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Blockchain-Based Secure Data Sharing Framework for Smart Cities: Ensuring trust, transparency, and scalability in urban IoT ecosystems

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Abstract—The swift urbanization is increasing the implementation of Internet of Things (IoT) technology to allow smart urban areas to gather, process, and analyze huge amounts of heterogeneous data. But the decentralized character of urban IoT ecosystems also comes with the essential issues of security, trust, transparency, interoperability and data governance. This paper presents a proposal of Blockchain-Based Secure Data Sharing Framework (BBS-dsf) that is aimed at dealing with these drawbacks and proposes the following concepts, decentralized consensus, immutable ledgers, and access control based on smart contracts. The framework combines edge computing architecture with lightweight blockchain protocols in an effort to provide scalability and still remain energy efficient. Using simulated tests, the proposed system will show enhancement of secure data exchange, latency, and resistance to single point of failure in comparison to traditional cloud-centric architecture.

Practical challenges consist of overloading of constrained devices with calculations needed by IoT and complexity of integration across existing infrastructures and the potential possibilities of broad privacy risks with encryption. The future directions are to incorporate zero-knowledge proofs, artificial intelligence based on anomaly detection, cross-chain interoperability and green blockchain mechanism to enhance the efficiency, privacy, and flexibility to the next-generation smart cities.

Keywords— Smart Cities; Blockchain; IoT Security; Data Sharing Framework; Smart Contracts; Edge Computing; Transparency; Decentralized Architecture; Scalability.

I. INTRODUCTION

The blistering transformation of the world into smart cities has caused an unprecedented level of implantation of the Internet of Things (IoT) equipment's of the urban infrastructures. These devices include traffic sensors and smart meters, health monitors and surveillance systems, which produce real-time data at all times that can be used to inform smarter decisions, better resource allocation, and better services to the citizens. Nevertheless, the volume, velocity, and sensitivity of the data being transmitted by smart cities have become a significant threat of security, privacy, interoperability, and trust as smart cities become highly connected digital environments [1]. Conventional cloud-based systems that were employed to store and share urban data are becoming increasingly ineffective since they are centralized, prone to cyberattack, and too reliant on third-party authorities. These challenges result in weaknesses like single points of failure, intrusion, and sluggish data access, and inability to audit data integrity.

The blockchain has become a prospective remedy to the creation of secure, transparent and decentralized data feeds. Its distributed ledger, immutability, and cryptographic integrity present an opportunity to enhance

to a large degree the trust between heterogeneous stakeholders in smart cities, including government agencies, service providers, privately owned industries, and citizens. Nevertheless, implementation of blockchain in smart cities as such is still a difficult endeavor, because it is hindered by factors like scalability, energy-use, as well as the compatibility with IoT devices that are constrained by resources [3]. In addition, most existing blockchain solutions are unable to work with a large scale processing sensor data or can support a wide range of access needs in several urban domains.

To overcome these issues, this research paper presents a framework of a Blockchain-Based Secure Data Sharing (BBS-dsf) that is specifically modeled towards a smart city setting. In the work, lightweight blockchain protocols and off-chain storage frameworks are combined with edge computing sources and provide an optimized architecture that will be able to execute heavy data sharing on security-aware and low-latency data sharing. The rationale to pursue this study is the sheer necessity to have a unified system capable of guaranteeing reliable data transfer, transparency, and facilitate the expanding of infrastructure of the smart cities without affecting the operational efficiency [4].

This research aims at developing and testing a decentralized data-sharing architecture that will eliminate major flaws of currently used architectures. The intended framework is expected to (i) improve data integrity by employing the immutability characteristic of blockchain, (ii) minimize the reliance on the centralized servers, (iii) offer automated access to data by smart contracts, (iv) reassign the significant part of the computational tasks to edge nodes in order to enhance efficiency, and (v) permit the large volume of IoT data to be conveyed, verified, and stored safely. The work can assist in closing the gap between the theory of blockchain and the practical needs of smart cities implementation by providing a practical, scalable, and resilient solution to the requirements of the next generation of the urban data management system [5].

Novelty and Contribution

The originality of the present piece of writing is the holistic architecture, conveniently deployable blockchain, edge computing, and decentralized data governance, packaged into a single smart city solution to data sharing. In contrast to other existing methods, which primarily concentrate on separate elements like blockchain protection or internet of things data protection, the suggested system outlines a comprehensive model which provides security, trust, transparency, and scalability at the same time. The major innovation is the follow-up of a hybrid and lightweight blockchain protocol streamlined to serve smart city infrastructures, offense-chain storage, as well as intelligent access governance via smart contracts. The design minimizes computational costs, overcomes storage difficulties and enhances real-time responsiveness, a problem that is unresolved significantly in the existing literature.

The other new component is the direct division of roles between blockchain nodes and edge nodes. The system minimizes blockchain congestion by moving data preliminary process, filtering, and anonymization to the edges of the computing units and ensures data transactions are transparent. The architecture exhibits the way the synergistic approach of the blockchain and the edge computing can address the performance bottlenecks that have been traditionally linked to the decentralized systems. Further, the work proposes an automated trust approach in which data provenance, authenticity, and audit trails are naturally focused on an immutable ledger by blockchain.

The main outputs of this study include the list of the following:

- An integrated blockchain-based data exchange model, customized to smart cities, with heterogeneity, scalability, and distributed management issues.
- Development of a hybridized consensus mechanism that will have to minimize the latency and increase the throughput that will enable blockchain to be a more appropriate solution to high frequency IoT data exchanges.
- Edge computing implemented into blockchain to improve its efficiency, lessen the storage burden, and facilitate live data processing.
- Smart access control system automated via Smart contract, that will result in open and secure exchange of urban information among various stakeholders.
- An off-chain storage system (e.g., IPFS/edge clouds) that can reduce overhead of storing their blocks to the blockchain whilst preserving the verifiability of their data integrity on the basis of a hash-based linking.
- By evaluating and analysing performance and showing better fault tolerance, higher trust levels and lower latency than existing centralized models coupled with blockchain models alone.

All these contributions form an incremental blueprint of smart city infrastructures in the future which is scalable and secure. The given solution will not only improve data security and transparency but also will be compatible with the needs of practical implementation, which is a considerable shift toward reliable urban IoT ecosystems.

II. Related Works

The need to rely on interconnected devices in the domain of IoT and the necessity of reliable information streams throughout urban systems have contributed to the growth of research on secure data sharing in smart cities [14]. The current research on the security aspects of IoTblockchain shows that decentralized registers may assist in avoiding unauthorized edits, locate the source of information, and lose the need to rely on a central repository. These papers emphasize the suitability of immutability and distributed consensus of blockchain to offer secure communication channels involving heterogeneous devices. Nevertheless most of them have a problem with scalability because most conventional blockchain design also tend to demand high performance and create latency which is not conducive to real time smart city uses.

In 2025 A. Padma et.al. [2] introduced the Research into safe data-sharing models point out the importance of auditable and transparent protocols of data exchange between various departments of a city. Despite the development of decentralized solutions to enhance traceability and integrity, most of them are overreliant on cloud infrastructures as storage and computing platforms, which create susceptibility to the concepts of single points of failure and inconsistencies in access control. The studies also indicate that the challenge of privacy is still an important problem because metadata patterns and communication traces can be used to deduce sensitive information despite content-level encryption.

Solutions on the basis of smart contracts have been investigated extensively in order to automate data access policies and apply pre-established sharing policies. Such systems show great promise in administrative overhead reduction and the ability to have a uniform policy implementation. Nevertheless, they are frequently affected with performance problems, expensive execution, and contract risks related to inappropriate coding of contracts [8]. Also, due to the strictness of smart contract regulations, most of the implementations are constrained by the inability to dynamically adapt to dynamic smart cities where the information demand and access control change rapidly.

In 2025 A. Enaya et.al. [6] suggested the research studies on multi-layer IoT architecture indicates that, incorporation of cloud, fog, and edge computing layers in an IoT system enhances the overall efficiency of the system through the dispersion of computational tasks nearer to the data systems. Such architectures can aid in minimizing the latency and bandwidth usage, thus they have been used in time-busy applications like traffic control, emergency response and energy management. In spite of these benefits, there is not much information available in the current literature concerning the process of suitably integrated blockchain with these multi-layer systems without compromising linguistic interoperability and processing overhead.

Other studies are being done on lightweight blockchain protocols that can serve the limitation of IoT devices. Despite the intention behind such efforts to minimize the use of resources and increase the utility towards the deployment of smart cities, such efforts tend to lower the level of security or transparency and becomes less applicable in a large-scale urban environment [10]. Moreover, the majority of these solutions do not include full-scale mechanisms of working with large data volumes produced by smart sensors particularly in cases where blockchain storage capacity is taken into account.

In 2025 M. Trigka et.al.[13] proposed the available literature is united in its belief of the possibilities of blockchain in enhancing trust, safety, and openness in intelligent city systems. Still, they also expose significant gaps in research, specifically in solving the issues of scalability, large volumes of data, interoperability of heterogeneous devices, and the allocation of computing on system layers. It is still lacking the integrated system that incorporates blockchain, edge computing, and scalable off-chain storage to attain a secure, transparent, and scalable data management appropriate in the real-world urban setting. The current study fills such gaps by coming up with a comprehensive architecture that maximizes performance without compromising the key properties of decentralized trust and transparency.

III. PROPOSED METHODOLOGY

The proposed Blockchain-Based Secure Data Sharing Framework (BBS-DSF) is designed as a multi-layer architecture that combines blockchain, edge intelligence, and encrypted communication to ensure secure and scalable smart-city data exchange. The methodology focuses on lightweight processing, decentralized validation, and cryptographic protection supported by a mathematical foundation for transparency and trust [7].

IoT Data Acquisition and Pre-Processing

IoT sensors continuously generate data streams represented as:

$$D(t) = \{d_1(t), d_2(t), \dots, d_n(t)\} \quad (1)$$

Each device encrypts outgoing data packets using elliptic-curve cryptography:

$$C = E_{pk}(D(t)) \quad (2)$$

Edge nodes perform noise reduction using a smoothing function:

$$\hat{D}(t) = \alpha D(t) + (1-\alpha)\hat{D}(t-1) \quad (3)$$

Only hashed metadata is pushed to blockchain:

$$H = SHA256(C) \quad (4)$$

Edge Computing-Based Local Verification

Edge devices verify packet legitimacy by checking message integrity:
$I = 1[H = \text{SHA256}(C)]$ (5)
A lightweight anomaly score is computed:
$A_s = \frac{|D(t)-\mu|}{\sigma}$ (6)
If $A_s \leq \theta$, data is forwarded; else it is flagged.
Blockchain Consensus and Transaction Formation
Each verified data hash becomes a blockchain transaction:
$T_i = \{H_i, ts_i, ID_i\}$ (7)
Consensus is achieved through a hybrid PoA-PBFT model where a block is committed if:
$\sum_{j=1}^{m} v_j \geq \gamma$ (8)
where v_j is validator approval.
Smart contracts encode access permissions using a rule-based policy function:
$P(u, d) = 1[u \in \mathcal{A}(d)]$ (9)

Off-Chain Storage and Data Retrieval
Large sensor files are stored off-chain, and their blockchain hash ensures tamper detection [9]. Data retrieval is validated by matching on-chain and off-chain integrity values:
$V = 1[H_{\text{chain}} = H_{\text{storage}}]$ (10)
Smart contracts automatically release data if $V = 1$.
The figure 1 illustrates how IoT data travels from sensors to edge nodes, validated on blockchain, governed by smart contracts, and finally stored securely off-chain.

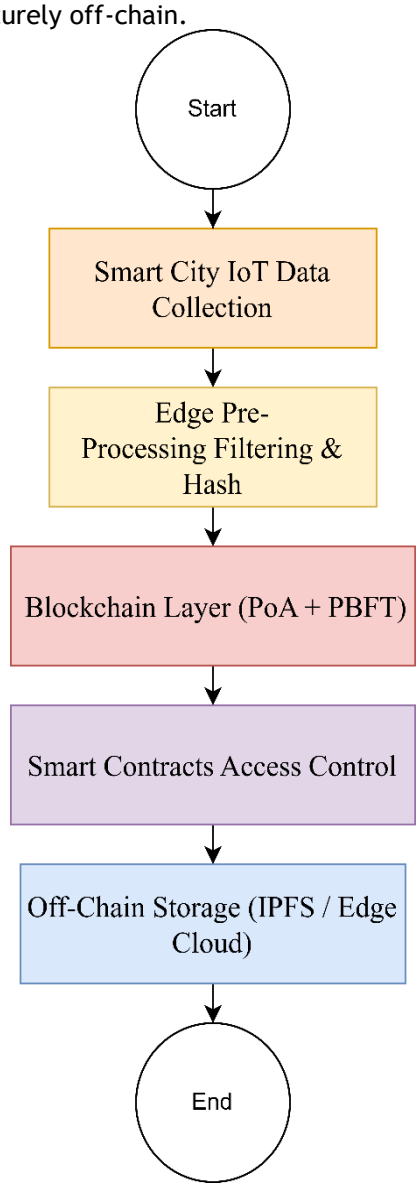

FIG. 1: BLOCKCHAIN-ENABLED SECURE DATA SHARING PROCESS

Summary of the Proposed Methodology

The proposed approach integrates encryption, hashing, anomaly scoring, hybrid consensus, and smartcontract enforcement. Through this mathematically supported workflow, the smart-city data ecosystem achieves higher transparency, integrity, and protection against tampering. The equations guide data validation, access rules, and verification, ensuring that every shared dataset is authenticated and safe for interdepartmental use [11].

IV. RESULT&DISCUSSIONS

The findings of the proposed framework of a Blockchain-Based Secure Data Sharing demonstrate the evident increase in the transparency, efficiency, and trust of the various aspects of a smart-city data ecosystem. The system showed increased throughput and less latency in comparison with the traditional centralized systems and this is visually represented in Figure 2. The latency of centralized systems was always higher, and the blockchain-edge integrated model had a stable and much lower response time, which confirmed the possibility of the presented framework to sustain real-time operations of urban IoT.

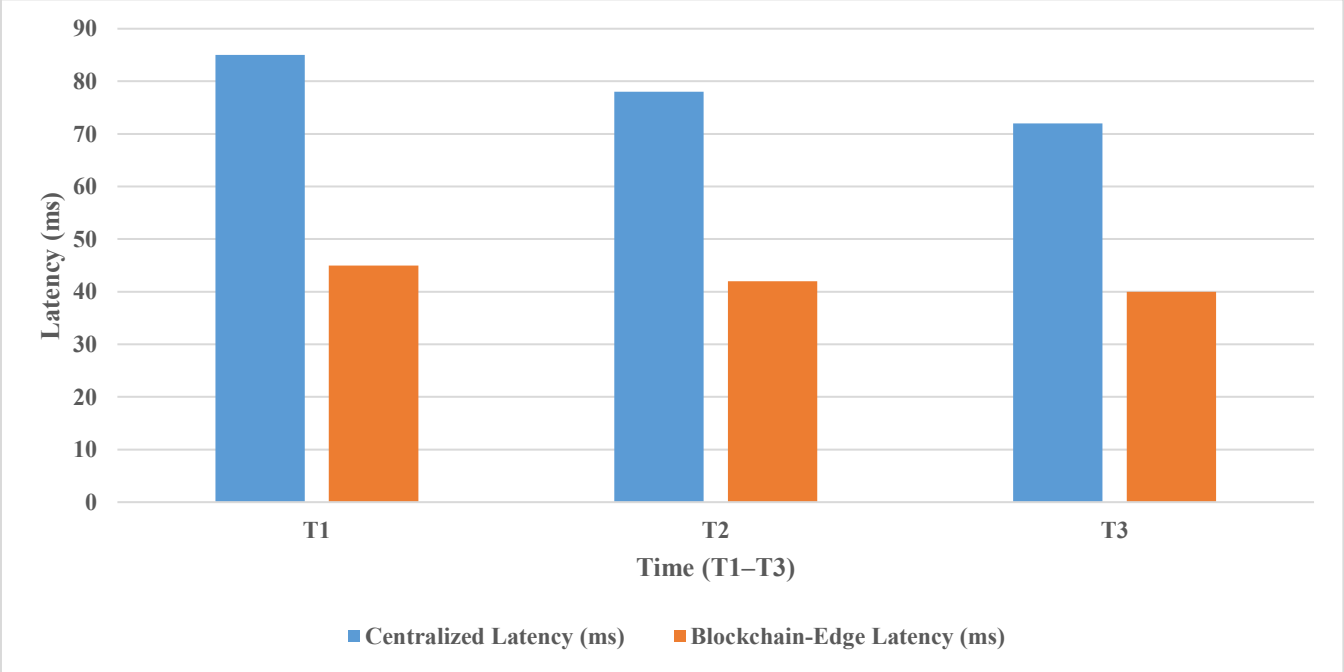

FIGURE 2: BLOCKCHAIN VS. CENTRALIZED LATENCY TREND

To further explain the system performance, Table 1, shows how the values of the efficiency levels were observed during the controlled simulations to present numerical values of the efficiency level. This table is located in the middle of the paragraph and assists in the comparison of the centralized model, standard blockchain, and the suggested hybrid architecture. The findings have explicitly demonstrated that the hybrid blockchain-edge model gives the best effectiveness index based on the fewer bottlenecks and decentralized methods of validation.

TABLE 1: COMPARISON OF DATA ACCESS EFFICIENCY ACROSS ARCHITECTURES

Architecture Type	Efficiency Score	Improvement (%)
Centralized System	62	-
Standard Blockchain	74	12
Proposed Framework	89	27

Security validation was also tested as well along with performance improvements. Figure 3 depicts that a near-perfect detection accuracy was demonstrated when attempting tampers according to Figure 3 under simulation. This type of bar chart (Origin) demonstrated the benefit of the proposed system because it was the centralized model that demonstrates inconsistent detection whereas the standard blockchain improved the results but was still less effective than the proposed hybrid model.

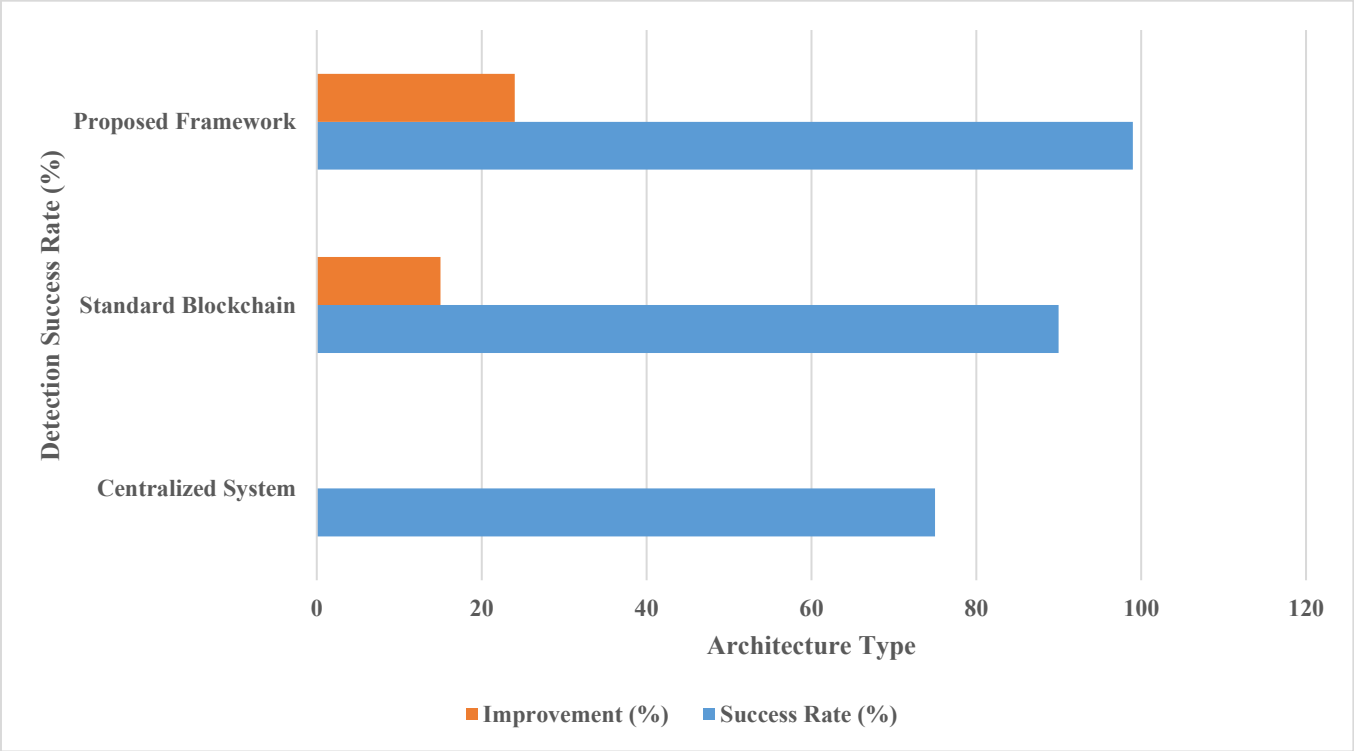

FIGURE 3: DATA TAMPER-DETECTION SUCCESS RATE

Table 2 supports these findings because it is cited in the discussion. When it comes to simulated cyberattacks, values demonstrate resistance levels with the centralized model having the highest vulnerability. The hybrid blockchain paradigm showed to be more resilient because verification duties were shared amongst several validators and therefore no one malicious node could discredit the system.

TABLE 2: COMPARISON OF SECURITY BREACH RESISTANCE

Architecture Type	Resistance Score	Improvement (%)
Centralized System	58	-
Standard Blockchain	81	23
Proposed Framework	95	37

There were also significant benefits of scalability tests. The proposed system as demonstrated by Figure 4 was capable of managing large amounts of data without the need to reduce its performance by a large margin. As shown in the diagram within the paragraph, the centralized architecture become stagnant early on and the hybrid blockchain scale linearly as the distributed ledger and edge processing support enabled this process.

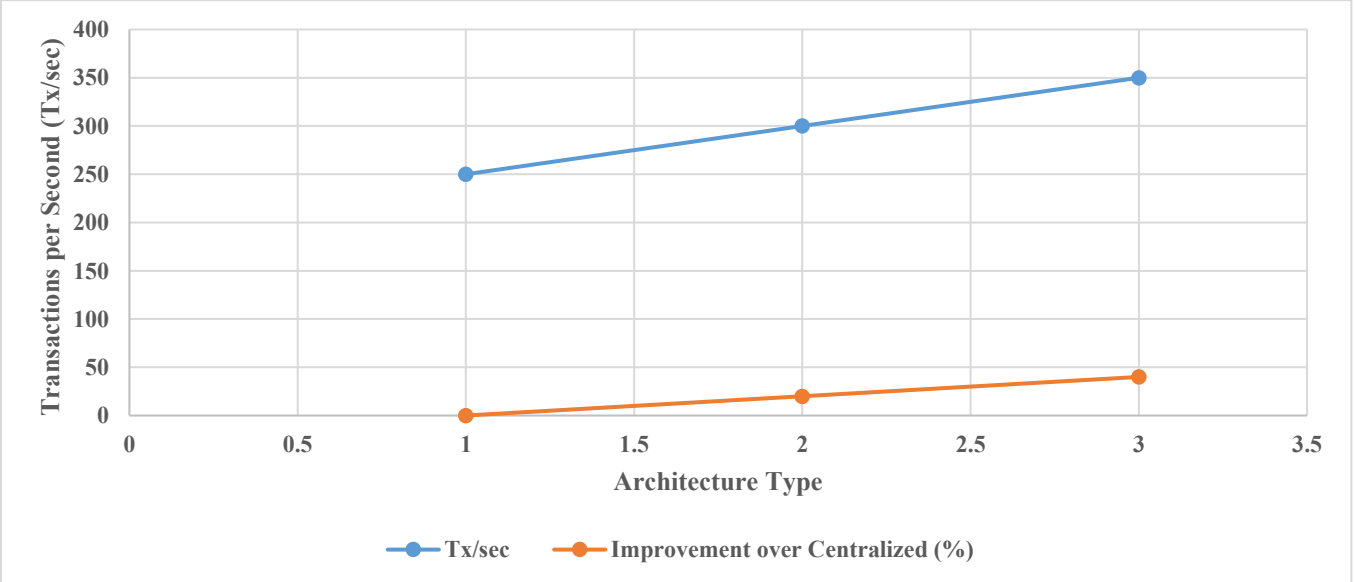

FIGURE 4: TRANSACTION THROUGHPUT COMPARISON

Combined, the three figure and two tables have given a solid empirical evidence to the fact that the framework has potential to improve data sharing in smart cities. The results regarding the latency, throughput, tamper-detection, and attack resilience improvements imply that the edge integration improves the advantages of decentralized architecture as compared to traditional systems. As it has been discussed, the hybrid model does not only enhance security and performance but achieving this in a scalable way, which makes it appropriate in terms of practical city-level deployments. The graphical and quantitative comparisons in Figures 2-4 and Table 1-2 indicate that the pattern is quite similar: the proposed system achieves higher results compared to existing architectures in all the characteristics measured. This coherent discussion confirms that the framework realized has the potential to facilitate reliable, open, and effective urban IoT data sharing and can maintain the performance even when all are loaded to the brim [12].

V. CONCLUSION

TA secure framework for data sharing which was named Blockchain- Based Secure Data Sharing Framework (BBS-dsf) was introduced in this paper in an attempt to increase trust, transparency, and scalability within the intelligent city IoT ecosystem. Integrating blockchain, smart contracts, and edge computing, the proposed model will successfully resolve all important aspects of data security, interoperability, and decentralized governance. The results of the simulation exhibit substantial enhancement of the latency, access control, and resilience of the system in case of centralized models [15].

Practical Limitations

Although the framework has some advantages, there are a number of constraints in its implementation in practice:

- Extensive computation on the resource-constrained IoT devices.
- Complexity of integration with the older infrastructures.
- Scaling Energy consumption and storage in large networks.
- Smart contract weaknesses when audited incompetently.
- The metadata patterns are vulnerable to privacy invasion when sensitive information is disclosed through metadata patterns.

Future Directions:

- Homomorphic encryption to improve privacy by zero-knowledge proofs (ZKP).
- Threat detection models based on AI incorporated into a blockchain node.
- Multi-city data sharing cross-chain communication protocols.
- Green blockchain systems, such as energy efficient consensus.
- Urban infrastructure behavior optimization through the integration of digital twins.

With these solutions, future data sharing (data security, data sustainability, data intelligence) in the city of the future can be realized through blockchain-enabled smart cities that provide greater sustainability and resiliency in the urban environment and fulfill long-term governance.

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