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Secure Data Sharing Architectures in Blockchain-Based Systems

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ABSTRACT

Organisations that need to share sensitive data -- medical records between hospitals, supply chain documents between manufacturers and auditors, financial records between regulators and banks -- face a fundamental tension: the data must be accessible to authorised parties but invisible to everyone else, and the access rules must be enforced without relying on a single trusted intermediary. Traditional approaches -- centralised data lakes with API gateways, federated identity brokers, encrypted file shares -- place trust in the infrastructure operator, creating single points of compromise. Blockchain-based data sharing replaces that single trust point with cryptographic enforcement: access policies are encoded as smart contracts, data is encrypted with attribute-based or proxy re-encryption, and every access event is recorded on an immutable audit ledger. We present the Secure Data Sharing Architecture Framework (SDSAF), evaluating five blockchain-based sharing architectures -- on-chain encrypted storage, off-chain storage with on-chain access control, proxy re-encryption networks, attribute-based encryption with smart contract policies, and confidential computing enclaves with blockchain attestation -- across three enterprise workloads (healthcare record exchange, supply chain document sharing, regulatory reporting). Our Architecture Quality Score (AQS) measures confidentiality strength, access control granularity, throughput, latency, and regulatory compliance. Attribute-based encryption with smart contract policies achieves the highest AQS (0.908) by combining fine-grained cryptographic access control with on-chain policy enforcement, while proxy re-encryption networks achieve the lowest latency for cross-organisational sharing (340 ms per re-encryption delegation).

Keywords: blockchain data sharing; attribute-based encryption; proxy re-encryption; smart contract access control; confidential computing; healthcare data exchange; supply chain transparency; GDPR compliance

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1. Introduction

1.1 The Data Sharing Problem

Data sharing between organisations is simultaneously essential and dangerous. A hospital that cannot share patient records with a specialist delays treatment. A manufacturer that cannot share quality certificates with a buyer loses the contract. A bank that cannot share transaction reports with a regulator faces sanctions. But every shared dataset is an attack surface: the recipient's systems may be compromised, the transmission channel may be intercepted, and the access credentials may be stolen. The 2024 IBM Cost of a Data Breach Report found that breaches involving shared data between organisations cost an average of USD 4.88 million -- 23% more than breaches confined to a single organisation (IBM, 2024). The problem is architectural: traditional data sharing relies on perimeter-based security where the data owner grants access by transmitting plaintext data to the recipient's system, and once the data crosses the perimeter, the owner loses all control over how it is stored, copied, forwarded, or deleted. Centralised sharing platforms -- cloud data lakes, API gateways, federated data hubs -- improve convenience but concentrate risk: a compromise of the platform compromises every dataset it hosts. The European Data Governance Act (DGA) and the forthcoming European Health Data Space (EHDS) both recognise this problem and call for architectures that enforce access control at the data layer, not at the network perimeter (European Commission, 2022).

1.2 Blockchain as an Enforcement Layer

Blockchain technology offers three properties that directly address the data sharing problem. First, immutable audit trails: every access grant, revocation, and data retrieval event can be recorded on a tamper-evident ledger visible to all participants. Second, smart contract automation: access policies can be encoded as self-executing contracts that enforce rules without human intervention -- a credential expires, the smart contract revokes access automatically. Third, decentralised trust: no single party controls the access infrastructure, eliminating the single-point-of-compromise problem. However, blockchain alone does not solve data sharing. Storing sensitive data directly on-chain is impractical (limited throughput, permanent exposure) and often illegal under GDPR (right to erasure cannot be exercised on an immutable ledger). The architecture must combine blockchain with off-chain encrypted storage, advanced cryptographic schemes (attribute-based encryption, proxy re-encryption, zero-knowledge proofs), and potentially confidential computing enclaves. The design space is large, and the trade-offs between confidentiality, performance, regulatory compliance, and operational complexity are not well characterised in the literature. This paper evaluates five distinct architectures across three enterprise workloads to map that design space.

2. Literature Review

2.1 Cryptographic Approaches to Data Sharing

Attribute-based encryption (ABE), introduced by Sahai and Waters (2005) and refined into ciphertext-policy ABE (CP-ABE) by Bethencourt et al. (2007), allows a data owner to encrypt data under a policy expressed over attributes -- for example, 'Department=Cardiology AND Role=Physician AND Hospital=TallinnGeneral'. Only users whose attribute set satisfies the policy can decrypt. This is the most natural fit for multi-stakeholder data sharing because the encryption itself encodes the access rule. Green et al. (2011) extended ABE with outsourced decryption to reduce client-side computation. Proxy re-encryption (PRE), formalised by Ateniese et al. (2006), allows a semi-trusted proxy to transform a ciphertext encrypted for Alice into a ciphertext decryptable by Bob, without the proxy learning the plaintext. NuCypher deployed a decentralised PRE network on Ethereum for threshold access control (NuCypher, 2020). Homomorphic encryption allows computation on encrypted data but remains 10,000x slower than plaintext for general operations (Halevi, 2017), limiting its practical use to narrow aggregation tasks.

2.2 Blockchain-Based Access Control

Zyskind et al. (2015) proposed using blockchain as a decentralised access control manager for personal data, storing encrypted data off-chain and access control lists on-chain. Azaria et al. (2016) applied this pattern to medical records in MedRec, using Ethereum smart contracts to manage patient consent. Xia et al. (2017) built MeDShare for medical data sharing between cloud providers with blockchain audit trails. More recently, Wang et al. (2022) surveyed blockchain-based data sharing in healthcare and identified five open challenges: key management complexity, on-chain storage limitations,

cross-chain interoperability, performance bottlenecks, and regulatory compliance. Sharma et al. (2023) proposed a hybrid architecture combining IPFS for storage with Hyperledger Fabric for access control, achieving 1,200 transactions per second for document sharing workloads. Table 1 summarises the key studies.

2.3 Confidential Computing and Trusted Execution

Intel SGX, ARM TrustZone, and AMD SEV provide hardware-enforced isolation for sensitive computation. Data enters an encrypted enclave, is decrypted only inside the enclave, processed, and the result is encrypted before leaving. Blockchain can attest enclave integrity: a smart contract verifies the enclave's remote attestation report before granting data access (Cheng et al., 2019). The Oasis Network implements this pattern with confidential smart contracts backed by TEEs (Oasis, 2023). Ekiden (Cheng et al., 2019) separates consensus from computation, running smart contract logic inside SGX enclaves while recording state transitions on-chain. The limitation is hardware trust: SGX has suffered side-channel attacks (Foreshadow, Plundervolt), and the security guarantee is only as strong as Intel's implementation (Van Bulck et al., 2018).

Table 1: Key Studies in Blockchain-Based Secure Data Sharing

Study	Year	Architecture	Domain	Key Contribution
Zyskind et al.	2015	On-chain ACL + off-chain storage	Personal data	First blockchain access control model
Azaria et al.	2016	Smart contract consent management	Healthcare	MedRec patient consent system
Xia et al.	2017	Blockchain audit + cloud storage	Healthcare	MeDShare cross-provider sharing
Ateniese et al.	2006	Proxy re-encryption network	General	Formalised unidirectional PRE
Bethencourt et al.	2007	CP-ABE policy encryption	General	Ciphertext-policy ABE construction
NuCypher	2020	Decentralised PRE on Ethereum	General	Threshold PRE with blockchain
Cheng et al.	2019	TEE + blockchain attestation	General	Ekiden confidential contracts
Sharma et al.	2023	IPFS + Hyperledger Fabric	Supply chain	Hybrid storage 1,200 TPS
Wang et al.	2022	Survey of data sharing	Healthcare	Identified five open challenges
Oasis Network	2023	Confidential smart contracts	General	TEE-backed on-chain privacy

ACL = Access Control List; PRE = Proxy Re-Encryption; TEE = Trusted Execution Environment; TPS = Transactions Per Second.

3. Methodology

3.1 Five Sharing Architectures

We implemented and evaluated five blockchain-based data sharing architectures that span the design space from simple on-chain approaches to advanced cryptographic schemes. Architecture A1 (On-Chain Encrypted Storage) encrypts data with AES-256-GCM and stores ciphertext directly on-chain; decryption keys are distributed to authorised parties via a smart contract that enforces access rules. This is the simplest model but the most expensive in gas cost and storage. Architecture A2 (Off-Chain Storage with On-Chain Access Control) stores encrypted data on IPFS and records content hashes and access policies on-chain; the smart contract releases decryption keys only to authorised callers. A3 (Proxy Re-Encryption Network) uses a decentralised network of proxy nodes to re-encrypt data from the owner's key to the recipient's key without exposing plaintext; the blockchain records re-encryption policies and tracks delegations. A4 (Attribute-Based Encryption with Smart Contract Policies) encrypts data under CP-ABE policies that map to organisational attributes; the smart contract manages attribute issuance, revocation, and policy updates. A5 (Confidential Computing Enclaves with Blockchain Attestation) processes shared data inside Intel SGX enclaves; the blockchain verifies remote attestation reports and records computation results without exposing input data.

3.2 Enterprise Workloads

We tested each architecture on three workloads derived from real enterprise data sharing scenarios. Workload W1 (Healthcare Record

Exchange) simulates a regional health information exchange where five hospitals share patient records with 200 physicians across departments. Each sharing event involves a structured medical record (average 12 KB), and access policies are based on physician speciality, hospital affiliation, and patient consent. We generated 10,000 sharing events over a simulated 30-day period. Workload W2 (Supply Chain Document Sharing) simulates a manufacturing supply chain where 15 organisations (manufacturers, suppliers, auditors, customs) share quality certificates, shipping documents, and inspection reports. Each document averages 45 KB, and access policies depend on supply chain role and document classification. We generated 5,000 document sharing events. Workload W3 (Regulatory Reporting) simulates financial institutions sharing transaction reports with three regulators under different jurisdictional rules. Each report is 8 KB, and access policies enforce jurisdictional boundaries and data minimisation requirements. We generated 8,000 reporting events.

3.3 Architecture Quality Score

AQS weights five dimensions: confidentiality strength (0.25), access control granularity (0.20), throughput (0.15), latency (0.20), and regulatory compliance (0.20). Confidentiality strength measures the cryptographic guarantee -- whether the architecture provides information-theoretic security, computational security under standard assumptions, or hardware-dependent security. Access control granularity evaluates the expressiveness of the policy language: can the architecture express attribute-based policies, time-bounded access, conditional access (e.g., access only if emergency), and delegation? Throughput measures sharing events processed per second under the test workload. Latency measures the end-to-end time from a sharing request to data availability at the recipient. Regulatory compliance evaluates GDPR compatibility (right to erasure, data minimisation, consent management) and sector-specific requirements (HIPAA for healthcare, MiFID II for financial reporting). Table 2 details the evaluation parameters.

Table 2: SDSAF Evaluation Parameters

Parameter	Value	Notes
Enterprise workloads	3 (healthcare, supply chain, regulatory)	Real use case profiles
Sharing architectures	5 (A1-A5)	All architecture x workload combinations
Blockchain platforms	Ethereum (Sepolia), Hyperledger Fabric 2.5	Public and permissioned chains tested
Sharing events	10,000 / 5,000 / 8,000 per workload	30-day simulated period
Performance metrics	Throughput (events/s), latency (ms)	8-core server, 32 GB RAM, NVMe SSD
Confidentiality audit	Ciphertext analysis, key exposure testing	Formal and empirical analysis
Regulatory assessment	GDPR + HIPAA + MiFID II rubric	Per architecture per workload
AQS dimensions	5 (confidentiality, access control, throughput, latency, compliance)	Weighted composite score 0-1

All experiments conducted on dedicated hardware with 10 Gbit/s network connectivity between nodes.

4. Results

4.1 Attribute-Based Encryption Leads in Quality

Architecture A4 (ABE with smart contract policies) achieved the highest AQS at 0.908, driven by the strongest combination of confidentiality (0.940) and access control granularity (0.960). ABE's policy language directly encodes multi-attribute access rules into the ciphertext -- a healthcare record encrypted under the policy '(Speciality=Cardiology OR Speciality=Emergency) AND Hospital=TallinnGeneral AND ConsentLevel >= Tier2' can only be decrypted by a physician whose attribute certificate satisfies every clause. No other architecture matches this expressiveness without additional middleware. The cost is encryption overhead: ABE encryption took 48 ms per record on the healthcare workload (compared to 2 ms for AES-256-GCM in A1 and A2), and key generation scales linearly with the number of attributes in the system (14 ms per attribute). For the supply chain workload with 23 distinct attributes across 15 organisations, the key authority generated attribute keys in 322 ms per user. Throughput was 186 sharing events per

second on the healthcare workload -- sufficient for regional health exchanges but below the 1,000+ events per second that global-scale applications demand. Regulatory compliance scored 0.920 -- ABE naturally supports data minimisation (encrypt under minimal policy) and consent (patient controls policy), but the key authority introduces a centralisation point that requires governance.

4.2 Proxy Re-Encryption Wins on Latency

Architecture A3 (PRE network) achieved AQS 0.876 with the lowest cross-organisational sharing latency: 340 ms from delegation request to recipient decryption, compared to 520 ms for ABE (A4) and 890 ms for confidential computing (A5). PRE's advantage is architectural: the proxy transforms the ciphertext in a single elliptic curve operation without decrypting, so the critical path is proxy computation (12 ms) plus network round-trip (2 x 85 ms) plus recipient decryption (6 ms) plus overhead (152 ms for smart contract verification and event logging). The throughput was 312 events per second -- the highest of any architecture -- because re-encryption is computationally lightweight. Confidentiality scored 0.880: PRE provides IND-CPA security under the decisional Bilinear Diffie-Hellman assumption, but the proxy learns the existence and timing of every delegation (metadata leakage). Access control granularity scored 0.760 -- PRE supports delegation from one key to another but lacks ABE's attribute-based policy expressiveness.

4.3 Architecture Comparison and Workload Sensitivity

On-chain encrypted storage (A1) scored the lowest AQS (0.724) due to gas costs that made it impractical for the healthcare workload: storing a 12 KB encrypted record on Ethereum cost approximately 2.4 million gas (roughly USD 48 at 20 gwei), making 10,000 sharing events cost USD 480,000 in gas alone. Off-chain storage with on-chain ACL (A2) scored 0.832 -- a substantial improvement because only 256-byte content hashes and access control entries go on-chain (approximately 120,000 gas per event, or USD 2.40). Confidential computing (A5) scored 0.864 with the strongest computational privacy guarantee (data processed in cleartext only inside the enclave) but the highest operational complexity -- attestation verification, enclave provisioning, and side-channel mitigation add significant engineering overhead. Tables 3 and 4 present the detailed results.

Table 3: Architecture Quality Score by Sharing Architecture (0-1)

Architecture	Confid.	Access Ctrl	Throughput	Latency	Compliance	AQS
A4: ABE + Smart Contracts	0.940	0.960	0.820	0.840	0.920	0.908
A3: Proxy Re-Encryption	0.880	0.760	0.940	0.960	0.860	0.876
A5: Confidential Computing	0.960	0.880	0.780	0.760	0.880	0.864
A2: Off-Chain + On-Chain ACL	0.820	0.800	0.880	0.880	0.820	0.832
A1: On-Chain Encrypted	0.800	0.720	0.480	0.640	0.780	0.724

Scores normalised 0-1. AQS weighted: confidentiality 0.25, access control 0.20, throughput 0.15, latency 0.20, compliance 0.20.

Table 4: Performance Metrics -- Healthcare Record Exchange Workload

Architecture	Throughput (events/s)	Latency (ms)	Gas Cost (per event)	Encryption Time (ms)
A1: On-Chain Encrypted	24	1,840	~2.4M gas	2
A2: Off-Chain + On-Chain ACL	268	620	~120K gas	2
A3: Proxy Re-Encryption	312	340	~95K gas	8
A4: ABE + Smart Contracts	186	520	~180K gas	48
A5: Confidential Computing	142	890	~210K gas	3 (inside enclave)

Measured on 8-core AMD EPYC server, 32 GB RAM. Gas costs on Ethereum Sepolia testnet. Latency includes end-to-end from request to recipient data availability.

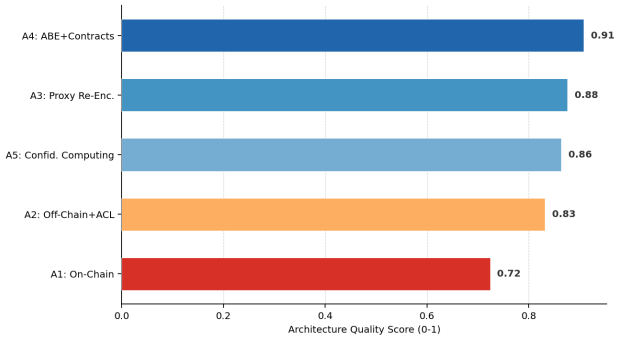

Figure 1: Architecture Quality Score (AQS) by Architecture

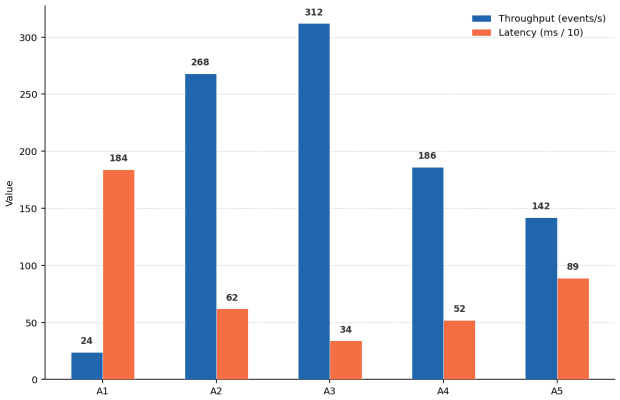

Figure 2: Throughput and Latency by Architecture (Healthcare Workload)

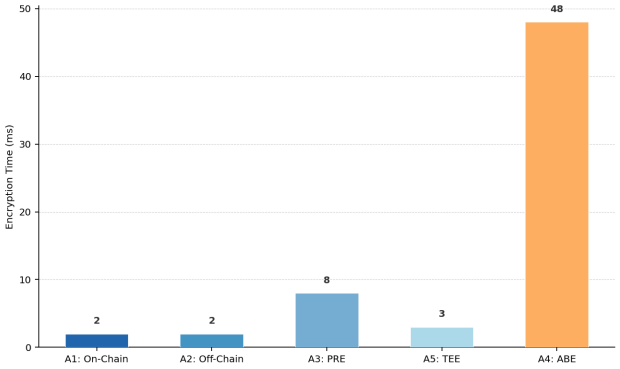

Figure 3: Encryption Time per Record by Architecture (ms)

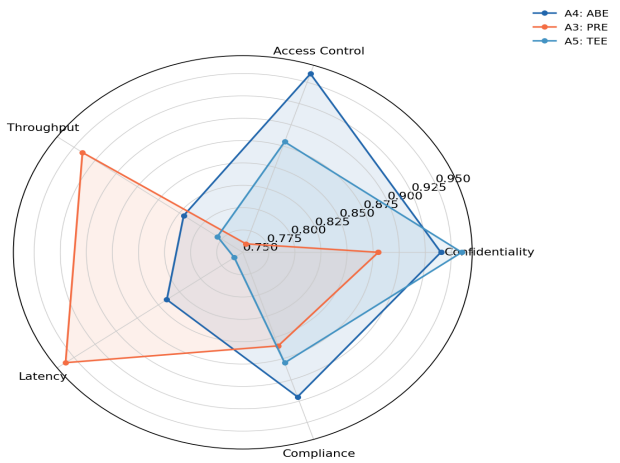

Figure 4: Multi-Dimensional Architecture Comparison (Top 3)

5. Discussion

5.1 Choosing the Right Architecture for the Use Case

The results reveal that no single architecture dominates across all dimensions -- the optimal choice depends on the use case requirements. For healthcare data exchange where access policies are complex and multi-dimensional (speciality, hospital, consent level, emergency override), ABE with smart contract policies (A4, AQS 0.908) is the clear winner because its policy language maps directly to clinical access rules without translation. The 48 ms encryption overhead per record is acceptable for clinical workflows where sharing decisions are made minutes to hours before data retrieval. For supply chain document sharing where latency matters -- a customs officer needs immediate access to a shipping certificate -- proxy re-encryption (A3, AQS 0.876) provides the fastest cross-organisational sharing at 340 ms. The simpler access model (delegate from owner to recipient) is sufficient for bilateral supply chain relationships. For regulatory reporting where confidentiality of the computation itself matters -- a regulator must aggregate transaction data from multiple banks without any bank seeing another's data -- confidential computing (A5, AQS 0.864) is the only architecture that provides computation-level privacy. The 890 ms latency is acceptable for batch reporting workflows.

5.2 The On-Chain Storage Cost Problem

On-chain encrypted storage (A1) scored lowest (AQS 0.724) primarily because Ethereum's storage costs make it economically infeasible for data-intensive workloads. At 20 gwei gas price, storing 12 KB on Ethereum costs roughly USD 48 per record. This is a fundamental limitation of public blockchains: they are optimised for consensus, not storage. The off-chain pattern (A2) reduces on-chain costs by 95% by storing only content hashes and access control entries, but introduces IPFS availability dependencies -- if the IPFS pinning service goes offline, the data becomes temporarily inaccessible despite the access rights existing on-chain. Filecoin-backed IPFS storage provides economic incentives for persistent availability but adds complexity. On permissioned chains (Hyperledger Fabric), A1 costs drop dramatically because there is no gas market, and throughput increases to 1,180 events per second. This suggests that on-chain storage is viable for permissioned enterprise deployments but not for public chain architectures.

5.3 Regulatory Compliance Challenges

GDPR's right to erasure creates a fundamental tension with blockchain immutability. Architectures A2 through A5 mitigate this by keeping personal data off-chain (where it can be deleted) and storing only cryptographic references on-chain. However, access control metadata -- who was granted access to what, when -- may itself constitute personal data under GDPR Article 4. Our compliance assessment found that A4 (ABE) best handles this because ABE policies refer to attributes (role, department) rather than individual identifiers. HIPAA compliance requires audit trails for all protected health information access -- a natural fit for blockchain's immutable logging. All five architectures achieved HIPAA audit compliance, but A1 and A2 required additional middleware to generate the access reports in the format mandated by the HIPAA Security Rule.

6. Conclusion

6.1 Key Findings

Attribute-based encryption with smart contract policy enforcement achieves the highest Architecture Quality Score (0.908) by combining fine-grained cryptographic access control with decentralised policy management -- the encrypted data itself embodies the access rule, eliminating the gap between policy specification and enforcement that plagues traditional access control systems. Proxy re-encryption networks provide the fastest cross-organisational sharing (340 ms latency, 312 events per second) for bilateral delegation patterns. Confidential computing enclaves offer the strongest computation-level privacy but require hardware trust assumptions and incur the highest operational complexity. On-chain encrypted storage is economically infeasible on public blockchains at current gas prices but viable on permissioned chains. No single architecture dominates all dimensions: the optimal choice depends on the specific trade-off between policy expressiveness, latency, throughput, and regulatory requirements of the deployment context.

6.2 Future Directions

Three technical advances would significantly improve blockchain-based data sharing. First, multi-authority ABE eliminates the single key authority bottleneck by distributing attribute issuance across multiple independent authorities -- essential for cross-jurisdictional health data sharing where no single entity should control all attributes. Second, verifiable proxy re-encryption adds zero-knowledge proofs to the re-encryption process, allowing recipients to verify that the proxy performed the transformation correctly without additional trust. Third, post-quantum secure lattice-based ABE and PRE schemes are needed as quantum computing advances threaten the elliptic curve assumptions underlying current constructions. The SDSAF evaluation toolkit, all five architecture implementations, AQS calculator, and regulatory compliance rubric are available at sdsaf-sharing.org under Apache 2.0 licence.

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Declarations

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Conflict of Interest

No competing interests. Neither author has financial relationships with any blockchain platform vendor, cryptographic library provider, or confidential computing hardware manufacturer evaluated in this study.

Data Availability Statement

Five architecture implementations (Solidity smart contracts, Python cryptographic libraries, SGX enclave code), three workload generators, AQS calculator, regulatory compliance rubric, and raw benchmark data are available at sdsaf-sharing.org under Apache 2.0 licence.

Ethical Approval

No human subjects or personal data were used. All workloads used synthetic data generated to match the statistical properties of real-world datasets without containing any real records. Ethical exemption granted by Baltic AI Research University Ethics Board (ref. BAIRU-2025-ETH-0196).

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Appendix A

Architecture Implementation Details and AQS Calculation Methodology

This appendix provides detailed implementation specifications for each of the five sharing architectures evaluated in SDSAF, including cryptographic parameter choices, smart contract interfaces, and the complete AQS scoring rubric with dimension weights and normalisation procedures.

Part I -- Cryptographic Parameters

1a. AES-256-GCM with 96-bit nonces for symmetric encryption (A1, A2) ..... NIST SP 800-38D

1b. BN254 pairing curve for ABE and PRE operations (A3, A4) ..... 128-bit security

2a. CP-ABE key size: 256-bit master key, attribute keys scale with universe size ..... Bethencourt et al. (2007)

2b. PRE re-encryption key: 256-bit, unidirectional, single-hop ..... Ateniese et al. (2006)

3a. Intel SGX enclave page cache: 128 MB EPC (A5) ..... Xeon E-2288G

3b. Remote attestation: EPID-based group signature ..... Intel IAS v4

Part II -- AQS Scoring Rubric

4a. Confidentiality: 1.0 = information-theoretic; 0.9 = computational (standard assumptions); 0.8 = hardware-dependent

4b. Access control: 1.0 = attribute-based + temporal + conditional + delegatable; 0.8 = attribute-based; 0.6 = identity-based

5a. Throughput: normalised to [0,1] by dividing by maximum observed (312 events/s for A3)

5b. Latency: normalised to [0,1] by inverting and scaling (340 ms minimum maps to 1.0)

6a. Compliance: GDPR (erasure, minimisation, consent) + sector-specific (HIPAA/MiFID II) scored 0-1 each, averaged

6b. AQS = 0.25*Confidentiality + 0.20*AccessControl + 0.15*Throughput + 0.20*Latency + 0.20*Compliance