Grenze International Journal of Engineering and Technology, June Issue

# Enhancing Electronic Health Record Interoperability through Blockchain Technology

Pathan Mushiya Katoon[1] and Dr. Anil V Turukmane[2]
[1]Research Scholar, School of Computer Science and Engineering, VIT-AP University, Vijayawada, AP, India
Email: mushiya.23phd7103@vitap.ac.in
[2]Professor, School of Computer Science and Engineering, VIT-AP University, Vijayawada, AP, India
Email: anil.turukmane@vitap.ac.in

***Abstract*—The swift digitization of healthcare has heightened the demand for secure, interoperable electronic health record solutions. Data fragmentation, security issues, and absence of standardization afflict conventional EHR systems. This study suggests that blockchain technology could mitigate these issues by enhancing interoperability throughout the healthcare sector. Blockchain technology has gained popularity in numerous real-world applications due to its traceability, immutability, and decentralization. Blockchain access authorization methods, consensus mechanisms, and block architectures differ by domain. Variations among blockchain systems create fragmentation, hindering interoperability. It has the potential to transform healthcare data management by enhancing security, granting patients autonomy, and facilitating efficient information exchange. Digital medical records securely save and administer diverse health information. EHR interoperability facilitates the seamless interchange of information among healthcare entities by instituting agreements for data storage, access, and interpretation, while safeguarding security, privacy, and trust.**

***Index Terms*— Blockchain, EHR, Interoperability, Cross-Chain Technology, Hyperledger Fabric, Ethereum, Notary Schemes and Hyperledger Cacti.**

## I. INTRODUCTION

BlockChain Technology has attracted significant public interest owing to its revolutionary features and disruptive capabilities. Functioning as a distributed ledger system, it enables direct transaction recording among participants, hence eliminating the need for intermediaries [1]. This digital ledger is upheld by a decentralized network of computers (nodes) that operates independently of centralized authority [2]. Owing to the security, immutability, accuracy, and transparency of blockchain technology, it is ideally suited for application across numerous domains [3].
EHR interoperability denotes the capacity of disparate electronic health record systems to function cohesively, facilitating the accurate exchange and interpretation of shared data irrespective of the originating vendor. This capability is essential for coordinating patient care among various healthcare providers, minimizing redundant testing, averting medication errors, facilitating clinical decision-making, enhancing population health management, and alleviating administrative burdens on healthcare professionals—ultimately improving patient outcomes while potentially lowering costs within the healthcare ecosystem.

*Grenze ID: 01.GIJET.11.2.550*

## II. BACKGROUND

Healthcare 2.0 (1991–2005) enhanced provider accessibility through digital monitoring, imaging, online communities, and cloud-based records, notwithstanding privacy apprehensions. Healthcare 3.0 (2005-2016) personalized interfaces, electronic records, wearable or implanted monitoring devices, and autonomous systems utilizing social media for data interchange. Cloud computing, big data analytics, artificial intelligence, blockchain, and virtualization facilitate real-time healthcare data and enable predictive and personalized care in healthcare 4.0 (2016–present) [4].

The Health Information and Management Systems Society defines interoperability as "the capacity of disparate information technology systems and software applications to communicate, exchange data, and utilize that data."20 inches Gordon and Catalini identified several advantages of employing blockchains for interoperability. Efficient interoperability can diminish the duration required to transmit medical records to alternative facilities. Distributing data on a well-structured blockchain system might reduce redundant treatment interventions for a patient, hence enhancing their safety [5].

The two approaches to solving EHR interoperability using blockchain technology offer distinct frameworks. The first approach envisions blockchain as a complete data repository, storing entire electronic health records directly on a healthcare-specific blockchain. Digital signatures create unique patient identifiers that link all records across providers and payers, allowing authorized stakeholders to access and contribute to comprehensive patient histories. However, this method faces significant scalability challenges due to the massive data requirements of complete EHRs. The second approach takes a hybrid path by storing only metadata (patient identity, visit details, provider information) on the blockchain, along with pointers to the actual records housed in a separate "Health One Cloud." This metadata-focused solution effectively addresses the scalability issues while still providing a unified system when the blockchain and cloud components work together as an integrated solution [6].

Healthcare interoperability generally involves data interchange between business entities, such as numerous hospital systems through a state-wide HIE (Health Information Exchange). The Health Information and Management Systems defines interoperability as “the capacity of disparate information technology systems and software applications to communicate, exchange data, and utilize the exchanged information.” Healthcare interoperability improves patient care by abolishing fax-based data entry, minimizing redundant clinical procedures such as imaging tests and laboratory prescriptions, and ultimately lowering healthcare system costs, waste, radiation exposure, and the need for invasive treatments. This integrated communication system enhances patient safety and increases access to essential, longitudinal clinical data at the time of care. Irrespective of the achievements of state Health Information Exchanges, interoperability is crucial for effective and comprehensive healthcare delivery, as it guarantees the availability of vital patient information at the necessary time and location [7].

Blockchain-enabled interoperability in Electronic Health Records (EHR) systems facilitates the secure and seamless exchange of patient data among diverse healthcare providers and platforms via distributed ledger technology, establishing a cohesive, tamper-resistant record of patient information with each transaction cryptographically validated and distributed across multiple nodes, thus mitigating centralized vulnerabilities and protecting privacy through permission-based access controls. This patient-centric ecosystem enables healthcare companies to promptly access and contribute to information without intermediaries, while smart contracts guarantee adherence to regulatory requirements such as HIPAA and create immutable audit trails that preserve data integrity and provenance. The adoption of standardized data formats like FHIR improves technological interoperability, allowing authorized doctors to get comprehensive medical histories irrespective of the care delivery setting, while stringent permission protocols regulate the transmission of health information across diverse systems. This extensive framework tackles healthcare's ongoing challenges of fragmentation and inadequate information exchange, while simultaneously strengthening privacy, reducing administrative burdens, minimizing errors, preventing fraud, and optimizing processes such as insurance claims and clinical trial management, ultimately improving patient outcomes through more coordinated care delivery within the healthcare ecosystem the working of EHR in Blockchain as a in a below figure1.

The primary issue of blockchain interoperability in Electronic Health Records (EHR) arises from the dispersion of healthcare data over multiple independent blockchain networks, each characterized by unique protocols, consensus methods, and data structures. This fragmentation poses substantial obstacles to the smooth interchange of information among various healthcare practitioners, researchers, and institutions, hence impeding the potential for holistic patient care. Although blockchain technology presents significant advantages for EHR systems, such as improved security, immutability, and patient data ownership, the absence of established frameworks for cross-chain communication results in patient records frequently being confined to particular networks.

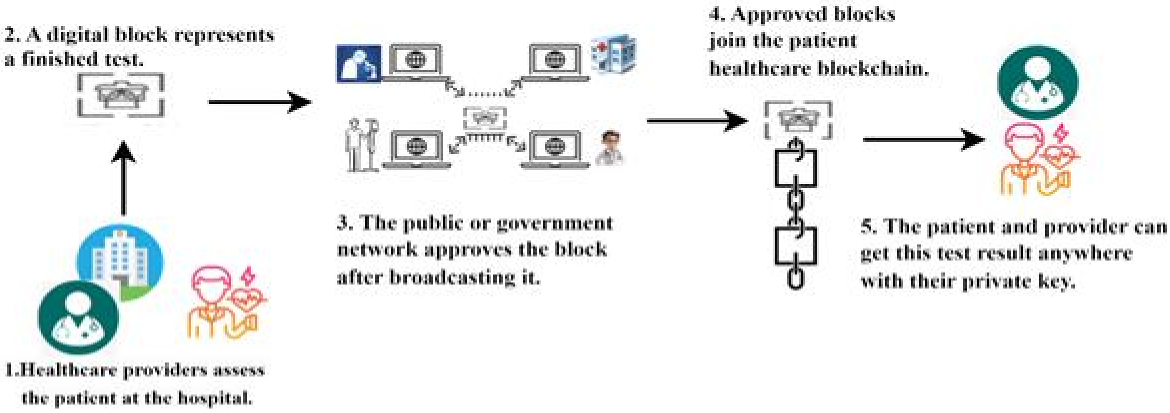



Fig1: EHR Working in BC

The cross-chain notion originated in 2012, was codified by the Tendermint team in 2014, and gained notoriety after Ethereum inventor Vitalik Buterin presented his "Chain Interoperability" paper at the R3CEV conference in 2016. This technology enables communication among several blockchains, improving their interconnection, scalability, and general functionality. With the rise of blockchain adoption in healthcare and other industries, researchers have concentrated on facilitating the seamless collaboration of autonomous blockchains, with interoperability being the essential capability for systems to execute operations across various blockchain entities or nodes. The cross-chain techniques and their phase of uses are displayed in the table I.

TABLE I.

| Interoperability Mechanism | Practical Applications | Appropriate Usage |
|---|---|---|
| Notary Schemes | Cryptocurrency Central Exchanges. Ripple employs notary techniques to facilitate asset transactions among global financial institutions. | Interoperability between BA and BB necessitates secure validation. Federations and notaries collectively endorse asset transfers between chains. |
| Hash-time-locks | Wan chain, Komodo, LN, etc. | Interoperable blockchains BA and BB must implement cross-chain atomic operations when both are public. |
| Side-Chain | Y BTC-Relay, Loom-Network, Liquid, etc. | When the mainchain needs scalability via the side-chain. When two-way-peg solutions need to be implemented. |

The Notary System was initially instituted in 2012 as a crucial component of the Interledger protocol. The primary objective of the notary technique is to authenticate and verify the accuracy of cross-chain transaction data across various blockchains, involving one or more credible institutions. A notary method is utilized during the execution of transactions across multiple blockchain platforms. A notary may consist of either a single third party or a collective of third parties. Their main goal is to gather transaction data and authenticate cross-chain transactions. The core premise of the notary system is to utilize an intermediate to establish links between two distinct blockchains. Notary schemes ought to be categorized into three types: centralized, distributed, and multi-signature. Each category will have certain requirements and be relevant in different contexts, which should be presented in a Table II.

TABLE II.

| Type | Transactions/Nodes per Second (TPS) | Factors Affecting Performance |
|---|---|---|
| Centralized | 10,000 - 1,000,000 TPS | Server Capacity, Network Bandwidth |
| Multi | 5 - 100,000 TPS | Consensus Mechanism, Node Count, Latency |
| Distributed | 1,000 - 1,000,000 TPS | Communication Overhead, Parallelism |

The subsequent sections of this document are structured as follows: Section II analyses the operational frameworks of two blockchain systems. The subsequent section examines the literature. Section IV delineates Hyperledger Cacti and the parameters for benchmarking. Section V presents and analyses the testing results. Section VI encapsulates the findings and delineates the future work.

## III. LITERATURE REVIEW

The authors have conducted several tests on blockchain interoperability between two separate systems, namely Ethereum and Hyperledger Fabric. The objective was to evaluate the effectiveness of different platforms in data sharing. The assessment was performed using the interoperability benchmarking tool of Hyperledger Cacti.

Hyperledger and Ethereum are two distinguished blockchain systems, each intended for distinct purposes and demographics of their target. Hyperledger is a collection of open-source frameworks designed for enterprise applications, focusing on permissioned networks and confidentiality. Conversely, Ethereum is a public blockchain platform recognized for its smart contract functionalities, facilitating the development of decentralized applications (DApps). The similarities and contrasts between two prominent platform parameters are illustrated in Table 2.

The article focused on the performance of Hyperledger Fabric and Ethereum to elucidate myths regarding blockchain as enterprises seek transaction transparency. The study aids enterprises in choosing the suitable blockchain platform for their applications by assessing 100 transactions based on success rate, latency, throughput, and resource utilization [1].

The paper analyses the execution and performance assessment methodologies of the Hyperledger Fabric blockchain network. It employs Hyperledger Caliper for benchmarking and advocates for Prometheus to monitor CPU performance. The research offers a thorough and comprehensible guidance for the establishment and assessment of Hyperledger Fabric blockchain networks, thereby enabling the actual implementation of this technology [2].

Blockchain technology has the potential to supplant inefficient medical records with an interconnected system that empowers patients to manage data access. Distributed ledger technology and symmetric key encryption safeguard clinician data through chain code permissions, enhancing latency and throughput [4].

The author aims to develop and evaluate a blockchain-based Personal Health Record (PHR) model to provide a complete and interoperable health record system that addresses the fragmentation of health data among healthcare providers [8].

Researchers evaluated Hyperledger Calliper's transaction rates and throughput at 3000 transactions per second to tackle scalability challenges. Blockchain surpassed traditional solutions, indicating its potential to safeguard healthcare data. The authors advocate for comprehensive feasibility analyses prior to the implementation of healthcare solutions [10].

The author examines the performance and reliability parameters of Hyperledger Fabric, as well as its resource utilization, particularly the degradation of platform components. A single transaction type increased RAM usage by 80% within three hours, reducing system availability from 99.35% to 98.17%. In the absence of these resource expansion challenges, the annual downtime amounts to 56.43 hours. The study enhances the reliability of blockchain applications in production [11].

A comparison was conducted between Ethereum and Hyperledger Fabric for IoT healthcare applications. To tackle the scalability challenges of blockchain adoption, they analysed the performance and latency of private networks. Hyperledger Fabric surpasses Ethereum in critical aspects, rendering it more suitable for private healthcare IoT ecosystems [12].

TABLE III. DIFFERENCE BETWEEN ETHEREUM AND HYPERLEDGER FABRIC

| **Aspect** | **Hyperledger Fabric** | **Ethereum** |
|---|---|---|
| Consensus Mechanism | Pluggable consensus (PBFT, Raft, Kafka) | Proof of Work (PoW) transitioning to Proof of Stake (PoS) |
| Smart Contracts | Chaincode (supports Go, Node.js, Java) | Solidity, Vyper, Yul |
| Performance | Higher throughput (1,000+ TPS) | Lower throughput (15-30 TPS on mainnet) |
| Privacy | Channels, private data collections | Limited privacy (all transactions visible) |
| Architecture | Modular (channels, ordering services) | Single global state |
| Identity Management | Certificate authorities | Public/private key pairs |
| Scalability | Horizontal scalability through channels | Layer 2 solutions (Optimism, Arbitrum) |
| Energy Consumption | Low | High (PoW), decreasing with PoS |
| Deployment | Private networks, cloud | Public mainnet, private networks |
| Immutability | High within channels | High across entire network |
| Interoperability | Limited outside ecosystem | Better with EVM compatibility |

## IV. METHODOLOGY

Over the past five years, extensive study has concentrated on blockchain as an emerging technology. These endeavours culminated in an abundance of scholarly studies, white papers, and community blogs. A concentrated examination of key facets of this technology remains essential to enhance comprehension of its practicality, particularly regarding performance and scalability [12]. Healthcare professionals utilizing distinct information systems can effortlessly share patient data and medical records. This connectivity can preserve lives by enabling medical teams to obtain essential diagnostic information from other hospital networks during surgeries or emergency treatment.

### *A. Hyperledger Fabric*

Hyperledger Fabric improves electronic health records with blockchain technology. Private channels protect patient information while providing access to healthcare providers. Data access via ID management is limited to authorized users alone. Integrating systems, enabling secure data transmission, and preserving complete audit trails while protecting patient confidentiality and complying with rules tackle major healthcare difficulties. The primary distinctions and additional comparable aspects of Ethereum and Fabric are enumerated below.

Hyperledger Fabric (HLF) is a framework for the development and implementation of solutions utilizing shared ledgers. This platform is an open-source standard developed and maintained by the Hyperledger Consortium under the auspices of the Linux Foundation [11].

The service provider aspect of an HLF system employs container-based technology for the management of smart contracts (chain codes). Chain codes are primarily responsible for governing business rules and determining the application's operational actions. The chain codes must be pre-installed in the environment prior to deployment.

The Hyperledger Fabric environment encompasses three distinct categories of containers:

1. The peer Node, which performs endorsement
2. The orderer Node that receives and assigns transactions to batches and send them back to the peer Node.
3. The Membership Service Provider (MSP) Node, responsible for membership and access to the platform.

### *B. Ethereum*

In late 2013, Vitalik Buterin's white paper introduced a blockchain network featuring programmable smart contracts that extended beyond Bitcoin's basic transactions. The project was unveiled in January 2014 by Gavin Wood, Charles Hoskinson, and Joseph Lubin. The genesis block of Ethereum was mined on July 30, 2015, launching the network with Ether following a $18 million crowdfunding effort in July-August 2014.

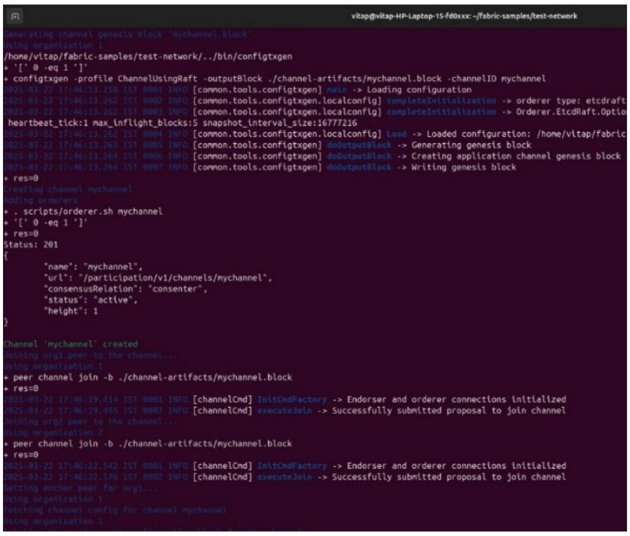
Ethereum smart contracts facilitate trust less, immutable digital agreements on the blockchain, automating transactions without intermediaries and transforming multiple sectors, including healthcare. Composed mainly in Solidity and performed by the EVM across decentralized nodes, these self-executing applications improve transparency and efficiency, notwithstanding issues related to upgrades, security vulnerabilities, and scalability. In healthcare, they safeguard patient data via cryptographic access restrictions, minimize administrative burdens through automation, ensure dependable audit trails, and restore data ownership to patients.

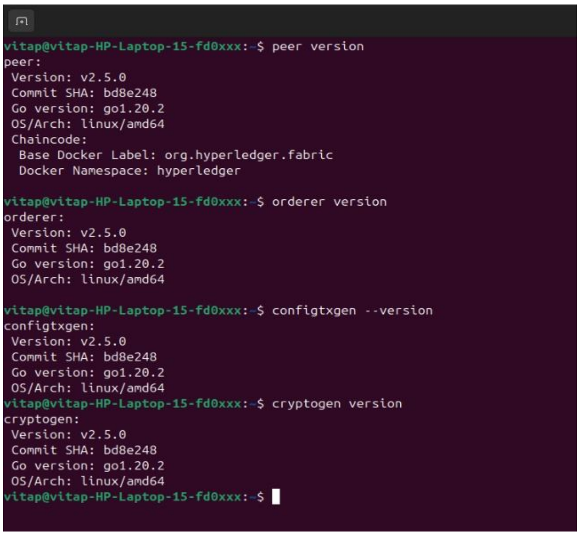
### *C. Working*

The implementation commences with the installation of the prerequisites for both platforms, as detailed in Table IV.

| **Component** | **Ethereum** | **Hyperledger Fabric** |
|---|---|---|
| Operating System | Ubuntu 20.04/22.04 LTS | Ubuntu 20.04/22.04 LTS |
| Processor | 64-bit CPU | 64-bit CPU |
| RAM | 4 GB (minimum), 8 GB+ (recommended) | 8 GB (minimum), 16 GB+ (recommended) |
| Storage | 100 GB+ SSD (for blockchain data) | 100 GB+ SSD |
| Docker | Not required | Required (Docker CE 20.10+) |
| Docker Compose | Not required | Required (v1.29+ or v2.2.3+) |
| Go Language | Required (v1.20+) for Geth | Required (v1.20+) |
| Node.js & npm | Required (v16+) for Web3.js | Required (v16+) |
| Python | Recommended (v3.8+) | Required (v3.8+) |
| curl | Required for API interactions | Required for API interactions |
| Git | Required for cloning repositories | Required for cloning repositories |

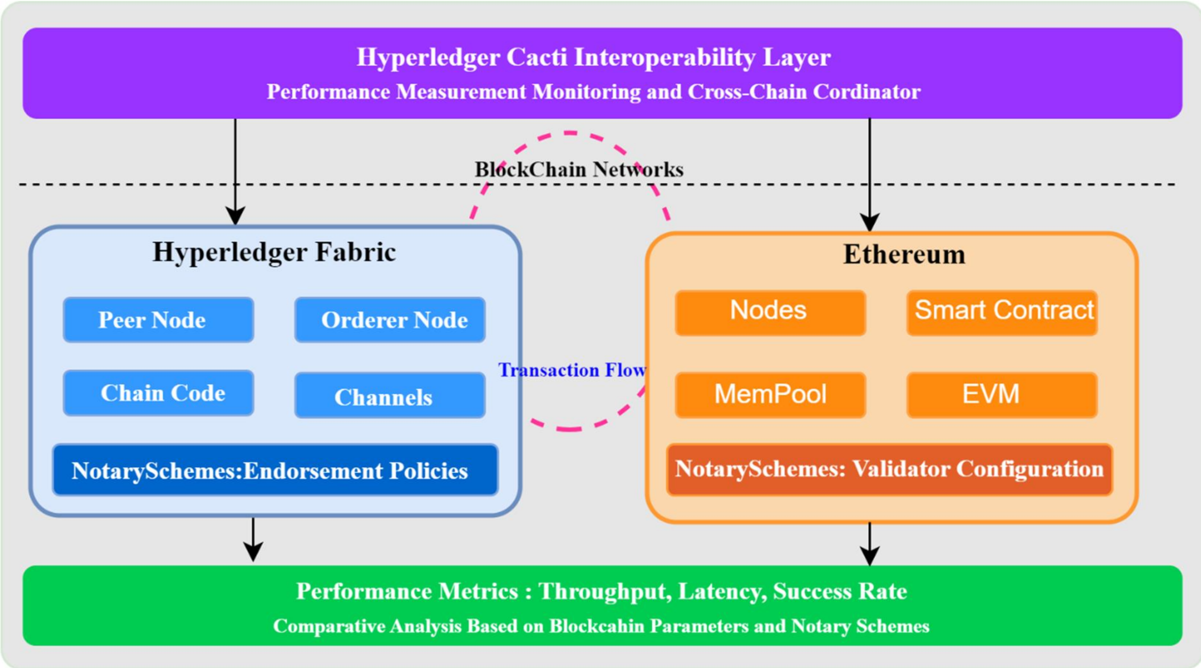
Upon completing the installation of all prerequisites, the principal phases in constructing a blockchain network encompass several essential components. Initially, the formation of peer nodes provides the foundation of a Hyperledger Fabric network, wherein these nodes uphold the ledger and execute smart contracts (chain code), simultaneously functioning as the network's backbone by validating and committing transactions. The creation of the orderer node is crucial as it facilitates the consensus mechanism, determines transaction order, generates blocks, and disseminates them to peers, ensuring that all network participants uphold a uniform perspective of the ledger. Chain node deployment entails initializing the blockchain through the creation of the genesis block and the configuration of initial network parameters, so establishing the foundational point for all subsequent blocks and delineating network policies and permissions. Ultimately, the construction of Geth (Go Ethereum) builds an Ethereum node environment, furnishing the infrastructure necessary for interaction with the Ethereum blockchain, facilitating smart contract deployment, transaction processing, and network involvement. The creation of them is shown in below figures.





The Hyperledger Cacti Performance Measurement Architecture facilitates interoperability between diverse blockchain networks. The Hyperledger Cacti Interoperability Layer serves as the principal coordination mechanism for performance evaluation, supervision, and cross-chain collaboration. The architecture connects two distinct blockchain networks: Hyperledger Fabric (shown in blue on the left) and Ethereum (represented in orange on the right). The elements of Hyperledger Fabric are Peer Nodes, Orderer Nodes, Chain code, Channels, and Notary Schemes accompanied by Endorsement Policies. The architecture of Ethereum comprises Nodes, Smart Contracts, Mempool, EVM (Ethereum Virtual Machine), and Notary Schemes with Validator Configuration. The red dotted line represents the transaction flow among different networks. The Performance Metrics layer at the foundation documents and analyses critical performance attributes, including throughput, latency, and success rate, enabling comparative analysis based on blockchain parameters and notary schemes. This architecture creates a framework for evaluating and improving cross-chain interactions between enterprise blockchain systems and public networks, as well as the architecture of cross-chain functionality employing Notary methods across diverse platforms, as seen below.




## V. RESULTS

The proposed method creates Electronic Health record (EHR) sharing system between Hyperledger Fabric and Ethereum networks using notary schemes as the interoperability mechanism. First, dedicated smart contracts will be deployed on both platforms to manage EHR data access and transfer requests. The notary scheme will establish a trusted third-party validation layer consisting of multiple notary nodes that verify and attest to transactions across both blockchains, ensuring data consistency and integrity during transfers. When an EHR sharing request is initiated, the source blockchain generates a proof of the data's existence and integrity, which notaries validate before the destination blockchain accepts the data. Hyperledger Cacti will be utilized as the performance measurement framework, capturing metrics including transaction latency, throughput, resource utilization, and consensus overhead during cross-chain operations. The methodology will include controlled experiments with varying transaction loads, network conditions, and data sizes to comprehensively evaluate the system's scalability and efficiency. Security aspects will be assessed through threat modelling and simulated attack scenarios to identify vulnerabilities in the cross-chain communication channels. The study will conclude with a comparative analysis against traditional blockchain interoperability approaches to determine the notary scheme's effectiveness for healthcare data exchange use cases.

## VI. CONCLUSION AND FUTURE WORK

Hyperledger Fabric with Ethereum facilitate secure and quick interoperability for notarized EHR data transmission across blockchains. Notary techniques safeguard data, access, and consensus across both blockchains. CACTI evaluate transaction latency, throughput, and resource use. The findings indicate that the suggested method facilitates secure and efficient data transmission. The latency and scalability of the interoperability framework can be enhanced through research. AI-driven smart contracts, privacy-oriented zero-knowledge proofs, and other consensus methodologies are available. Establishing connections between blockchain networks and examining hybrid cloud-blockchain systems are viable solutions.

## REFERENCES

[1] Dabbagh, M., Kakavand, M., Tahir, M., & Amphawan, A. (2020, September). Performance analysis of blockchain platforms: Empirical evaluation of hyperledger fabric and ethereum. In 2020 IEEE 2nd International conference on artificial intelligence in engineering and technology (IICAIET) (pp. 1-6). IEEE.

[2] Kaushal, R. K., & Kumar, N. (2023, October). Blockchain implementation with Hyperledger fabric and approach for performance evaluation. In 2023 IEEE International Conference on Blockchain and Distributed Systems Security (ICBDS) (pp. 1-5). IEEE.
[3] Khan, K. M., Fahim, A., Saleem, D. M., & Jokhio, M. (2023). Empirical Investigation on Blockchain Interoperability. VFAST Transactions on Software Engineering, 11(1), 25-36.
[4] Tanwar, S., Parekh, K., & Evans, R. (2020). Blockchain-based electronic healthcare record system for healthcare 4.0 applications. Journal of Information Security and Applications, 50, 102407.
[5] Schmeelk, S., Kanabar, M., Peterson, K., & Pathak, J. (2022). Electronic health records and blockchain interoperability requirements: a scoping review. JAMIA open, 5(3), ooac068.
[6] Gupta, N., Jha, A., & Roy, P. (2016). Adopting blockchain technology for electronic health record interoperability. Cognizant Technol. Solutions, Teaneck, NJ, USA, White Paper.
[7] Gordon, W. J., & Catalini, C. (2018). Blockchain technology for healthcare: facilitating the transition to patient-driven interoperability. Computational and structural biotechnology journal, 16, 224-230.
[8] Roehrs, A., da Costa, C. A., da Rosa Righi, R., da Silva, V. F., Goldim, J. R., & Schmidt, D. C. (2019). Analyzing the performance of a blockchain-based personal health record implementation. Journal of biomedical informatics, 92, 103140.
[9] Das, S. R., Zaman, D. N., Asirvatham, D., Ashfaq, F., Masud, M., & Shorfuzzaman, M. Empirical Performance Analysis of Hyperledger Fabric. Available at SSRN 5127328.
[10] Melo, C., Oliveira, F., Dantas, J., Araujo, J., Pereira, P., Maciel, R., & Maciel, P. (2022). Performance and availability evaluation of the blockchain platform hyperledger fabric. The Journal of Supercomputing, 78(10), 12505-12527.
[11] Ucbas, Y., Eleyan, A., Hammoudeh, M., & Alohaly, M. (2023). Performance and scalability analysis of ethereum and hyperledger fabric. IEEE Access, 11, 67156-67167.