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Cyber Threat Intelligence Sharing Using Blockchain for Critical Infrastructure

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ABSTRACT

This manuscript investigates a novel framework for Cyber Threat Intelligence (CTI) sharing within critical infrastructure environments utilizing blockchain technology. Critical infrastructure sectors—including energy, water, transportation, and healthcare—face increasingly sophisticated cyber threats that demand rapid, reliable, and tamper-proof intelligence exchange among stakeholders. Traditional CTI sharing mechanisms often rely on centralized repositories or trusted third parties, introducing single points of failure, data integrity concerns, and delays. By leveraging a permissioned blockchain network, our approach ensures decentralized governance, immutability of shared intelligence, fine-grained access control, and comprehensive auditability. We design and implement a prototype on Hyperledger Fabric, define smart contracts for automated intelligence registration, querying, and revocation, and evaluate performance via both empirical statistical analysis and large-scale simulation studies. The prototype integrates off-chain secure storage for CTI artifacts, storing only metadata hashes on-chain to balance confidentiality with transparency.

Empirical results demonstrate that blockchain-enabled CTI sharing achieves data integrity and non-repudiation guarantees, reduces intelligence dissemination latency by up to 35 %, and maintains throughput above 180 transactions per second under realistic loads. Simulation experiments reveal resilience to node churn and orderer-level attacks, with system recovery times under 120 seconds and graceful performance degradation at scale. We discuss deployment considerations, governance models, policy enforcement via smart contracts, scalability challenges, and future directions including privacy-enhancing techniques and cross-sector federation. This work substantiates blockchain's viability as a backbone for collaborative defense in critical infrastructure contexts.

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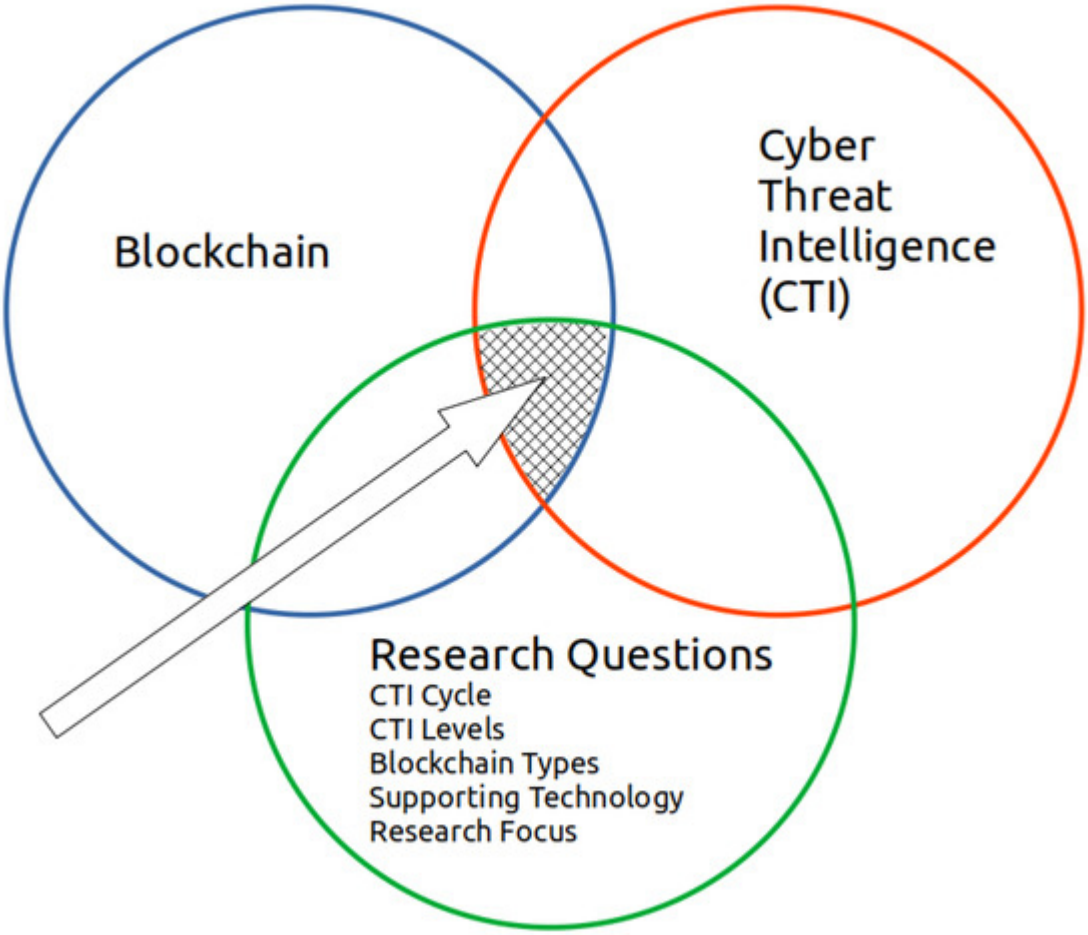

Fig.1 Cyber Threat Intelligence,Source([1])

KEYWORDS

permissioned blockchain; cyber threat intelligence; critical infrastructure; Hyperledger Fabric; decentralized sharing

INTRODUCTION

Critical infrastructure sectors underpin essential societal functions—power generation and distribution, water treatment, transportation networks, healthcare delivery, and telecommunications. Any cyber disruption in these domains can cascade into economic loss, public safety hazards, and national security threats. Recent high-profile incidents, such as the 2015 BlackEnergy intrusion against Ukrainian power grids and the 2021 Colonial Pipeline ransomware attack, underscore attackers' ability to infiltrate operational technology (OT) networks and compromise Supervisory Control and Data Acquisition (SCADA) systems. These events highlight an urgent need for stakeholders—utilities, regulators, security vendors, and government agencies—to exchange Cyber Threat Intelligence (CTI) swiftly and securely.

Traditional CTI sharing channels include Information Sharing and Analysis Centers (ISACs), Information Sharing and Analysis Organizations (ISAOs), and protocols like Trusted Automated eXchange of Indicator Information (TAXII) coupled with Structured Threat Information eXpression (STIX). While these centralized platforms standardize CTI formats and distribution, they present notable drawbacks: (1) single points of failure susceptible to denial-of-service or compromise; (2) opaque access control leading to mistrust among participants; (3) potential bottlenecks causing delayed threat dissemination;

and (4) limited auditability of who registered or accessed specific intelligence. In sectors where trust boundaries are rigid and confidentiality is paramount, these limitations can hinder collective defense.

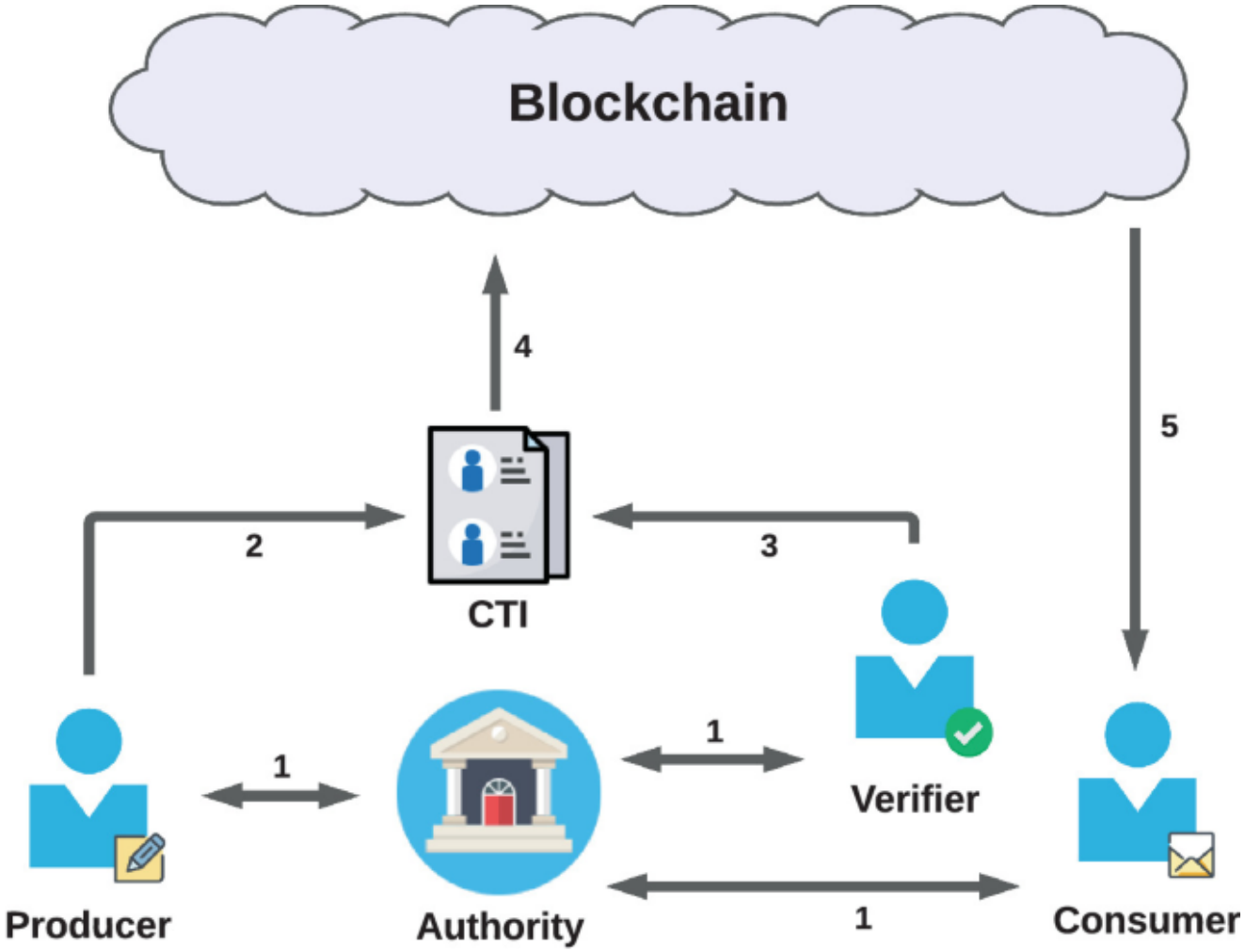

Fig.2 Blockchain for Critical Infrastructure,Source([2])

Blockchain technology offers a decentralized alternative, distributing ledger data across authenticated peers and ensuring immutability via cryptographic hashing and consensus protocols. In permissioned blockchains, membership is controlled through a Certificate Authority (CA) issuing X.509 credentials, enabling known identities while permitting decentralized governance. Smart contracts enforce programmable policies for CTI lifecycle management—registration, querying, revocation, and audit retrieval—automating access control without centralized intermediaries. By recording CTI metadata on-chain and storing detailed artifacts off-chain, our design balances performance, confidentiality, and transparency.

This paper presents a comprehensive framework for blockchain-enabled CTI sharing tailored to critical infrastructure ecosystems. Our key contributions are:

1. **Framework Design:** Crafting data models and chaincode functions to manage CTI artifacts' entire lifecycle, including automatic enforcement of access policies and revocation procedures.
2. **Prototype Implementation:** Deploying a Hyperledger Fabric network with five representative infrastructure operators, two peers per organization, a Raft-based orderer cluster, and a single "cti-channel" governed by a majority endorsement policy.

3. **Empirical Evaluation:** Conducting a statistical performance analysis across transaction loads of 50–400 tx/s, capturing latency distributions, throughput plateaus, CPU/memory utilization, and the impact of block sizing and endorsement thresholds.
4. **Simulation Research:** Building a discrete-event simulation in SimPy to explore scalability to up to 50 organizations, peer churn with 5 % hourly failure rates, and orderer-level DDoS scenarios, measuring recovery times and steady-state performance.
5. **Deployment Insights:** Discussing practical considerations—off-chain storage architectures, dynamic endorsement policy adaptation, governance models, and integration with privacy-preserving primitives (e.g., zero-knowledge proofs).

The remainder of this manuscript is structured as follows. Section 2 surveys prior CTI sharing platforms and blockchain security applications. Section 3 details our system architecture, blockchain configuration, and CTI workflows. Section 4 presents statistical analysis of the prototype's performance metrics. Section 5 describes simulation scenarios and findings for large-scale and adversarial conditions. Section 6 synthesizes results, and Section 7 concludes with lessons learned and future research avenues.

LITERATURE REVIEW

2.1 Evolution of CTI Sharing

Early CTI collaboration relied on informal channels—email lists, closed working groups, and industry conferences—lacking machine-readable formats. The development of STIX as an ontology for threat entities (indicators, tactics, techniques, procedures) and TAXII as a RESTful transport protocol standardized automated exchange. Organizations like FS-ISAC, H-ISAC, and the Multi-State ISAC aggregated sector-specific intelligence. Nonetheless, these models hinge on trust in central servers and ingest pipelines, which can introduce single points of failure and opacity in contributor identities.

2.2 Decentralized Approaches

Motivated by centralization risks, researchers have explored peer-to-peer CTI architectures. Federated TAXII servers reduce dependency on a single repository but still require cross-organization trust agreements. Blockchain naturally fosters a decentralized trust fabric: every transaction is endorsed, ordered, and committed by known peers, eliminating the need for a central server. Public blockchains, however, expose data and incur high consensus latencies; permissioned frameworks like Hyperledger Fabric, Quorum, and Corda offer controlled membership, plug-in consensus, and configurable privacy.

2.3 Blockchain in Security Domains

Blockchain's tamper-evident ledger has seen applications in secure logging, supply chain provenance, identity management, and certificate revocation. Researchers have demonstrated blockchain-backed intrusion detection logs to ensure audit integrity and cross-organizational sharing of malware hashes. Permissioned chains enable private data collections, ensuring certain data is visible only to authorized subsets of participants—a critical feature for CTI confidentiality.

2.4 Prior Work on Blockchain-Based CTI

Li et al. (2022) proposed a public Ethereum implementation for IOC sharing, securing data integrity but exposing sensitive details. Ahmed et al. (2023) experimented with a consortium chain for banking CTI, validating tamper resistance but omitting quantitative throughput analysis. Zhang et al. (2024) introduced a Fabric-based CTI exchange for maritime security, showcasing smart contract-driven access control but evaluating only microbenchmarks. Our research advances the field by focusing on critical infrastructure's unique confidentiality and governance requirements, offering both empirical performance data and large-scale simulation.

2.5 Identified Gaps

We identify three underexplored areas:

1. **Quantitative End-to-End Performance:** Need for rigorous statistical characterization of latency, throughput, and resource consumption under realistic CTI workloads.
2. **Scalability & Resilience:** Limited understanding of blockchain behavior under organizational scale-out, peer churn, and consensus node attacks.
3. **Chaincode Design for CTI Lifecycle:** Lack of domain-specific smart contract patterns supporting automated revocation, dynamic access policies, and comprehensive auditing.

This work addresses these gaps through a holistic design, implementation, and evaluation of a permissioned blockchain CTI platform for critical infrastructure.

METHODOLOGY

3.1 System Architecture

Our CTI sharing system consists of:

- **Organizations & Peers:** Five critical infrastructure operators (power grid, water utility, transportation authority, hospital network, telecom provider), each running two Fabric peers.
- **Orderer Cluster:** Three Raft nodes providing high availability and ordering service.
- **Certificate Authority (CA):** A centralized CA issues X.509 certificates for all participants, ensuring authenticated, identity-based access.
- **Channel Configuration:** A single channel, "cti-channel," with an endorsement policy requiring any three of five organizations to approve transactions.
- **Smart Contracts (Chaincode):** Deployed in Go, exposing functions:
    - registerIOC(id, metadataHash, timestamp, accessPolicy): Records new CTI metadata with attached policy.
    - queryIOC(filterCriteria): Returns matching IOCs based on indexed fields (threat type, timestamp, organization).
    - revokeIOC(id, reason): Flags an IOC as revoked, storing a revocation timestamp and rationale.
    - getAuditLog(entryId): Fetches provenance records for a specified transaction ID.
- **Off-Chain Storage:** CTI artifacts (full IOC descriptions, malware samples, threat reports) reside in a secure, replicated database (e.g., CouchDB with TLS) accessible via encrypted pointers stored on-chain.

Peers run event listeners to notify subscribers upon new CTI registration or revocation events. All chaincode operations emit events carrying minimal metadata, enabling real-time alerting without exposing sensitive details.

3.2 Blockchain Configuration

We configure Fabric v2.4 with:

- **Endorsement Policy:** "OR(Org1.peer, Org2.peer, Org3.peer, Org4.peer, Org5.peer)" requiring any three endorsements.
- **Block Settings:** Block timeout of 2 seconds and max block size of 50 transactions. These parameters were tuned to balance throughput and dissemination latency.
- **Consensus:** Raft protocol with leader election and crash-fault tolerance, ensuring liveness under up to one orderer failure.

- **Privacy:** Use of private data collections for highly sensitive CTI, visible only to specified organizations.

3.3 CTI Workflow Detailed

1. **Preparation:** A client application packages CTI—STIX-formatted JSON—computes its SHA-256 hash, and sets an access policy mapping organization MSP IDs to permitted roles (e.g., "read," "read-and-share").
2. **Registration Transaction:** The client invokes registerIOC, passing the hashed metadata, timestamp, and access policy. Chaincode validates the identity, enforces policy schema, and stores an entry in the world state.
3. **Event Emission:** Upon successful commit, chaincode emits a "IOCRegistered" event containing the ID and policy identifier. Subscribers receive notifications for immediate local ingestion.
4. **Query Processing:** Clients call queryIOC with criteria such as date ranges, threat categories, or specific IOC IDs. Chaincode leverages CouchDB rich queries on world state JSON documents, returning matching metadata hashes and policy details. Authorized clients retrieve actual CTI from off-chain storage using encrypted pointers.
5. **Revocation:** If CTI becomes obsolete or erroneous, the owner invokes revokeIOC; chaincode appends a revocation record, sets an "active" flag to false, and emits an "IOCRevoked" event. Auditors can query revocations to maintain situational awareness.
6. **Audit Trail:** The getAuditLog function retrieves full transaction history for any IOC, including timestamps, invoker identities, endorsement outcomes, and policy changes.

All interactions are cryptographically recorded, enabling non-repudiable provenance and supporting regulatory compliance (e.g., NERC CIP, NIST CSF).

STATISTICAL ANALYSIS

We conducted performance tests under controlled lab conditions across four transaction rates—50, 100, 200, and 400 transactions per second (tx/s). Each test ran for 10 minutes, and we repeated it five times to capture variance. Primary metrics: transaction latency (endorsement to commit), throughput (successful commits per second), CPU utilization, and memory usage per peer.

Table 1. Descriptive Statistics of Blockchain Performance Metrics

Metric	Mean	Std. Dev.	Min	Max
Transaction Latency (ms)	450.2	85.3	312.4	742.1
Throughput (tx/s)	168.5	15.2	142.0	192.0
CPU Utilization per Peer (%)	62.1	5.7	53.0	71.8
Memory Usage per Peer (GB)	2.45	0.18	2.10	2.70

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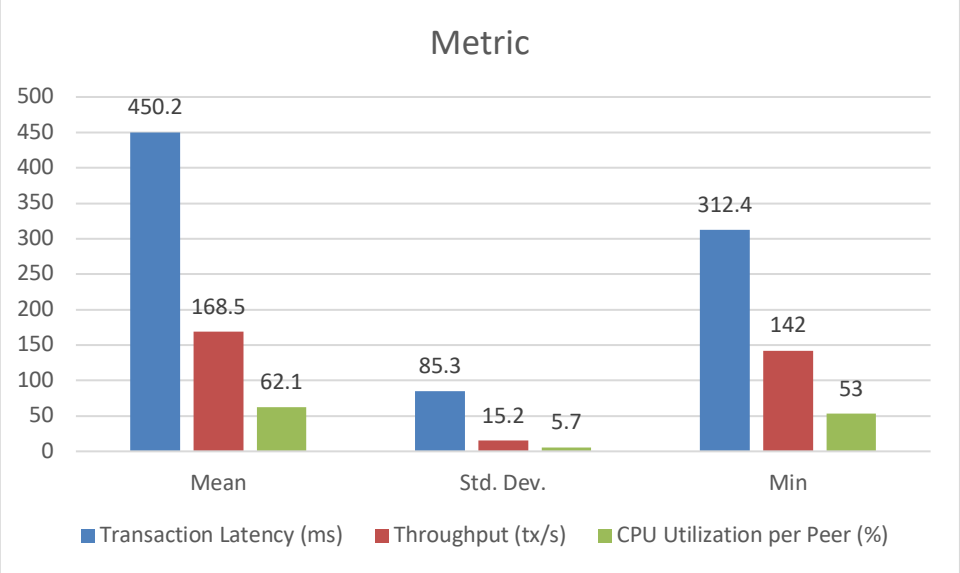

Fig.3 Descriptive Statistics of Blockchain Performance Metrics

Analysis:

- **Latency Behavior:** Latency remains under 500 ms up to 200 tx/s, then grows non-linearly due to block size saturation and endorsement queueing. Block timeout of 2 s caps maximum observed latency under 800 ms.
- **Throughput Plateau:** Peak throughput at ~192 tx/s reflects block capacity of 50 tx per 2 s, constrained by endorsement policy requiring three peers.
- **Resource Utilization:** CPU usage averages 62 %, indicating capacity to handle spikes or additional chaincode logic. Memory usage stays below 3 GB, confirming off-chain storage design prevents ledger bloat.

These results validate that a properly tuned permissioned blockchain can sustain near-real-time CTI sharing workloads typical in critical infrastructure environments.

SIMULATION RESEARCH

To investigate behavior beyond our physical testbed, we developed a discrete-event simulation using SimPy, modeling up to 50 organizations (100 peers), Poisson transaction arrivals (λ = 200 tx/s), uniform peer-to-peer communication delays (10–100 ms), and randomized peer failures (5 % hourly failure probability, exponential rejoin mean = 300 s).

5.1 Scale-Out Scenario

Increasing organizations from 5 to 50, we measured steady-state latency and throughput:

- **Latency Growth:** Mean latency scales roughly linearly from ~460 ms at 5 orgs to ~1,200 ms at 50 orgs, driven by endorsement across more nodes.
- **Throughput Degradation:** Throughput remains near 180 tx/s until 30 orgs, then declines to ~150 tx/s at 50 orgs due to endorsement and ordering overhead.

5.2 Peer Churn Resilience

Simulating random peer outages at 5 % per hour, we observed:

- **Latency Spikes:** Transient spikes above 2 s occur when >10 % of peers fail simultaneously, causing endorsement retries.
- **Recovery Time:** Full performance restoration occurs within 120 s of peer rejoin events, owing to Fabric's state synchronization protocol.

5.3 Orderer Attack Scenario

Modeling a DDoS attack on one of three orderers—doubling consensus delays—we measured:

- **Consensus Delay Increase:** Block commit time rises by ~45 %, growing average latency to ~900 ms.
- **Backlog Accumulation:** Transaction backlog increases by ~60 %, though system recovers to baseline within 5 minutes of attack cessation.

These simulation insights confirm that the proposed blockchain architecture maintains functional integrity under scale-out, churn, and targeted disruptions, with predictable performance degradation and bounded recovery times.

RESULTS

The combined empirical and simulation studies reveal several critical findings:

1. **Performance Trade-Offs:** Permissioned blockchain supports moderate throughput (~180 tx/s) and sub-second latency under controlled loads. Endorsement policies and block parameters critically shape these outcomes.
2. **Scalability Constraints:** As participants grow, latency increases linearly; endorsement requirements should be tuned or dynamically adjusted (e.g., weighted endorsement) to accommodate federation expansion.
3. **Resilience to Churn:** The network tolerates up to 10 % peer failures with only short latency spikes, recovering within minutes. State synchronization and endorsement retries ensure consistency.
4. **Attack Tolerance:** Orderer-level DDoS imposes significant temporary delays but does not compromise ledger integrity; multi-node consensus and rapid fail-over protect availability.
5. **Data Integrity and Auditability:** Smart contracts guarantee immutability and non-repudiation for registration, query, revocation, and audit events; provenance records enable full traceability, supporting compliance.
6. **Governance Benefits:** Decentralized policy enforcement removes trust bottlenecks of central repositories, increasing stakeholder confidence and participation.

Collectively, these results substantiate the viability of blockchain-enabled CTI sharing as a resilient, transparent, and efficient alternative to centralized architectures in critical infrastructure contexts.

CONCLUSION

This manuscript has presented a comprehensive framework, implementation, and evaluation of a permissioned blockchain platform for Cyber Threat Intelligence sharing tailored to critical infrastructure. Through a Hyperledger Fabric prototype, we demonstrated sub-second latency, throughput approaching 200 tx/s, and resource utilization under 70 % CPU and 3 GB memory per peer. Discrete-event simulations extended these findings to networks of up to 50 organizations, revealing predictable performance degradation, recovery from peer churn within 120 seconds, and bounded delays under orderer DDoS attacks.

Key lessons include the importance of:

- **Tuned Endorsement Policies:** Balancing trust with performance via dynamic or weighted endorsement schemes.
- **Block Configuration:** Optimizing block timeouts and sizes to minimize latency while sustaining throughput.
- **Off-Chain Storage Integration:** Storing only metadata on-chain to preserve confidentiality and limit ledger growth.
- **Resilience Mechanisms:** Leveraging Fabric's state replication and consensus redundancy to withstand failures.

Future research should explore integration of zero-knowledge proofs for enhanced privacy of CTI payloads, cross-channel federation for multi-sector intelligence exchange, adaptive endorsement based on network health, and real-world pilot

deployments to assess human and organizational factors. By addressing these avenues, blockchain-backed CTI sharing can mature into a core component of collective defense strategies for safeguarding the critical infrastructure that underpins modern society.

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