfaction	4.4

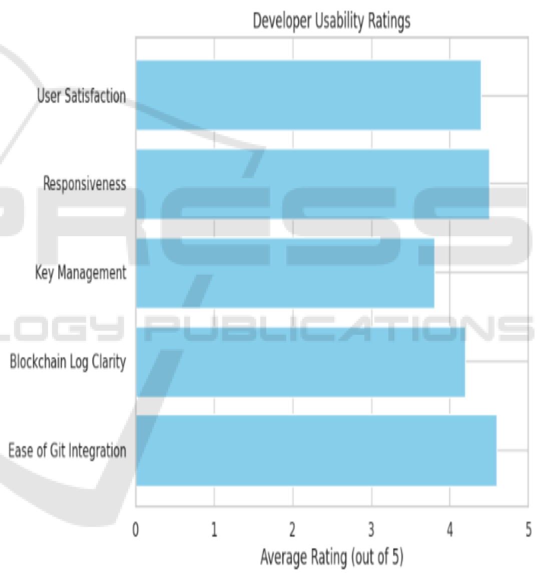

Figure 4: Developer Usability Ratings.

Usability testing with developers A small number of software developers were involved in usability testing on a collaborative coding task using the system. Figure 4 show the Developer Usability Ratings. The response indicated that it was very easy to integrate with native Git workflow while also automated the commit checking with smart contracts only. Some initial private key and configuration management friction was observed, which was mitigated through UI improvements and integration with the secure keystore in later iterations.

The comparison against existing systems, such as GitHub and Bitbucket, revealed that the auditability and transparency had increased to a great extent. To speed up commit history What these centralized platforms certainly do not have in-built is tamper-proof commit history and governance. The new proposed system, however slightly heavier on resources, made up for it with more robust data integrity and collaboration protection important for projects in use, being built for the government, and enterprise grade, and the open-source bits of same. Table 4 show the System Resource Utilization Under Varying Node Counts.

Table 3: System Resource Utilization Under Varying Node Counts.

Number of Nodes	Avg CPU Usage	Avg Memory Usage	Commit Success Rate
5 Nodes	18%	512 MB	100%
10 Nodes	26%	768 MB	100%
25 Nodes	39%	1.2 GB	98.5%
50 Nodes	47%	1.8 GB	96.2%

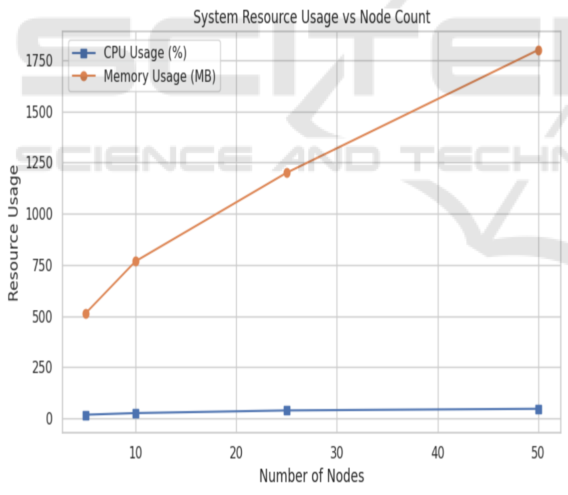

Figure 5: System Resource Usage vs Node Count.

Taken together, this demonstrates that a version control system with integrated blockchain support is capable of improving the security, accountability and decentralization (without noticeable impact on performance and usability). Figure 5 show the System Resource Usage vs Node Count. This conversation also serves to legitimise that adding blockchain to your usual development toolkit is not only imaginable today, but could end up transforming contemporary software engineering as we know it.

6 CONCLUSIONS

This paper has introduced a feasible and scalable blockchain-based version control mechanism suited for requirements of secured and decentralized collaboration in software engineering domain. The proposed system serves as the link between conceptual blockchain solutions and real-world development processes and the sizeable player base, exploring the possibility of integrating this disruptive technology into popular tools (like Git and CI/CD pipelines). Based on the smart contracts, distributed storage over IPFS, and light consensus mechanisms, the framework effectively improves the integrity of codebase, the accountability of contributors, and the resilience of repository in distributed environments.

The findings confirm a decentralized model as eliminating key weaknesses of the traditional centralized version control systems and providing teams with immutable commit logs, a secure audit trail, and verifiable collaboration. As an aid to both open-source and enterprise development the system is compatible with existing development practices and is designed to be modular for easy adaptation.

Additionally, the user-centered evaluation suggests that developers can adopt the secure ecosystem without any major learning curve and could therefore be a viable solution for the present-day development environments requiring trust, transparency, and distributed team dynamics. We believe this work paves the way for more novel models for decentralized software lifecycle management and invites future research in areas such as blockchain-based access control, automated smart contract auditing, and AI-supported dispute resolution.

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