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A Permissioned Blockchain NFT Framework for Secure Pharmaceutical Asset Ownership and Trading: Permissioned TokenPharma [*]

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ABSTRACT: Pharmaceutical trading requires a robust system to verify asset authenticity, prevent counterfeiting, and ensure transparent ownership transfer. However, public blockchains face significant challenges, including high latency, unpredictable finality, high transaction gas cost, and the absence of regulatory governance. To address these challenges Hyperledger Besu-enabled Permissioned-TokenPharma (P-TokenPharma) framework was implemented, leveraging the IBFT 2.0 Byzantine Fault Tolerance consensus mechanism. It preserves the fundamental NFT-enabled asset ownership logic and supports peer-to-peer pharmaceutical trading. In addition, it offers regulated node membership, deterministic transaction finality, and governance control enabled by compliance. This system integrates ERC-721 smart contracts, supporting on-chain ownership and metadata stored off-chain via Inter Planetary File System (IPFS). The proposed system significantly improves throughput by 2.1x, reduces transaction latency by up to 45%, and improves efficiency by eliminating gas consumption compared to classical blockchain models. In addition, Ethash consumes 39.23% (1.65x) more memory than Besu-IBFT, and under the same workloads, sustains 1.55x higher CPU overhead than Besu.

Keywords: Blockchain, ERC-721, Hyperledger Besu, IBFT 2.0, NFTs, P-TokenPharma.

Contents

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1. Introduction

Pharmaceutical trading and supply chains face issues such as counterfeiting, fragmented traceability, and unreliable verification due to the lack of a unified, trusted system across manufacturers, distributors, and regulators. Traditional centralized digital systems often face a lack of immutability, centralized failures, and provenance transparency, allowing counterfeit products into legitimate channels. To overcome these challenges, the emerging technology blockchain offers decentralized, immutable ledgers and secure transaction management [4]. Blockchain models represent pharma assets using different Ethereum Request for Comment (ERC) standards. The ERC-20 standard represents fungible assets; in contrast, the ERC-721 standard represents unique, non-interchangeable assets with the NFT (Non-Fungible Token) format. Existing models, especially NFTs [14], have been explored to represent physical assets uniquely. For instance, TokenPharma [13] used ERC-721 tokens to securely encode product identity, ownership, and metadata. Binding physical assets to digital tokens allows stakeholders to verify origin, transfer, and authenticity. However, deploying such systems on public Ethereum [7] revealed operational and regulatory challenges, prompting interest in permissioned blockchain environments for secure, compliant pharmaceutical asset management.

The existing model demonstrated that NFTs can reliably encode pharmaceutical asset identities, but deploying it on the public Ethereum network revealed key limitations. Public gas markets cause unpredictable, often high transaction fees, making large-scale tracking financially challenging [5]. Ethereum probabilistic finality also introduces delays, as confirmations depend on block depth, which is problematic for healthcare workflows requiring timely validation. Additionally, the open and unregulated nature of public networks prevents pharmaceutical companies from enforcing membership and compliance rules or ensuring data governance. Network congestion and variable block times further cause inconsistent latency, impairing real-time traceability and auditing [10]. These challenges hinder P-TokenPharma adoption in strict regulatory environments that demand deterministic settlement, controlled participation, cost efficiency, and reliable performance. Therefore, transforming TokenPharma into a permissioned system is essential. It should offer deterministic finality, feature controlled validators, lower operational costs, and enhance throughput—all while maintaining support for NFT-based asset encoding.

The P-TokenPharma architecture combines the reliability of ERC-721 NFTs with the predictable consensus of Hyperledger Besu IBFT 2.0. Each pharmaceutical asset is represented as a unique ERC-721 token that contains ownership details and NFT lifecycle data. These tokens operate on a permissioned Besu network with validator nodes authorized by consortium members or stakeholders. A permissioned setup ensures that only verified entities, such as manufacturers, logistics providers, pharmacies, and regulators, can participate. IBFT 2.0 provides fast, deterministic block finality, preventing chain forks and enabling dependable real-time asset verification [11]. Additionally, the architecture features an off-chain IPFS layer to store extended metadata, including manufacturing certificates, lab reports, storage logs, and authenticity documents [3]. This hybrid system minimizes on-chain storage while ensuring tamper-proof references through cryptographic hashes embedded in NFT metadata. It also includes smart-contract [8] based access controls to restrict asset transfers and metadata updates to authorized users. The network restricts contract deployment, validation, and asset modification, with each participant having verifiable identities for transparency and accountability. Overall, this design maintains TokenPharma-NFT principles while delivering a performance-efficient and compliant blockchain infrastructure. In the proposed system, regulatory agencies can monitor activities without direct participation, providing traceability and control that is missing in public blockchains. Embedding rules into the blockchain helps maintain compliance with asset, transfer, and metadata requirements, supporting a secure, transparent ecosystem.

This study explores three main questions. RQ1: Can NFT-based pharmaceutical asset ownership be maintained effectively within a permissioned blockchain? The results show ERC-721 logic can be preserved while improving regulatory control and trust. RQ2: Does IBFT 2.0 consensus improve performance over public Ethereum? Benchmarking confirms significant gains, showing IBFT is suitability for enterprise. RQ3: Can governance and identity frameworks enhance compliance and accountability? The permissioned Besu model demonstrates how controlled participation and identity access ensure secure, traceable operations. The work introduces P-TokenPharma, a hybrid system combining NFT assets, deterministic BFT consensus, and off-chain metadata. This offers a scalable, regulator-friendly platform for secure pharmaceutical asset management.

1.1. Key Contributions of the article

- The decentralized permissioned blockchain framework P-TokenPharma has been designed and developed based on the ERC-721 token standards and deployed on Hyperledger Besu to facilitate peer-to-peer pharmaceutical trading.
- The framework designed on Ethereum and NFT to trade pharmaceuticals and provide ownership of pharma asset in a permissioned model. The design of smart contract and complete prototype of the P-TokenPharma have been presented.
- Smart contracts CreateToken, RegulatorApprovalAndRecall, ListOrResellToken, BuyToken, and PhramTradingEscrow have been created and deployed on the EVM to automate pharmaceutical transactions, ensure compliance with regulations, control role-based access for participants.
- The permissioned architecture Hyperledger Besu leveraged with IBFT 2.0 consensus employed for deterministic block finality, BFT fault tolerance, and predictable performance for pharma workflows.
- The proposed framework's performance has been evaluated using Hyperledger Caliper by measuring various factors such as CPU usage, memory consumption, latency, throughput, block finality, and other metrics. The results were compared with existing models in terms of scalability, efficiency, and fault tolerance.

1.2. Organization

The rest of the paper is organized as follows. Section 2 presents the existing research on public Ethereum and the role of NFTs in Healthcare. The ERC standards, EVM, and smart contracts setup, and Ethereum blockchain limitations in pharma trading are discussed. In section 3, the designed principles of P-TokenPharma and the hybrid NFT architecture combine ERC-721 with a permissioned Hyperledger Besu network using IBFT 2.0. Section 4 introduces testbed setup, the governance and identity-enabled model, explaining regulated membership, validator control, and role-based permissions for compliance. Section 5 analyzes performance gains from migrating TokenPharma to a Besu IBFT environment, focusing on deterministic finality, lower latency, and no gas constraints. It details Hyperledger Caliper benchmarking, experimental parameters, and compares the public Ethereum version with P-TokenPharma. The paper concludes by highlighting P-TokenPharma potential as a scalable, regulator-friendly platform for secure, transparent pharmaceutical asset management in Section 5.

2. Relevant Study

NFT-based supply chain solutions are popular for representing unique assets and verifying provenance. In our work, TokenPharma [13] showed how ERC-721 tokens can link physical pharmaceuticals to digital identities on Ethereum, aiding ownership tracking, authenticity, and preventing counterfeiting. Research also explores NFT asset management in luxury goods [15], agriculture [2], art logistics, and IoT traceability, emphasizing NFTs role in representing items and ensuring traceability. However, many use public blockchains with issues like high gas fees, slow confirmation, and open access, complicating regulatory enforcement. While these approaches highlight NFTs potential in supply chain authentication, they often overlook the compliance, performance, and governance needs of regulated sectors like pharmaceuticals.

Permissioned blockchain platforms such as Hyperledger Besu are well-suited for enterprise applications, providing controlled access, consistent performance, and regulatory compliance [6]. Besu supports Ethereum-compatible smart contracts and offers a flexible permissioning system for consortium governance . It enables detailed access control, ensuring only authorized nodes can validate transactions, deploy contracts, or access data . The Istanbul Byzantine Fault Tolerant (IBFT 2.0) consensus algorithm guarantees deterministic finality, tolerates crashes, and resists malicious validators, reducing delays and reorganization issues, ideal for environments requiring transactional certainty [1]. Research indicates that IBFT-based systems enhance throughput, enable low-latency settlements, and offer predictable costs, crucial for finance, supply chain, and infrastructure sectors. However, despite increasing interest, limited research exists on integrating permissioned blockchains with complex asset models like ERC-721 NFTs.

Consortium blockchains are increasingly adopted in healthcare and pharmaceuticals due to their ability to balance decentralization with control. Research indicates that private blockchain networks enhance drug traceability, data management, e-prescription security, and cold-chain monitoring by enabling secure data sharing among authorized entities [9]. Scholars recomanded private blockchains for vaccine distribution, counterfeit prevention, and cross-border medicine tracking, offering advantages over centralized databases [12]. In enterprise settings, emphasis is placed on verifying identities, governance, and transaction compliance. Nevertheless, most healthcare blockchains employ generic asset models instead of cryptographically unique digital twins like NFTs. Although these models address governance and compliance concerns, they do not fully leverage tokenized ownership or NFT provenance within permissioned pharmaceutical environments.

Most of the existing systems studied NFTs and permissioned blockchains separately and their integration into pharmaceutical regulation is still unexplored. Existing NFT supply chain models, such as TokenPharma, mainly operate on public blockchains, which are unsuitable for applications that require identity verification, governance, and deterministic settlement. Research on permissioned networks like Hyperledger Besu and IBFT 2.0 emphasizes performance and trust but rarely employs advanced token standards, such as ERC-721, to represent unique physical pharmaceutical assets. Currently, there is no solution that combines NFT-based representation of pharmaceutical assets with a consortium-controlled IBFT 2.0 blockchain, enabling regulatory oversight, role-based participation, and compliance workflows. This gap restricts secure, authentic, tokenized ownership and controlled validation, which are essential for enterprise pharmaceutical tracking and ensuring secure, transparent, and regulation-compliant global supply chains.

3. Proposed Permissioned NFT Framework

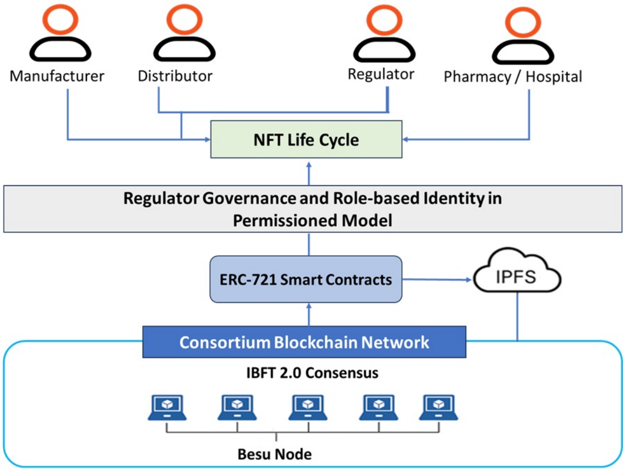

Figure 1: Proposed Permissioned-TokenPharma Architecture

3.1. Methodology

The proposed Permissioned-TokenPharma (P-TokenPharma) leverages Hyperledger Besu and IBFT 2.0. The architecture of the model is shown in the Figure. 1. It integrates ERC-721 tokenization, regulated node participation, and a hybrid data system. Key actors include Manufacturers who mint NFTs for new pharmaceutical batches; Distributors responsible for custody transfers; Pharmacies that receive and dispense products; and Regulators who ensure compliance and monitor asset histories via observer nodes. The NFT lifecycle begins with minting by manufacturers, followed by owner-to-owner transfers authenticated by smart contracts and stored permanently on-chain. Metadata linked to each NFT is stored on IPFS, verifying product identity, certificates, and quality records. The final transfer, when a product is dispensed, completes its lifecycle. This ecosystem ensures each pharmaceutical asset is uniquely represented, transparently exchanged, and continuously verifiable throughout its entire journey.

3.2. Network Architecture

The P-TokenPharma network is built on a consortium-managed Hyperledger Besu platform designed for fully permissioned operation. Participants such as manufacturers, distributors, regulators, or pharmacies each run a Besu node connected through certificate-based enrollment. Validator nodes are assigned exclusively to trusted entities, overseeing block creation and consensus. Features of Besu's permissioning, both on-chain and off-chain, enable the network administrator to whitelist node identities, regulate contract deployment, and enforce access controls at the organizational level. The governance structure defines roles, responsibilities, and voting processes for validator onboarding, contract updates, and policy changes. Only authorized organizations can deploy smart contracts, preventing unauthorized code from entering the system. Access control lists authenticate participant identities and restrict asset operations, while regulators operate observer nodes for live oversight without influencing consensus. This setup guarantees security, transparency, and operational trust, ensuring adherence to pharmaceutical regulations.

3.3. Consensus Mechanism-IBFT 2.0:

IBFT 2.0 serves as the main consensus mechanism for P-TokenPharma, ensuring deterministic transaction finality and robust fault tolerance essential for regulated pharmaceutical operations. It allows a designated validator group to collaboratively propose, prepare, and finalize blocks, guaranteeing transaction finality within a single block and eliminating reorganization risks. With Byzantine fault tolerance, it can tolerate up to f faulty validators in a network of 3f+1 nodes. The validation process consists of four steps—proposal, pre-prepare, prepare, and commit—enabling all honest validators to reach consensus before finalizing a block. This deterministic approach contrasts with the probabilistic finality of PoW, which consumes significant energy and results in unpredictable block times. By removing mining and restricting validation to authorized nodes, IBFT 2.0 enhances speed, trust, and control, making it ideal for enterprise-level pharmaceutical supply chains where transaction certainty, auditability, and compliance are vital.

3.4. Smart Contract Layer (ERC-721)

Algorithm 1 Create_Token in Permissioned-TokenPharma

```
Require: Caller $u$ has MANUFACTURER_ROLE, system not paused
Require: $batchId \neq \emptyset$, $drugName \neq \emptyset$, $ipfsHash \neq \emptyset$, $priceWei > 0$
Ensure: New NFT asset registered and initial listing created (inactive)
Verify $u$ has MANUFACTURER_ROLE
Verify system status $\neq$ PAUSED
Verify input fields are non-empty and $priceWei > 0$
$tokenId \leftarrow$ PharmaToken.mintPharmaToken($u, ipfsHash$)
Create Asset record:
    $Asset[tokenId] \leftarrow \{tokenId, batchId, drugName, ipfsHash,$
        $manufacturer = u,$
        $regulatorApproved = \textbf{false}, recalled = \textbf{false}\}$
Create initial Listing (inactive):
    $Listing[tokenId] \leftarrow \{tokenId, seller = u, priceWei, active = \textbf{false}\}$
Emit event AssetCreated($tokenId, batchId, u, ipfsHash, priceWei$)
return $tokenId$
```

P-TokenPharma maintains the core ERC-721 smart contract logic originally created in TokenPharma, now enhanced with features for regulatory approval and controlled access. Manufacturers use the mint() function to generate unique NFTs representing pharmaceutical products or batches, which include permanent identifiers and metadata hashes. Ownership exchanges occur through transferFrom( ), safeTransferFrom( ), and a specialized resell( ) function designed for supply chain transactions. Functions such as ownerOf( ), tokenURI( ), and approve( ) facilitate identity confirmation, traceability, and regulated transfer processes. The IBFT version adds additional rules to uphold compliance, including requiring regulator signatures for certain transfers, restricting transfers during recalls, and needing audit approval for metadata modifications. Role-based modifiers prevent unauthorized minting, burning, or transfer of NFTs. By combining ERC-721 standards with adherence mechanisms, the smart contract ensures that pharmaceutical asset management remains secure, transparent, and compliant with regulations, while being compatible with Ethereum-based tools.

Algorithm 2 Regulator Approval and Recall of Pharma NFT

```
Require: Caller $r$ has REGULATOR_ROLE
Ensure: Only compliant assets are tradable; recalled assets are blocked
procedure APPROVE_ASSET($tokenId$)
    Verify $r$ has REGULATOR_ROLE
    Verify $Asset[tokenId]$ exists
    $Asset[tokenId].regulatorApproved \leftarrow$ true
    $Listing[tokenId].active \leftarrow$ true
    Emit event ASSETAPPROVED($tokenId, r$)
end procedure
procedure RECALL_ASSET($tokenId, reason$)
    Verify $r$ has REGULATOR_ROLE
    Verify $Asset[tokenId]$ exists
    $Asset[tokenId].recalled \leftarrow$ true
    $Listing[tokenId].active \leftarrow$ false
    Emit event ASSETRECALLED($tokenId, r, reason$)
end procedure
```

The Algorithm. 1 in the P-TokenPharma system is used to create a token for a pharma asset, which is generated with each asset tokenId, drugName, ipfsHash, and manufacturing details by the mintPharmaToken() method. After creating the asset, it should be open for trading in the Pharma Trading Marketplace. The regulator role, verification mechanism, assetApproval(), and emits() are the main steps in the Algorithm 2. The main methods of Algorithm 3 are listForSale() and cancelListing(). In this, pharma assets are listed or delisted for trading. Algorithm 4 includes methods such as buyToken(), safeTransferFrom(), and TokenPurchased() to facilitate buying tokens from the marketplace. Algorithm 5 primarily has methods like deposit(), withdraw(), and refundUser() to manage funds and payments.

3.5. Metadata and Storage Layer

P-TokenPharma uses a hybrid metadata architecture balancing transparency, privacy, and storage efficiency. Each NFT links to an IPFS hash, ensuring tamper-proof metadata and lowering storage costs. Key documents like certificates, lab results, authenticity proofs, and logistics records are stored on IPFS. To meet privacy standards, the system separates public metadata (product IDs and expiry dates) from private data (quality reports, dispensing records). Private data can be encrypted before upload to prevent unauthorized access. Regulators can verify metadata via IPFS gateways or APIs for validation. The on-chain link prevents tampering; changes invalidate the IPFS hash. This storage division combines blockchain security with decentralized file persistence, offering a scalable, secure, and compliant metadata solution.

4. Implementation

4.1. Development Environment

The P-TokenPharma implementation uses Hyperledger Besu as the blockchain execution client, configured in permissioned mode with IBFT 2.0 consensus. Smart contracts are developed using Solidity, compiled and tested through Hardhat. Besu's node-level and account-level permissioning features are

Algorithm 3 List_or_Resell_Token in PharmaceuticalMarketPlace

```
Require: Caller $s$ is a whitelisted participant (manufacturer / distributor / pharmacy)
Require: $priceWei > 0$; System not paused
Ensure: Token listed for primary or secondary sale
procedure LIST_FOR_SALE($tokenId, priceWei$)
    Verify system status $\neq$ PAUSED
    Verify $priceWei > 0$
    Verify $PharmaToken.ownerOf(tokenId) = s$
    Verify $Asset[tokenId].regulatorApproved = \textbf{true}$
    Verify $Asset[tokenId].recalled = \textbf{false}$
    $Listing[tokenId] \leftarrow \{tokenId, seller = s, priceWei, active = \textbf{true}\}$
    Emit event TOKENLISTED($tokenId, s, priceWei$)
end procedure
procedure CANCEL_LISTING($tokenId$)
    Verify $Listing[tokenId].seller = s$
    $Listing[tokenId].active \leftarrow \textbf{false}$
    Emit event TOKENUNLISTED($tokenId, s$)
end procedure
```

enabled to restrict network participation, ensuring that only approved organizations can run validator or non-validator nodes. Contract deployment is executed through Hardhat scripts configured to interact with the Besu JSON-RPC endpoint. The permissioning configuration includes node whitelists, account restrictions, and organization-level access policies, ensuring a tightly controlled operational environment. This setup maintains compatibility with existing Ethereum developer tooling while delivering a permissioned blockchain infrastructure suitable for regulated pharmaceutical operations.

4.2. Deployment Workflow

The deployment process starts with registering pre-approved participants, each receiving a network identity and certificate before joining the consortium. After validators and non-validators are onboarded, an authorized manufacturer node deploys the ERC-721 P-TokenPharma contract. NFT minting occurs through an approval process where regulators verify batch metadata before manufacturers call the mint( ) function. Ownership transfer employs ERC-721's safe transfer operations, guaranteeing secure movement of pharmaceutical assets between distributors and pharmacies. Each transfer triggers blockchain events like Minted, Transferred, and MetadataUpdated, providing full traceability and audit capabilities. The IBFT 2.0 engine ensures each transaction is finalized deterministically, so asset transfers are instantly confirmed and visible to all authorized participants. This organized workflow promotes secure, transparent, and compliance-focused asset registration and trading.

4.3. Integration with Existing TokenPharma Contracts

P-TokenPharma stays fully compatible with the original TokenPharma ERC-721 contract because of Besu's complete EVM support. Only minor adjustments were necessary, such as adding regulator-specific approval checks and implementing permissioned execution rules. The essential functions—like minting, ownership management, and metadata referencing—are unchanged. The main difference is in deployment: unlike on Ethereum, where gas markets and probabilistic finality affect execution, Besu-IBFT offers deterministic settlement and zero gas cost. Deployment also happens in a controlled environment where only approved accounts can initiate deployment or invoke functions that change state. These changes enable the contract to operate smoothly within a consortium-governed pharmaceutical supply chain, while remaining fully compatible with existing Ethereum tools and standards.

4.4. Experimental Setup

Performance evaluation was carried out using Hyperledger Caliper to benchmark the P-TokenPharma deployment under controlled throughput and latency conditions. The network is configured with 50

Algorithm 4 Buy_Token in PharmaceuticalMarketPlace

```
Require: Caller $b$ is a whitelisted participant
Require: System not paused
Require: Exact payment $msg.value = Listing[tokenId].priceWei$
Ensure: NFT ownership transferred from seller to buyer and payment settled
procedure BUY_TOKEN($tokenId$)
    Verify system status $\neq$ PAUSED
    Verify $b$ is a whitelisted participant
    $L \leftarrow Listing[tokenId]$
    $A \leftarrow Asset[tokenId]$
    Verify $L.active = \textbf{true}$
    Verify $A.regulatorApproved = \textbf{true}$
    Verify $A.recalled = \textbf{false}$
    Verify $L.seller \neq \textbf{address}(0)$
    Verify $L.seller \neq b$
    Verify $msg.value = L.priceWei$
    $L.active \leftarrow \textbf{false}$ // Close listing before transfer
    PHARMATOKEN.SAFETRANSFERFROM($L.seller, b, tokenId$)
    Send $L.priceWei$ to $L.seller$ using a secure value transfer
    Assert payment success, otherwise revert
    Emit event TOKENPURCHASED($tokenId, L.seller, b, L.priceWei$)
end procedure
```

nodes, including one boot node, which is also called the besu node. The network comprised 4 to 7 IBFT validator nodes, including manufacturers, distributors, pharmacies, and regulators. Various transaction load profiles, such as minting NFTs, transferring ownership, and reading metadata, were tested to measure performance. Caliper recorded key metrics like transactions per second (TPS), average latency, CPU usage, memory consumption, and block finality time. All tests compared the Besu-IBFT network with the legacy Ethereum deployment of P-TokenPharma under similar workload conditions. This setup ensured a consistent environment for evaluating performance gains from features like deterministic finality, zero-gas execution, and permissioned operations consensus.

4.5. Performance Benchmarking with Hyperledger Caliper

To assess the performance of the proposed Permissioned-TokenPharma (P-TokenPharma), the Hyperledger Caliper was utilized as the performance benchmarking tool. The key performance metrics, latency, throughput, resource utilization, block finality, and scalability have been measured. The designed smart contracts have been compiled using the Solidity compiler. It has generated an Application Binary Interface (ABI) in JSON format, including its relevant bytecode for deployment. The bytecode was deployed on a permissioned Hyperledger Besu blockchain network configured with IBFT consensus. Each deployment produced a unique smart contract address, which Caliper used to execute and benchmark NFT-enabled pharmaceutical trading. Figure. 2 shows the Hyperledger Caliper working pattern, Solidity smart contract deployment, JSON-ABI, smart contract bytecode generation, and the Hyperledger Besu model. During the evaluation phase, Caliper executed the overall 1000 transactions across varied control rates at 50, 150, and 250 transactions per second (TPS).

Algorithm 5 PharmaTrading Escrow: Deposit, Withdraw, Refund

```
Require: Escrow contract deployed and linked to marketplace
Ensure: Secure handling of participant balances
procedure DEPOSIT
    Require system not paused
    Require $msg.value > 0$
    if $balances[u] = 0$ then
        $numberOfUsers \leftarrow numberOfUsers + 1$
    end if
    $balances[u] \leftarrow balances[u] + msg.value$
    Emit event DEPOSIT($u, msg.value$)
end procedure
procedure WITHDRAW($amount$)
    Require system not paused
    Require $balances[u] \geq amount$
    $balances[u] \leftarrow balances[u] - amount$
    Transfer $amount$ to $u$ (non-reentrant)
    Emit event WITHDRAW($u, amount$)
end procedure
procedure REFUND_USER($user, amount$)
    Require caller has OWNER_ROLE or REGULATOR_ROLE
    Require $balances[user] \geq amount$
    $balances[user] \leftarrow balances[user] - amount$
    Transfer $amount$ to $user$
    Emit event REFUND($user, amount$)
end procedure
```

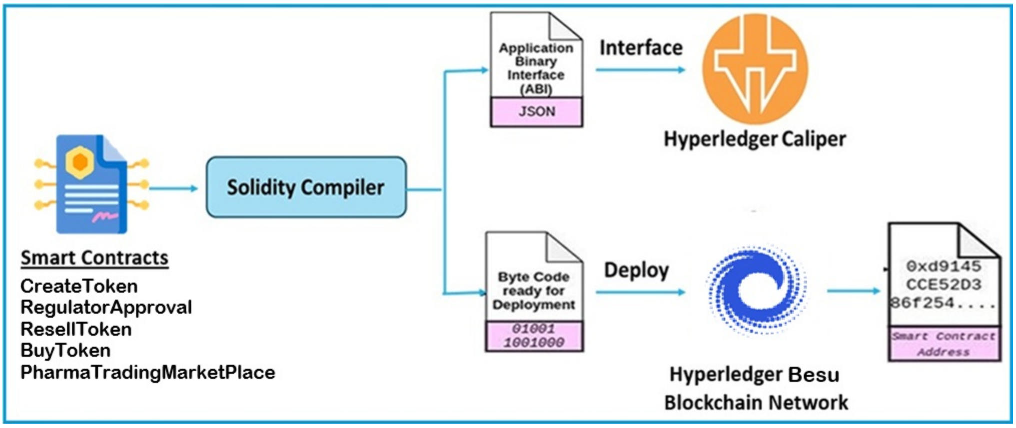

Figure 2: Experimental Configuration using Hyperledger Caliper

Table 1: Comparison Under Test with 1000 Transactions at Varied Rate Control

Cons	**TXs**	**Suc**	**Send Rate (TPS)**	**Avg. Latency (S)**	**Throughput**	**Memory Use(MB) MIN,MAX,AVG**	**Avg. CPU Use (%)**
Ethash	1000	760	50, 150, 250	7.20	38, 116, 161	880, 996, 938	87
HF Kafka	1000	812	50, 150, 250	6.26	41, 123, 163	760, 890, 825	79
HF Raft	1000	946	50, 150, 250	6.02	43, 135, 176	700, 780, 740	71
HB IBFT	1000	1000	50, 150, 250	5.14	50, 134, 223	520, 620, 570	56

5. Performance Results and Discussion

The performance of the proposed P-TokenPharma has been evaluated using Hyperledger Caliper, and the results have been compared with existing blockchain models. In this section, two types of blockchain platforms, Ethereum and Hyperledger Besu, and three types of consensus algorithms, RAFT, Kafka, and Ethash, have been analyzed. Block time, latency, throughput, success and failure rate, and resource utilization metrics have been compared. The metric-wise results from the Caliper have been presented in Table 1. The performance results of the IBFT2.0-enabled P-TokenPharma system show that it outperforms other consensus mechanisms. The metrics and their performance results are discussed below.

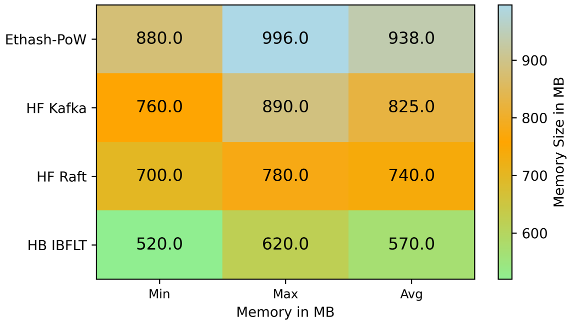

Figure 3: Memory Usage (Min, Max, Avg)

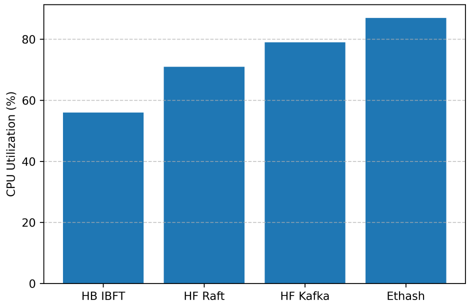

Figure 4: CPU Utilization

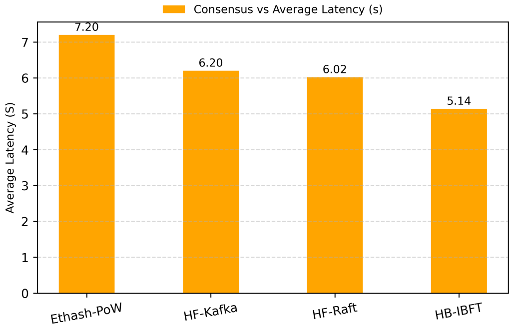

Figure 5: Average Latency

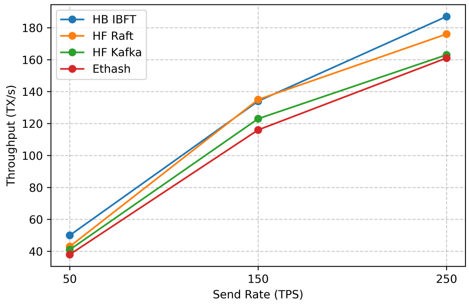

Figure 6: Transactional Throughput

5.1. Memory Usage

The size of the memory essential to complete a transaction in the P-TokenPharma network is known as memory usage. The minimum, maximum, and average memory usage in MBs have been stored in a Table. 1. The memory usage of different consensus and the proposed system is shown graphically in Figure. 3. It has been observed that Ethash consumes 39.23% more memory than the proposed Besu-IBFT.

5.2. CPU Utilization

Figure. 4 represents the CPU utilization of the proposed model over other existing models. It is the required CPU time to complete pharma transactions. The average CPU utilization details are deposited in Table 1. According to the results, Ethash sustains 1.55x higher CPU overhead than the Besu-IBFT.

5.3. Latency

The interval between transaction start and network confirmation is called the latency of the system. It significantly influences the efficiency of the pharmaceutical trading in Permissioned-TokenPharma. The average system latency is shown in Figure. 5 comparing the latency results of Raft, Kafka, and Ethash consensus. It is observed that the IBFT latency decreased by up to 45% compared to Ethash. It also performs better than Raft and Kafka. These experimental results show that the lowering of the latency of the proposed model plays a pivotal role in the pharmaceutical permissioned trading in the healthcare sector.

5.4. Throughput

Throughput is calculated as the number of transactions that are handled by the network per unit of time. In the network, transactions are processed very quickly as the system throughput is increases. Pharma trading applications require higher throughput to support interannual transactional operations for stakeholders. The final throughput results are depicted in Figure.6. The proposed system's throughput has been improved 2.1x compared to the public blockchain models.

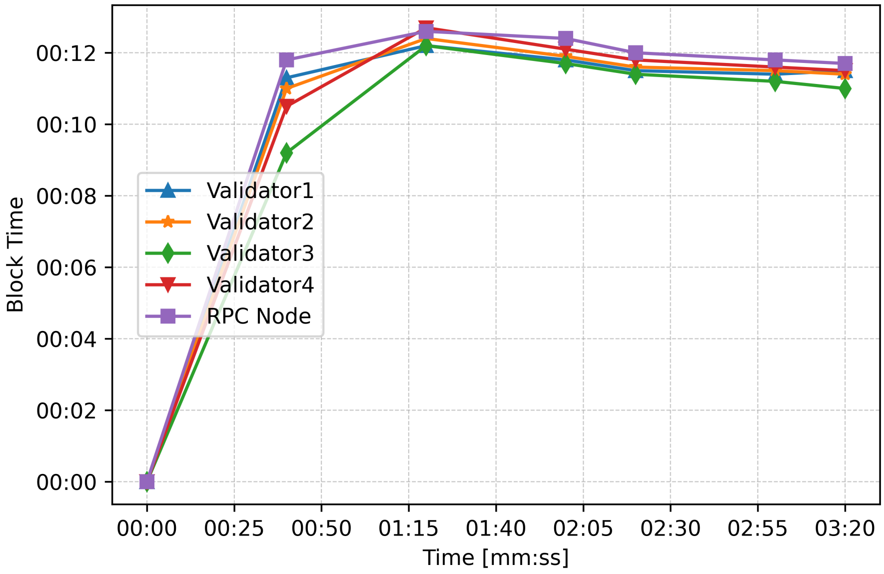

Figure 7: Block Time

5.5. Block Time

The time required to create a block on each node is called block time. For an enterprise application, block time indicates the growth of the chain. Figure. 7 illustrates the block time. The minimum, maximum, and variance of block times have been calculated. It is recorded that 1-5 seconds are taken for the block creation in the proposed P-TokenPharma. It is observed that the block time remains stable in the proposed system.

Table 2: Metric-wise Result Analysis: Public-TokenPharma Vs Permissioned-TokenPharma

Metrics	**Public Ethereum Models**	**Permissioned IBFT P-TokenPharma**	**Improvement**
Block Time	12–15 seconds [13]	1–5 seconds	Much faster
Gas Cost per Transaction	30,000 – 70,000 Gas [13] [5]	0 gas (permissioned execution)	Eliminated
Block Finality Time	Probabilistic (6–12 blocks) [9]	Deterministic (1 block)	Instant finality
Validator Mechanism	Open, miners (PoW) [9]	Authorized validators (IBFT 2.0)	Governed participation
Throughput Stability	Highly variable	Consistent and predictable	High stability
CPU Utilization	Higher under load	Lower due to non-mining consensus	More efficient
Moderate-to-high	Moderate	Better resource balance	Moderate-to-high
Drops under congestion	Scales with validators [13]	Enterprise-ready	Drops under congestion

5.6. Comparative Results and Discussion

The comparative results of Permissioned-TokenPharma versus the public TokenPharma [13] have been deposited in Table 2. The results show that the block time of the public models is recorded as 12-15 seconds, and 1-5 seconds in the permissioned model, which is much faster. The block instant finality is built into the permission model, and 6-12 blocks are probabilistically generated in the public Ethereum model. The Gas cost per transaction in Ethereum [5] is 30000-70000, and in the permissioned model, gas fees reduced (Zero) in the P-TokenPharma. In the public model, unauthorized miners can also finalize blocks without regulatory permission. But in the permissioned model, authorized validators govern participation and block finality [9].

The permissioned NFT architecture in P-TokenPharma offers advantages over public blockchains, including promoting regulatory compliance through identity verification, controlled contract deployment, and transparent audit trails vital for pharmaceutical supply chains. It limits access via node and account permissions, preventing unauthorized disruptions and building trust. The IBFT 2.0 consensus ensures high performance, deterministic finality, low latency, and ongoing high throughput, supporting real-time tracking and authentication of pharmaceutical assets. Structured logs, regulator observer nodes, and tamper-proof NFT ownership histories improve auditability, aiding compliance and investigations. These features make the permissioned NFT system secure, reliable, and enterprise-ready.

6. Conclusion and Future Scope

This paper introduces P-TokenPharma (Permissioned TokenPharma), leveraged with ERC-721 NFTs and Hyperledger Besu's IBFT 2.0 consensus mechanism. This model is designed to address the challenges of public Ethereum deployment models. The proposed model enabled regulated node membership, deterministic transaction finality, and governance control enabled by compliance. It dramatically improved throughput by 2.1x and reduced transaction latency by up to 45%. In addition, Ethash consumes 39.23% (1.65x) more memory, and sustains 1.55x higher CPU overhead than Besu-IBFT. The performance results of the P-TokenPharma highlight the advantages over the existing public Ethereum models. Future enhancements include integrating Internet of Things (IoT) data using an IoT sensor suite for real-time compliance monitoring. For privacy verification, the model needs to incorporate a zero-knowledge proof ZKP. For compliant digital settlements, a CBDC-based payment layer is required, and for sensitive data sharing, off-chain privacy channels must be created. These initiatives aim to improve further security and scalability of the pharmaceutical trading and supply chain management.

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