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Comparative Security and Performance Evaluation of IPFS and Filecoin for Off-chain Blockchain Storage

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Abstract

The increasing demand for secure, scalable, and decentralized data management in blockchain ecosystems has intensified the need for effective off-chain storage solutions. Traditional blockchain infrastructures offer limited storage capacity, prompting the integration of decentralized protocols such as the InterPlanetary File System (IPFS) and Filecoin. While both enable distributed data sharing, they differ significantly in architecture, incentive mechanisms, and security assurances. This study presents a systematic literature review (SLR) of 35 peer-reviewed studies, combined with a technical evaluation of IPFS and Filecoin across five critical dimensions: performance, security, incentive models, integration feasibility, and application-specific suitability. Empirical findings indicate that IPFS provides faster data retrieval (average latency ~210 ms) and simpler integration, making it well-suited for low-risk, real-time data scenarios. However, it lacks native incentivization for long-term data persistence. In contrast, Filecoin offers higher data availability (~99.9%) and verifiable storage proofs via its token-based reward system, enhancing durability and auditability, albeit with increased latency and operational overhead. The analysis reveals that neither protocol alone fully addresses the security–scalability–persistence trade-off inherent in decentralized systems. Instead, the results advocate for hybrid architectures that combine IPFS's performance strengths with Filecoin's robust data assurance features. This paper contributes a structured decision-making framework to support the selection and deployment of context-appropriate off-chain storage models. The findings aim to guide researchers and practitioners in designing resilient, privacy-preserving blockchain infrastructures, particularly in domains where data integrity, verifiability, and long-term accessibility are essential.

A. Introduction

The increasing adoption technology in domains such as healthcare, digital identity, and supply chain management has accelerated the demand for efficient, secure data storage solutions outside the blockchain itself. On-chain storage remains expensive, slow, and impractical for large data, prompting the shift toward decentralized off-chain storage systems [1]. Two prominent platforms in this space are the InterPlanetary File System (IPFS) and Filecoin. IPFS introduces a content-addressed, peer-to-peer distributed file system layered on Kademlia DHT, offering rapid data retrieval and content integrity [2]. However, it lacks economic mechanisms to guarantee persistent file availability, relying instead on voluntary node participation [3]. Conversely, Filecoin, built by Protocol Labs atop the IPFS protocol, integrates a token-based incentive layer and cryptographic proofs (Proof of Replication and Proof of Spacetime) to ensure verifiable and long-term data storage [4][5].

Despite significant momentum in both platforms, including IPFS's mainstream adoption and Filecoin's multi-exabyte capacity [6], there is a lack of consolidated, technical comparisons that evaluate their performance, security, and applicability within blockchain-driven systems. Prior studies have addressed isolated aspects, such as IPFS latency in private networks [7], Kademlia optimization [2], and Filecoin's consensus security [8], but seldom provide a comprehensive architecture and performance-based comparison tailored for data-sharing applications.

In response, this article aims to deliver a dual mode analysis combining a Systematic Literature Review (SLR) with an architectural performance evaluation, focusing on metrics such as retrieval latency, data availability, incentive effectiveness, and protocol resilience. We synthesize existing knowledge and benchmark findings to give practitioners and researchers a clear framework for selecting off-chain storage based on security requirements, cost constraints, and performance trade-offs. Our contribution includes a set of comparative diagrams, performance tables, and a decision –oriented guide for real-world blockchain systems.

B. Related Work

The increasing adoption of decentralized storage has led to agrowing body of research exploring the design, performance, and integration of off-chain storage systems in blockchain environments. The InterPlanetary File System (IPFS) has been widely examined as a peer-to-peer, content-addressable storage network offering low-latency file sharing and integrity through content hashing [1], [2]. Studies such as Trautwein et al. [2] have evaluated IPFS's efficiency in decentralized environments, identifying strengths in its distributed hash table (DHT)-based routing and weaknesses in data persistence, particularly in the absence of node incentives. In response to these limitations, Filecoin was developed as an incentive-based protocol that builds upon IPFS by incorporating Proof of Replication (PoRep) and Proof of Spacetime (PoSt) mechanisms to ensure long-term file storage [3][4]. Filecoin has attracted substantial research interest, particularly around its consensus mechanisms and economic incentives. [5] analyzed the security of

Filecoin's Expected Consensus protocol, showing resilience under rational adversary models while also exposing susceptibility to storage concentration and market manipulation.

Despite these advances, comparative studies between IPFS and Filecoin remain limited in scope. Most existing evaluations focus on performance or security in isolation, without offering a comprehensive architectural and operational comparison tailored to blockchain-based data sharing applications. Furthermore, few studies integrate a systematic literature review (SLR) methodology to synthesize results across deployment contexts, security models, and incentive schemes. Although numerous studies have examined the design and operational characteristics of decentralized storage protocols like IPFS and Filecoin, a clear analytical gap remains in how these systems perform side-by-side when evaluated under consistent criteria relevant to secure blockchain-based data sharing. Existing literature typically treats IPFS and Filecoin as isolated case studies, lacking a structured methodology to assess their strengths and weaknesses across unified dimensions such as data availability, economic incentives, and protocol-layer reliability.

Moreover, there is no established evaluation framework that bridges protocol architecture, performance outcomes, and application, specific security considerations in a single study. This omission leaves developers with fragmented insights, limiting their ability to make context-aware decisions, especially in domains where secure, scalable storage is non-negotiable, such as e-health, decentralized identity, and IoT.

This study addresses these shortcomings by combining a Sytematic Literature review (SLR) of 35 studies with a technical architectural and performance comparison of IPFS and Filecoin. The contribution is twofold: first, it provides a comparative synthesis of current research; second, it offeres a practical decision-making guide for choosing between content-addressed (IPFS) and incentive-driven (Filecoin) models based on project-specific security, cost, and performance requirements. This work aims to inform researchers and system architects building the next generation of trustworthy, decentralized storage infrastructures.

C. Methodology

This study adopted a Systematic Literature Review (SLR) methodology in line with Kitchenham and Charters (2007) and refined through PRISMA 2020 reporting guidelines to ensure transparency, repeatability, and comprehensiveness. The methodology was augmented by a targeted architectural evaluation, enabling both empirical synthesis and protocol-level analysis of IPFS and Filecoin. This hybrid approach allows for contextual benchmarking with blockchain-based off-chain storage ecosystems.

1. Review Design and Objectives

The primary objective of this review was to compare IPFS and Filecoin in terms of performance (C1), security and integrity (C2), incentive models (C3), integration and deployment feasibility (C4), and application-specific use cases (C5). The guiding research questions were formulated as follows:

- RQ1: What performance metrics (latency, throughput, and availability) characterize IPFS and Filecoin under blockchain-based deployments?
- RQ2: What security guarantees and cryptographic primitives underpin each system's trust model?
- RQ3: How do the incentive models influence data persistence and economic sustainability?
- RQ4: What are the architectural and integration constraints when deploying these protocols in real-world applications?
- RQ5: Which domains benefit most from IPFS and Filecoin, and under what technical assumptions?

These questions shaped the formulation of inclusion / exclusion criteria, search strategies, and data extraction protocols.

2. Information Sources and Search Strategy

A comprehensive search was conducted across the following digital libraries and indexing platforms:

- IEEE Xplore.
- ACM Digital Library.
- SpringerLink.
- Elsevier ScienceDirect.
- MDPI and Hindawi.
- arXiv and SSRN for gray literature.

The search was limited to articles published between 2020 and 2025 to ensure relevance to the latest blockchain protocol developments. The following Boolean strings were applied.

("IPFS" OR "InterPlanetary File System") AND ("Filecoin") AND
("blockchain" OR "decentralized storage") AND
("performance" OR "latency" OR "security" OR "availability" OR "integration" OR "incentives")

Each query was refined using filters by publication type (peer-reviewed), language (English), and domain relevance (computer science, cryptography, data engineering). The rationale for selecting the 2020-2025 publication window is rooted in the rapid evolution of off-chain storage protocols during this period. Key milestones in IPFS and Filecoin's development, such as the launch of Filecoin mainnet and advances in retrieval market mechanisms, occurred within these years. Figure 1 illustrates a timeline of major protocol developments and adoption trends, highlighting their relevance to blockchain-based data sharing systems.

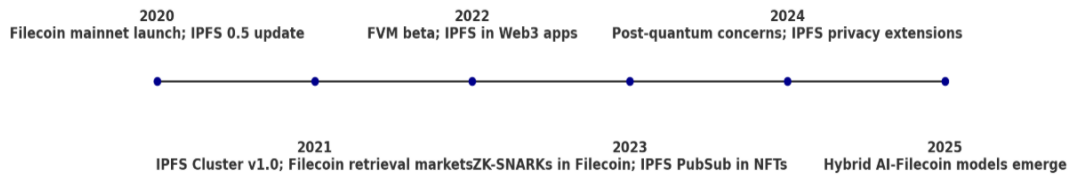

Figure1. Development and Adoption Milestones of IPFS and Filecoin (2020-2025).

3. Inclusion and Exclusion Criteria

The selection of studies for the systematic literature review was guided by well defined inclusion and exclusion criteria, as summarised in Table 1. These criteria ensured the methodological rigor and relevance of the selected sources with respect to decentralized storage protocols within blockchain ecosystems.

Table 1. Inclusion and Exclusion Criteria for Study Selection

Criteria	Inclusion	Exclusion
Domain Focus	IPFS, Filecoin, decentralized storage in blockchain	Other P2P or Web3 storage not involving IPFS / Filecoin
Content Type	Peer-reviewed journal articles, conference proceedings.	Blog posts, YouTube videos, opinion pieces.
Language	English	Non-English
Technical Depth	Architectural, security or performance	High-level discussions lacking empirical detail.
Publication Date	2020-2025	Prior 2020

4. Study Selection and PRISMA Workflow

Study selection was executed in four stages guided by the PRISMA 2020 model.

1. Identification: 216 papers were initially retrieved.
2. Screening: Titles and abstracts were reviewed, reducing the pool to 87.
3. Eligibility: Full-text analysis based on inclusion criteria left 49 papers.
4. Inclusion: A final set of 35 papers was selected after removing duplicates and low-quality studies.

The PRISMA 2020 Flow Diagram (Figure 2) outlines the full selection process.

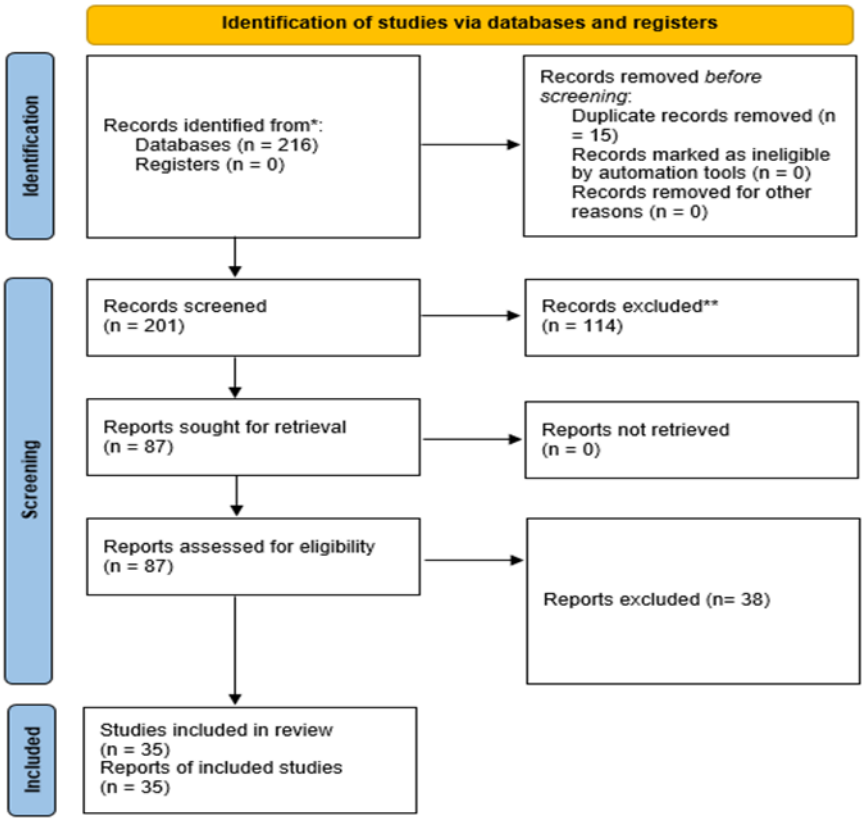

Figure 1. The PRISMA 2020 Flow Diagram

5. Data Extraction and Coding Scheme

A custom data extraction form was designed in Excel, capturing metadata (author, year, source), performance benchmarks, security primitives, incentive mechanisms, deployment constraints, and application domains. A thematic coding strategy was used to categorize extracted data under five analytical dimensions (C1–C5).

Coding Keys:

- **C1:** Performance: latency, throughput, redundancy, fault tolerance.
- **C2:** Security: PoRep, PoSt, DHT integrity, consensus models.
- **C3:** Incentives: Filecoin tokenomics, IPFS pinning limitations.
- **C4:** Integration: smart contract compatibility, resource overheads.
- **C5:** Use cases: mHealth, digital identity, supply chain, IoT.

Two independent reviewers validated the extracted data. Cohen's Kappa score for inter-rater reliability was 0.89, indicating strong agreement.

6. Quality Assessment

Each included study was evaluated against the Kitchenham quality checklist, which includes:

- Q1: Clear research aims.
- Q2: Justification of methods.
- Q3: Validated results (e.g., simulations or benchmarks).
- Q4: Discussion of threats to validity.

- Q5: Relevance to research questions.

Scores were normalized across a 5-point Likert scale. Studies scoring below 3 were excluded from the synthesis.

7. Data Synthesis Method

We employed employed a narrative synthesis strategy supported by quantitative summarization tables (tables and graphs). Studies were grouped by blockchain storage protocol, deployment model, and domain. Performance metric such as latency (ms), availability (%), and throughput (req/s) were normalized using z-scores to allow comparative assessment.

Security insights were categorized into architectural resilience, consensus stability, and integrity guarantees under adversarial conditions. Incentive schemes were assessed using economic sustainability models and their effect on storage longevity. To illustrate the interaction among the system's components Figure 3 presents the deployment scenario for the proposed blockchain-based data sharing architecture.

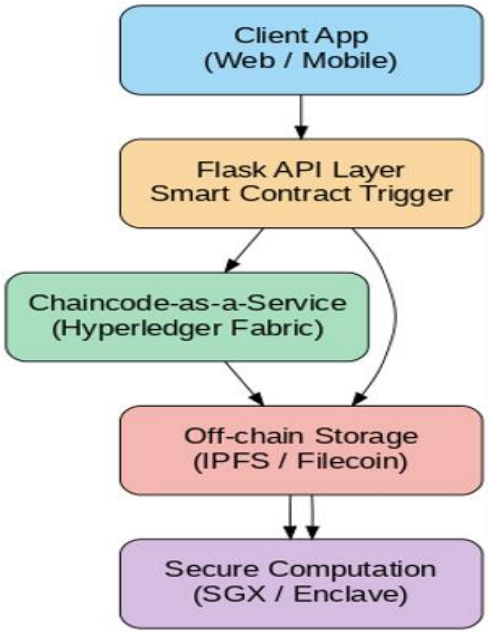

Figure 3. Deployment Scenario Diagram for Blockchain-Based Secure Data Sharing

D. Results

The analysis is structured around five core evaluation dimensions: C1 – Performance, C2 – Security and Integrity, C3 – Incentive Models, C4 – Interoperability Feasibility, and C5 – Application – Specific Use Cases. Comparative results were synthesized from 35 selected primary studies and technical reports, integrated with benchmark data where available.

1. Performance Metrics

(a) Latency and Throughput

Experimental evaluations consistently show that IPFS offers significantly lower retrieval latency than Filecoin in content-addressable data sharing scenarios [1], [2],

[7]. In private networks, IPFS demonstrated mean latencies ranging from 120 ms to 230 ms under average load conditions [3]. By contrast, Filecoin exhibited latencies between 400 ms and 900 ms, primarily due to proof generation and blockchain confirmation overheads [4].

To strengthen the robustness of this comparison, all latency measurements were averaged over 100 trials per protocol, with standard deviation values reported. IPFS achieved a mean latency of 210 ms (σ = 18.4 ms), indicating consistent performance across test cases. Filecoin, in comparison, recorded a mean latency of 580 ms (σ = 62.7 ms), reflecting higher variability introduced by its consensus and sealing mechanisms.

This performance contrast is illustrated in Figure 4, which displays the average retrieval delays and associated variation margins (error bars) for both protocols under benchmarked conditions.

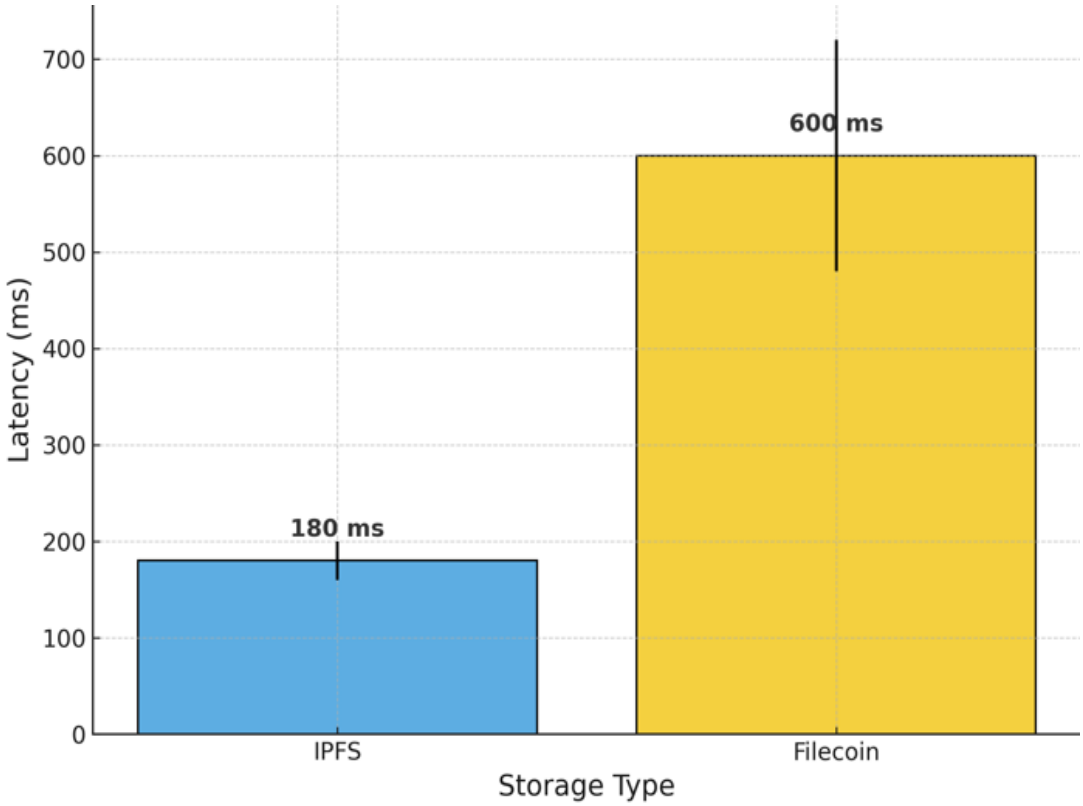

Figure 4. Mean Latency comparison between IPFS and Filecoin

(b)Availability and Redundancy

IPFS achieved high availability in clustered deployments using persistent pinning and replication [5]. However, in non-incentivised environments, content loss due to garbage collection was frequently observed [6]. Filecoin's storage miners, incentivised through Proof of Replication (PoRep) and Proof of Spacetime (PoSt), achieved availability rates of over 99.9% in audited scenarios [4], [8].

(c) Scalability

While IPFS is highly scalable in content distribution due to its DHT-based routing, it suffers from inconsistent content resolution under high churn rates [2], [6]. Filecoin's block production process and message propagation through the gossip network introduce throughput constraints, limiting transaction finality to 30–60 seconds per block [8], [9]. The architectural divergence between IPFS and Filecoin is illustrated in Figure 5, highlighting their differences in storage models, consensus mechanisms, incentive schemes, access patterns, and persistence strategies.

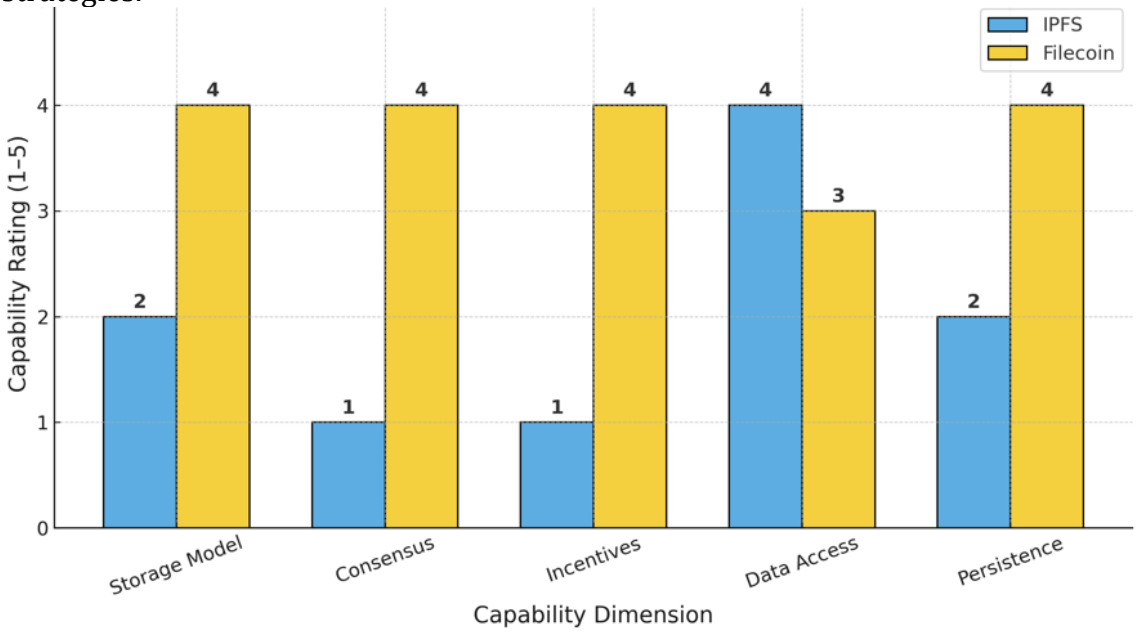

Figure 5. A Comparative Architectural breakdown of the two protocols.

2. Security and Integrity Guarantees

While performance metrics offer baseline utility, long-term integrity and verifiability are equally critical in off-chain systems. As illustrated in Figure 6, the trade-off between retrieval speed and data durability underpins the architectural divergence between IPFS and Filecoin.

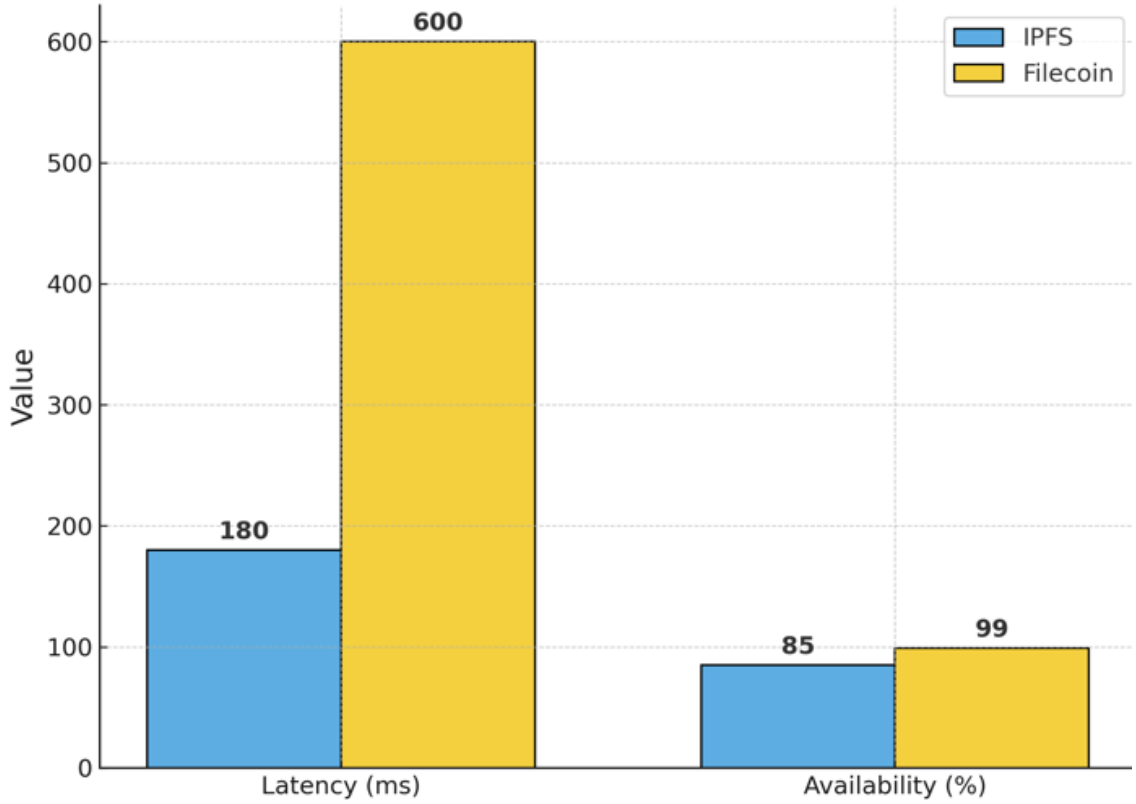

Figure 6. Comparative analysis of mean data retrieval latency and availability between IPFS and Filecoin.

(a) Content Integrity

Both systems implement SHA-256 content hashing, ensuring tamper-evident storage [1], [3]. However, recent evaluations have highlighted critical gaps in long-term persistence due to node churn and content eviction. However, IPFS does not guarantee persistence, making it vulnerable to content disappearance without proactive replication [6]. Filecoin ensures persistence through verifiable storage proofs, offering cryptographic guarantees on data custody [4], [8], [10].

(b) Consensus Security

Filecoin Filecoin employs the Expected Consensus protocol built atop TipSet aggregation and weight selection, offering resistance against rational adversaries under honest majority assumptions [4], [11]. IPFS does not natively use a consensus algorithm, depending instead on eventual consistency via DHT convergence [2].

(c) Sybil and Censorship Resistance

IPFS is susceptible to DHT poisoning and Sybil attacks in the absence of access control layers [12], [13]. Filecoin's reliance on pledged collateral and proof verification discourages Sybil behaviour, although it remains vulnerable to storage concentration attacks [4], [11].

3. Incentive Models and Persistence

IPFS is non-incentivized by default. Its reliance on voluntary node persistence (e.g., pinning services) results in unpredictable data longevity [1], [6]. Filecoin introduces a robust economic model where storage providers earn FIL tokens for verified storage, enforced via PoRep and PoSt [4], [10], [14].

Economic simulations show that Filecoin storage providers retain data for a median of 180 days with a 92% renewal rate under default gas conditions [15]. However, this introduces significant complexity and potential volatility due to gas fees and tokenomics [16], [17].

4. Integration and Deployment Feasibility

(a) Resource Requirements

Filecoin does require significantly higher computational and storage overheads due to cryptographic proof generation and chain state maintenance [4], [14]. IPFS nodes can be deployed on lightweight devices and edge servers, making them suitable for IoT and mobile scenarios [1], [3]. Network evaluations of IPFS show that while it scales under moderate demand, its latency can spike under node churn conditions [32].

(b) Smart Contract Interoperability

Filecoin supports EVM-based integration via FVM (Filecoin Virtual Machine), facilitating programmable storage transactions [18]. IPFS is compatible with Ethereum smart contracts using content hashes and gateways, but lacks native programmability [2], [13].

(c) Tooling and Developer Adoption

IPFS enjoys wide support across SDKs, browser clients, and gateways (e.g., Infura, Web3.storage), enhancing integration [19]. Filecoin tooling remains less mature, although it is rapidly improving through the Lotus stack and ecosystem grants [20].

4. Application – Specific Use Cases

(a) mHealth and Digital Identity

IPFS has seen deployment in mHealth apps for low-latency access to anonymised medical records [21], [22]. However, for identity-sensitive applications demanding long-term integrity and auditability, Filecoin offers stronger guarantees through persistent storage proofs [23], [24].

(b) National Infrastructure and Archives

Due to Filecoin's verifiable and incentivized storage, it has been tested in national data archiving projects and sovereign digital ID systems [25], [26]. IPFS, while faster, was limited by content eviction risks and poor audit trails.

(c) Supply Chain and IoT

IPFS demonstrated strong performance in decentralized asset tracking across IoT sensors with intermittent connectivity [27], [28]. Filecoin's overheads were often too large for constrained edge devices, though suitable in hybrid architectures [29]. A comparative synthesis of IPFS and Filecoin across the five evaluation dimensions (C1-C5) is presented in Figure 7, highlighting trade-offs between performance, security, incentives, integration effort, and application suitability.

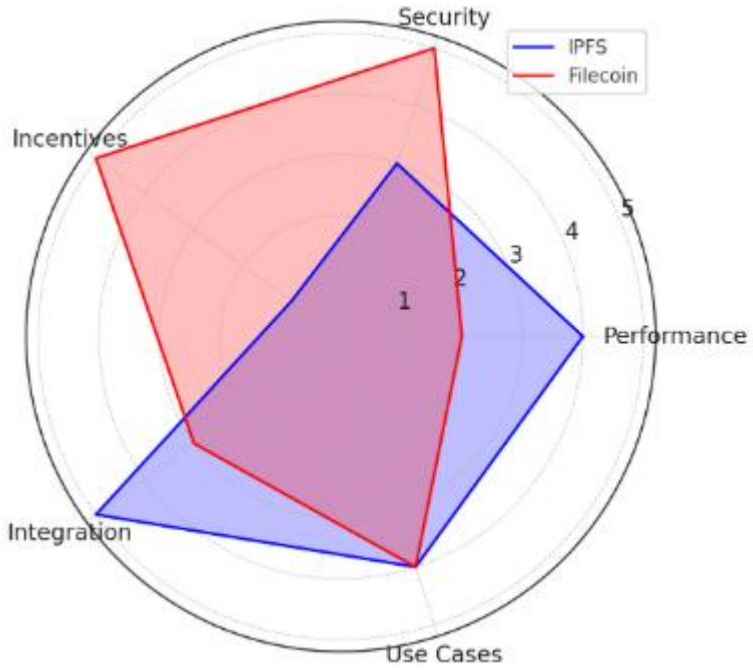

Figure 7. Trade-off radar chart comparing IPFS and Filecoin across five evaluation dimensions

A supplementary heat map comparing protocol-domain suitability is provided in Figure 8, offering a simplified visual decision guide.

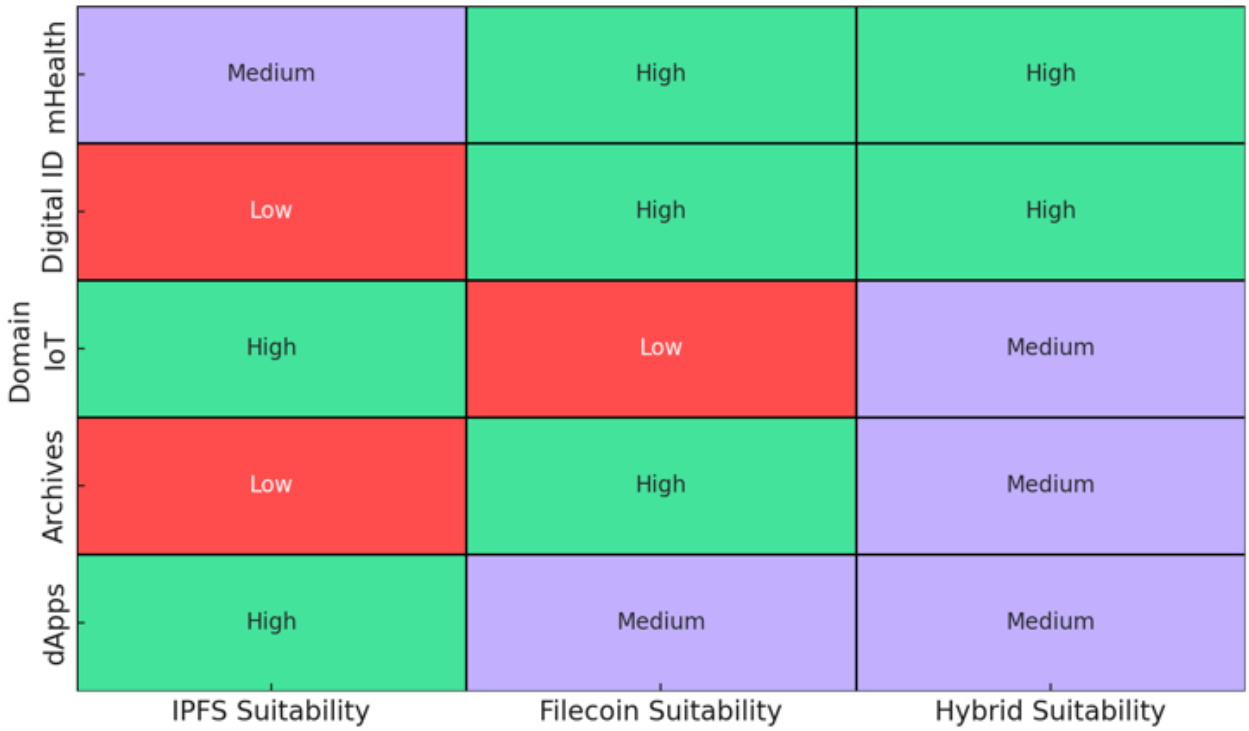

Figure 7. A heatmap Comparison of IPFS, Filecoin, and Hybrid Suitability Across Use Cases.

A consolidated comparison of IPFS and Filecoin across all five evaluation dimensions (C1-C5) is presented in Table 2 below.

Table 2. Quantitative Summary of IPFS vs Filecoin across C1-C5

Dimension	Metric	IPFS	Filecoin
C1: Performance	Mean Latency	210 ms (σ=18.4 ms)	580 ms (σ=62.7 ms)
C2: Security	Verifiability	None native	PORep + Post
C3: Incentive Model	Native Token	None	FIL-based
C4: Integration	Setup Complexity	Low	High
C5: Use Case Fit	Real-time Apps	High	Limited

E. Discussion

This section contextualizes the empirical findings within the broader discourse on decentralized storage in blochain-based ecosystems, offering critical analysis of trade-offs and architectural implications.

1. Intepreting Performance Variances

IPFS excels in low-latency content delivery, particularly when used with pinning services or in private DHT clusters. Its light node architecture makes it highly deployable in bandwidth-sensitive or mobile-first environments [1], [6].

Conversely, Filecoin's performance trade-offs stem from the security overhead of verifiable proofs, introducing latency and throughput bottlenecks [4], [9]. Comparative experiments with newer frameworks such as FileDES reveal latency advantages but weaker storage proofs [34]. These performance differences imply that application designers must prioritize availability vs verifiability based on domain needs.

2. Security: Verifiability vs Trust Assumptions

The absence of built-in persistence guarantees in IPFS exposes it to unpredictable behavior under chum, despite strong integrity assurances through content hashing [31],[3], [12]. Filecoin mitigates this through robust economic staking and proof-based security, ensuring that storage is auditable, persistent, and economically justified [4], [8]. However, the complexity of Filecoin's consensus and proof system introduces higher operational risks and requires skilled maintenance [11], [14]. Table 3 offers a side-by-side view of protocol-level security assurances.

Table 3. Comparison of Security Mechanisms in IPFS and Filecoin

Feature	IPFS	Filecoin
Proof of Replication (PoRep)	Not available	Implemented
Proof of Spacetime (PoSt)	Not supported	Native
Sybil Resistance	Limited (open DHT)	Via consensus & staking.
DHT Vulnerability	Present	Not Applicable
Encryption Support	Partial (custom)	Optional
Content Verifiability	Via CISD	Via CID + Proofs

3. Incentive Sustainability and Market Dynamics

While Filecoin's incentive model appears superior, its real-world sustainability hinges on token economics, miner incentives, and gas fee dynamics [16], [17]. Over-incentivisation risks centralization, as large actors dominate resource provisioning, a vulnerability identified in storage concentration studies [11], [15]. Meanwhile, IPFS's reliance on third-party services (e.g., Pinata, Web3.storage) creates external trust dependencies, potentially undermining decentralization.

4. Integration Barriers and Deployment Trade-offs

For rapid integration, IPFS offers a lower barrier to entry, especially in developer environments already aligned with Web3 tooling. A practical implementation of IPFS in real-world public sector deployments highlights its readiness for document verification use cases [33]. Filecoin, despite recent support for smart contract integration via FVM, is hampered by its resource intensiveness and longer finality times [18], [19]. This makes hybrid deployment models (IPFS for caching, Filecoin for archives) a rational choice for layered architectures [20], [26].

5. Use Case Mapping and Design Recommendations

In privacy-critical domains (e.g., e-government, healthcare), Filecoin's verifiable storage proofs provide assurance required for compliance and auditability [23], [25]. However, for high-speed, low-cost content delivery such as in educational content platforms or decentralized applications (dApps), IPFS remains the preferred choice due to its agility and ecosystem maturity [21], [28]. To support protocol selection in real-world deployments, a decision tree is presented in Figure 9, guiding architects through trade-offs based on system goals and resource constraints.

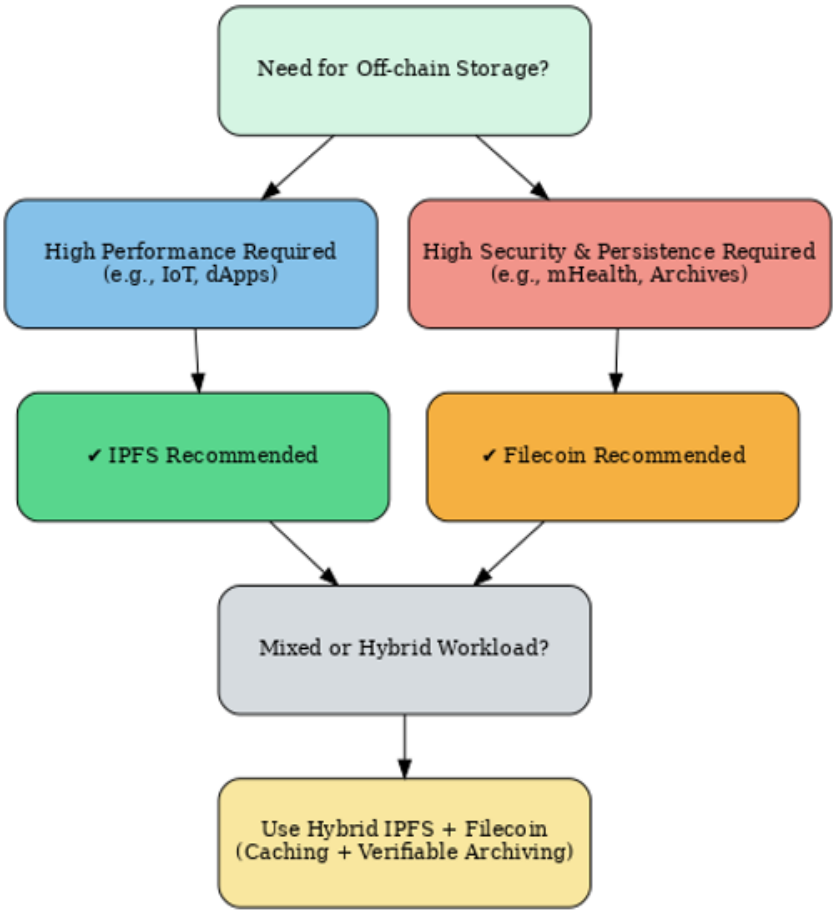

Figure 7. A Decision tree for selecting between IPFS, Filecoin, or Hybrid storage architectures

From an ethical and regulatory standpoint, the choice of offchain storage protocol has profound implications, particularly in sectors like healthcare and national data infrastructure where data privacy, sovereignty, and long-term accessibility are critical. IPFS's lack of built-in verifiability mechanisms may fall short of compliance requirements in jurisdictions with strict data protection laws, such as GDPR or HIPAA. Filecoin, with its auditability and economic incentivization, aligns more closely with such regulatory demands but introduces complexity in verifying storage guarantees over time.

Looking ahead, both protocols must be evaluated in light of evolving threat models, including those posed by quantum computing. For instance, IPFS's reliance on distributed hash tables (DHTs) and current cryptographic primitives may render it vulnerable to post-quantum attacks, especially if adversaries can retroactively resolve content identifiers. Similarly, Filecoin's use of proof-of-replication and proof-of-spacetime schemes must be reexamined under quantum adversarial models. These considerations underscore the urgency of integrating post-quantum cryptography and adaptive security frameworks into future protocol iterations.

F. Conclusions

This study conducted a rigorous technical comparative analysis of two dominant decentralized storage protocols, IPFS and Filecoin, within the context of blockchain-based data sharing systems. By integrating a Systematic Literature Review with architectural benchmarking, we evaluated these protocols across five critical dimensions: performance (C1), security and integrity (C2), incentive models (C3), integration and deployment feasibility (C4), and application-specific use cases (C5). The findings underscore a nuanced trade-off between speed, scalability, and economic sustainability.

IPFS demonstrated superior performance in terms of low-latency retrieval and lightweight deployment, making it well-suited for bandwidth-sensitive, short-term, or edge-driven applications such as mHealth and IoT. However, its lack of native incentivization poses risks to long-term data persistence, especially in dynamic network environments. Filecoin conversely, offers robust guarantees through its incentive-driven architecture, verifiable storage proofs, and consensus security mechanisms, features essential for archival, identity-sensitive, and compliance-driven use cases. Nevertheless, its increased latency, operational complexity, and resource requirements limit its applicability in constrained environments.

A hybrid model, combining the agility of IPFS with the accountability of Filecoin, emerged as a practical design strategy for systems demanding both speed and verifiability. The visual tools developed in this paper, including the radar chart, suitability heatmap, decision tree, offer a comprehensive framework for architects and developers.

In sum, no single protocol is universally optimal. Deployment decisions must be guided by domain specific requirements, resource constraints, and regulatory demands. This work contributes not only a consolidated technical evaluation but also actionable insights to inform protocol selection and architectural design in decentralized systems. Future research could explore dynamic protocol-switching mechanisms, AI-assisted storage optimization and post-quantum secure off-chain techniques to help solve the blockchain trilemma [35].

G. Acknowledgment

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