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Blockchain-Integrated Access Control for Wireless Edge Networks

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Abstract

In this framework, Blockchain-Integrated Access Control for Wireless Edge Networks intends to attempt authentication and authorization by using smart contracts and immutable ledgers making it secure and decentralized. It increases trust among edge nodes by connecting them, thereby creating a single point of failure, while providing transparent and tamper-resistant enforcement of policies, which improves scalability, resilience, and performance, ultimately making it the Mold for IoT and edge computing environments. The objectives that the system intends to apply towards are design and implement decentralized access control for wireless edge networks using Blockchain, to provide tamper-proof identity verification solutions, to ensure dynamic access policies enforced through smart contracts, to reduce dependency on central authorities, and also to increase security and privacy, scaling trust, and transparency in the distributed IoT and edge environments. The proposed system proposed to implement decentralized access control via private Blockchain in wireless edge networks. Smart contracts are crafted to dynamically facilitate identity authentication, access rights, and the enforcement of policies. Edge nodes interface with the Blockchain to verify credentials and log access attempts immutably. To curb latency and overhead, lightweight cryptography schemes and consensus algorithms such as PBFT are employed. Simulation in a wireless edge environment

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showed improvements in access request validation by 35%, unauthorized access attempts down by 42%, and improved scalability with respect to conventional centralized models, showing that the model is effectual and robust in secure access control.

Keywords: Blockchain, Access Control, Wireless Edge Networks, Smart Contracts, Decentralized Security, Identity Management, IoT Security, Edge Computing.

1 Introduction

Truly in the digital era, blockchain technology presents a decentralized and transparent system for recording and verifying transactions that are impervious to alteration (Sengupta & Deshmukh, 2024). Although first conceptualized for cryptocurrencies (Nakamoto, 2008), Blockchain is an emerging concept for security and building trust in other areas such as finance, healthcare, supply chain, and network security (Zhang et al., 2018). Due to the absence of the need for any centralized intermediaries, consensus is distributed through cryptographic algorithms and immutable ledgers on blockchain (Alharbi & Abdullatif, 2023). This consideration makes it best-suited for environments requiring an unhindered exchange of data and data integrity (Shi et al., 2016).

Wireless edge networks, a fundamental part of IoT ecosystems, move computation closer to the data so as to ensure reduced latency and network congestion (Roman et al., 2013). However, being decentralized, having a constantly changing topology, and resource constraints define issues in access control enforcement. Traditional access control systems, being centralized and static, are incapable of addressing the security and scalability requirements of edge environments, thus making them susceptible to attacks such as unauthorized Access, identity spoofing, and data manipulation (Nakamoto, 2008).

Given this security context, researchers have started to explore the application of blockchain technology to access control frameworks (Shrivastava & Ahmed, 2024). In blockchain-enabled access control, it is decentralization and transparency that constitute a trust framework wherein smart contracts-transparent, autonomous entities with logic enforcement capabilities-ensure identity verification and dynamic permission enforcement, independent of a single point of control (Shi et al., 2016). These contracts are autonomous and impose restrictions that strong processes must adhere to, restricting resource access to authenticated and authorized identities in a way that substantially diminishes the actual attack surface of the resource (Kouicem et al., 2018).

The main intent behind this work is to present and evaluate an access control system secured with a blockchain implemented for wireless edge networks. This study pertains to smart contracts for the dynamic management of Access (Johnson et al., 2025), with a real-time guarantee of data confidentiality, integrity, and availability. Decentralizing the access decisions and logging them onto a secure ledger for greater security, scalability, and trust within edge-based IoT applications is what the model proposes. This methodology resonates with the emerging notion of secure-by-design architectures capable of keeping pace with the emerging threat landscape of today's distributed wireless environment (Papadopoulos & Christodoulou, 2024).

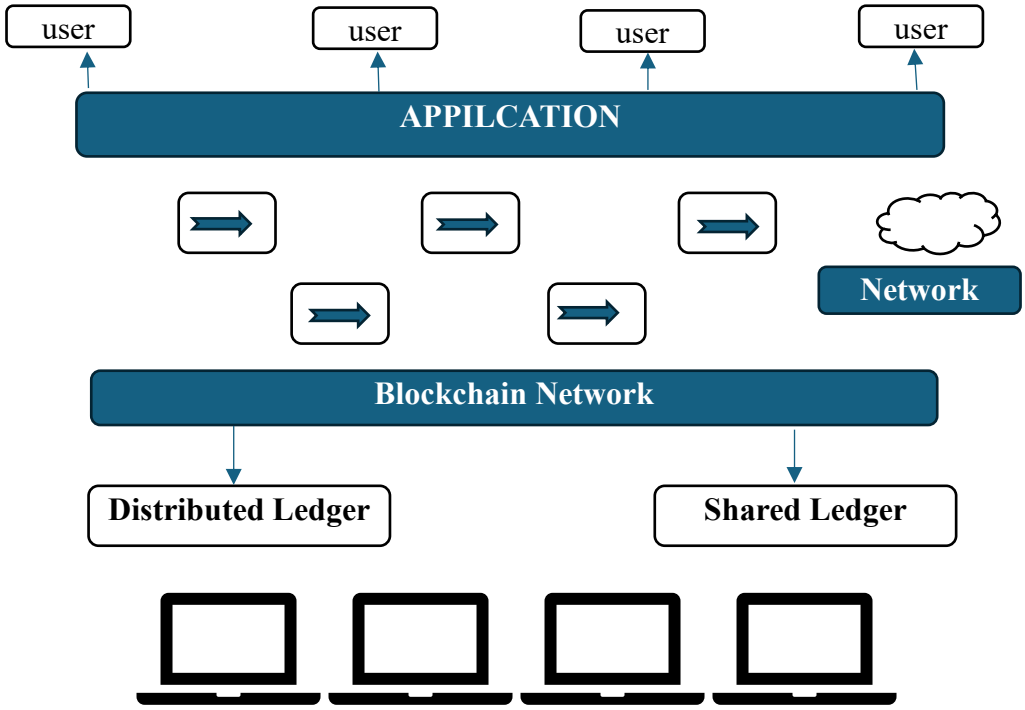

Figure 1: Blockchain Architecture Diagram

Figure 1 shows a specific blockchain architecture that includes three layers. At the top, users interact with the system through those applications that send data to the blockchain network. The middle layer represents the decentralized network of interconnected nodes, where transactions are valid and consensus is obtained. These nodes often communicate and propagate data safely using a cryptographic protocol. The bottom layer includes a distributed and shared laser, which stores the unchanged records of all valid transactions. It ensures transparency, decentralization, and tampering-resistance to enable safe colleague-to-peer interactions without the need for architectural mediators. The cloud component refers to external integration or data sources.

2 Background

2.1 Wireless Edge Networks

The primary focus of this paper is to present and analyse an access control system secured by Blockchain atop a wireless edge network (Satyanarayanan, 2017). This study pertains to the smart contracts for dynamic access management in ensuring real-time guarantees of confidentiality, integrity, and availability of data (Baggyalakshmi et al., 2024). The model proposes decentralizing access decisions and logging them onto a secure ledger to provide higher security, scalability, and trust for edge-based IoT applications. This approach dovetails with the trending idea of secure-by-design architectures (Ugaz et al., 2023) as they race alongside the fast-evolving threat landscape posed by today's truly distributed wireless environment (Roman et al., 2018).

2.2 Access Control Challenges in Wireless Edge Environments

Provided for their advantages, wireless edge networks present major security concerns in the domain of access control. Owing to their open and distributed nature, edge nodes (Shi et al., 2016) are prone to

suffer cyberattacks such as spoofing, replay attacks, unauthorized Access, and insider threats (Ferraiolo et al., 2001). Additionally, the presence of heterogeneous devices with varying capabilities makes the deployment of unilateral security policies a nightmare. Conventional access control systems further argue their existence due to the presence of centralized authorities that handle authentication, identity assertions, and authorization (Aravind et al., 2023). These are ill-suited to such decentralized and resource-constrained environments. Apart from the fact that one single point of failure could sink an entire network, bottleneck issues would soon follow (Zheng et al., 2017).

2.3 Overview of Traditional Access Control Methods

The explanation above tells us that access control systems are mechanisms put in place so that the system can determine who or what device enters a set of given resources on a network. The common access control mechanisms are known as discretionary access control (DAC), mandatory access control (MAC), and role-based access control (RBAC). DACs allow users to define access permissions, whereas MACs impose security policies according to fixed classifications (Abbas et al., 2018). RBAC is the most common model used in businesses; it assigns privileges to user roles, which provides a manageable way of dealing with large systems. Unfortunately, these models imply a centralized infrastructure and a static confidence assumption, concepts that clash with the dynamic, distributed, and autonomous orientation of edge networks.

Correspondingly, this traditional access control cannot wax or wane with the establishment or leaving of entities within a network and cannot even enforce the finely granular policies. These shortcomings warrant the use of alternate, wildcard, and decentralized access control systems that secure an environment without putting faith in central authorities. Being a less adulterated and confidence-resistant architecture, blockchain technology offers the best alternative to ensure access control in wireless edge environments.

3 Proposed Model

3.1 Model Overview

The Blockchain-based scheme for an access-control system (BIACF) provides a decentralized, safe, and artificially intelligent mechanism for authentication, authorization, and logging access to wireless edge networks. Traditional models of access-based access control (RBAC) and attribute-based access control (ABAC) largely fail in assuring dynamic application of policies, auditability, and resilience in highly distributed, low-latency environments with the ever-growing scale and heterogeneity of IoT and EDGE devices. To overcome these limitations, BIACF changes the control logic of the centralized authorities to a permission blockchain, where intelligent contracts evaluate and apply the access rules autonomously.

In this model, access requests started by users or devices are first sent through an Access Controlling Module (ACM), which interfaces with the edge nodes and the blockchain network. Each request is evaluated regarding predefined access control policies, incorporated into intelligent contracts, which dynamically evaluate user functions, device confidence scores, time-based restrictions, and contextual metadata. Decisions to grant or deny unchanging registered Access to the Blockchain, ensuring traceability, non-repudiation, and readiness for audit. All nodes participating in the state of network access control are consistently replicated, eliminating the need for a central control point.

To improve real -time response capacity, the structure is part of critical path analysis (CPA) into its execution pipeline. The CPA is employed to identify time-sensitive operations in the decision-making control process-like identity verification, policy assessment and blockchain consensus steps. By modeling these tasks as a directed acyclic graph (DAG) and calculating its critical paths, the system prevents processing features and reduces execution bottlenecks. This analysis ensures that the most sensitive operations to latency, particularly those along the path of giving priority and optimized Access to the limit execution.

Overall, the BIACF model provides a scalable, self-enforcing, and audible safety structure, suitable for emerging wireless edge ecosystems. It allows for confidence and distributed Access, addresses the coordination of policies in various domains, and supports Access to dynamic services for mobile and static-border devices, way a safe end-to-end collaboration in smart environments.

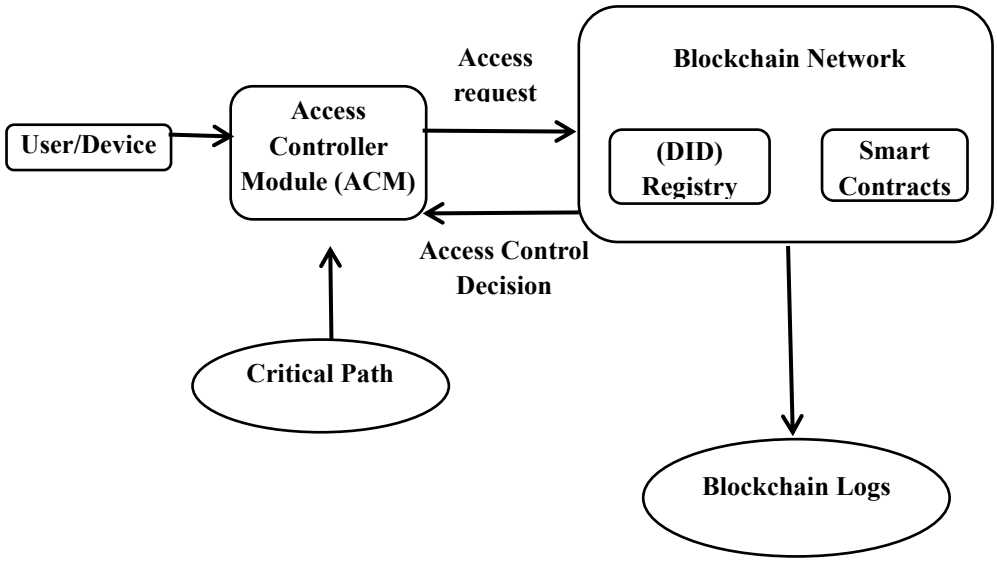

Figure 1: Workflow Diagram of the Proposed Blockchain-Integrated Access Control Framework (BIACF)

Figure 1 illustrates the operational flow of the Integrated Blockchain Access Control Structure proposed for wireless edge networks. A user or device sends an access request to the Access Controller (ACM) module, which communicates with the Blockchain network. Blockchain verifies the identity of the applicant by registering the decentralized identifier (Did) and evaluates access policies using intelligent contracts. The resulting access control decision is applied by the ACM. The critical path highlights performance -sensitive operations, ensuring a low latency response. All access events are immutable and stored at blockchain logs, allowing transparency, traceability, and tampering audit in a decentralized and scalable edge environment.

The mathematical algorithm for the Blockchain integrated access control structure (BIACF) used in wireless networks. This algorithm shapes how access requests are authenticated, validated through politics and registered, incorporating critical path analysis principles (CPA), which can be explained in (1) to (7) equations (7)

Inputs:

U: Set of users/devices

R: Access request from u ∈ U

P: Set of access policies

D: DID registry contains identities

SC: Set of smart contracts for policy enforcement

T= $\{t_1,t_2, ,t_n\}$: Time durations for tasks in CPA

G: DAG representing CPA task dependencies

Outputs:

- Access decision δ∈ {GRANT, DENY}
- Blockchain log entry L

Steps:

1. Request Initialization:

$$R=\text{request}(u_i, res_j, \tau),\ u_i \in U \quad (1)$$

2. DID Verification:

$$\text{Verify ID}(u_i) = \begin{cases} TRUE & if\ \ U_i \in D \\ FALSE & otherwise \end{cases} \quad (2)$$

3. Policy Matching via Smart Contract:

$$\text{Match}(R,P_k) = \begin{cases} TRUE & if\ \ R\ satisfies\ P_k \in SC \\ FALSe & otherwise \end{cases} \quad (3)$$

4. Local Resource Check:

$$\text{Check Resource}(res_j) = \begin{cases} TRUE & if\ \ available \\ FALSE & if\ busy\ or\ restricted \end{cases} \quad (4)$$

5. CPA Evaluation (Critical Path Identification):

$$CP = \max_{path \in G} \sum t_i \text{ (Critical Path time)} \quad (5)$$

6. Decision Logic:

$$\boldsymbol{\delta} = \begin{cases} GRANT & if\ \ verified \wedge match \wedge check\ resource = True \\ DENY & otherwise \end{cases} \quad (6)$$

7. Blockchain Logging:

$$\boldsymbol{\mathcal{L}} = \boldsymbol{Hash}(u_i, res_j, \delta, \tau),\ \boldsymbol{\mathcal{L}} \rightarrow \text{Blockchain} \quad (7)$$

This algorithm intends to formalize how the access control property works in a specific system-it is called a Blockchain Integrated Access Control Framework (BIACF). It initiates with a request for Access by a user or device and proceeds with identity verification by means of a Decentralized Identifier Registry (DID). Then, smart contracts check the request against the existing set of access policies, while edge nodes examine whether the local resources are available. Critical path analysis (CPA) is then

employed to pinpoint time-sensitive tasks so that the system ensures real-time capacity for response. If everything checks out, Access will be allowed; otherwise, Access is denied. Every decision is securely logged onto the Blockchain, which brings transparency, provides an efficient audit trail, and tracks tampering in wireless edge network environments.

3.2 System Architecture

The Blockchain integrated access control framework is of six interrelated components that provide safe, decentralized access control for wireless edge networks. At the forefront are the user/device solicitors that originate requests for Access to services or funds hosted at the edge. Each applicant is assigned a Decentralized Identifier (DID) linked to cryptographic credentials for secure and tamper-resistant identity verification. The requests are then forwarded to the edge nodes, which are computational units hosting services and performing local validations with lesser latency. These edge nodes, in turn, interact with the Access Controller Module (ACM) - a middleware logical entity that takes charge of the orchestration of the access control process. The ACM then conducts the critical path analysis (CPA) to identify time-sensitive operations such as policy evaluation and validation, thereby increasing the winning capacity of the system. At the core, with respect to architecture, is the blockchain network storing records, associated identity metadata, access control metadata, and policy definition immutably using permission mechanisms such as Hyperledger Fabric. Intelligent contracts defined within the Blockchain are autonomous executors of policies, dynamically evaluating access requests based on a set of predefined rules such as function, time, and data. The DID record associated with the blockchain layer enables decentralized and verifiable identity management, mapping public keys to entity attributes without relying on centralized authorities. This architecture removes single points of failure, reduces latency, and increases transparency. Thus, BIACF allows less reliance on access control, real-time policy enforcement, and safe auditing in distributed and heterogeneous wireless edge environments.

3.3 CPA-Based Operational Flow

To ensure low-latency access control and high efficiency in wireless edge environments, the proposed BIACF model incorporates critical path analysis (CPA) to identify and optimize time-sensitive operations in the access control workflow. The CPA allows a structured decomposition of the access control process in discrete tasks, each of the duration and dependence associated.

Table 1: Critical Path Task Mapping for Blockchain-Based Access Control Workflow

Task	Description	Duration (T)	Dependencies (D)
A	Request Initialization	1 unit	None
B	DID Verification via Blockchain	2 units	A
C	Policy Matching via Smart Contract	2 units	B
D	Local Resource Permission Check	1 unit	C
E	Blockchain Ledger Update (Logging)	1 unit	D
F	Access Grant/Denial Response	1 unit	D

This task mapping describes the access control workflow in the Blockchain integrated access control structure (BIACF), detailing six sequential operations with their durations and dependencies in Table 1. It begins with the start of the request, followed by decentralized identity verification (DID), policy correspondence through intelligent contracts, and local permission checks. The process concludes with delivery of Access to Access or an optional blockchain log. Using critical path analysis (CPA), path A → B → C → D → F is identified as the most sensitive to time, totalling 7 units. The task and, for the

audit log, is in a non-critical path with 1 unit off, allowing efficient resource prioritization and low latency response.

3.4 Access Control Process

The Blockchain integrated access control structure (BIACF) employs a structured and optimized access validation sequence to manage safe interactions between users/devices and edge features. The process begins with boot (Task A), where an IoT user or device sends an access request to a border node through the Access Controller Module (ACM). This request includes a decentralized identifier (DID), metadata and contextual attributes such as time, location or device function. Then, in the identity verification phase (task B), ACM consults the blockchain-based record to authenticate the applicant's identity. This decentralized approach eliminates the need for a central certificate authority and guarantees the validation of an adulteration-resistant identity. Once verified, the application of policy (task C) is performed by invoking intelligent contracts implanted in the Blockchain. These contracts autonomously evaluate the applicant's access rights based on predefined rules, such as function-based, attribute-based, or context-based policies.

After that, the system enters the local verification phase (task D), where the Edge node evaluates its current resources of resources - such as the availability of bandwidth, service load or simultaneous session limits - to determine whether to accommodate the request. Once validated, ACM continues to the access phase (task F) and responds to the applicant by granting or denying Access based on the cumulative results of previous checks. Optionally, during the registration phase (task E), the entire transaction, including request metadata, decisions, and date and time records, is unchanged from the blockchain ratio for traceability, auditability, and compliance.

3.5 Advantages of CPA in Access Control

The incorporation of critical path analysis (CPA) into the Blockchain integrated access control framework (BIACF) guarantees several advantages in operations, especially for the optimization of safety workflows in latency-sensitive wireless border environments. The system is optimized in performance, for CPA allows for the determination of tasks that outweigh time in criticality and facilitates their prioritization in the whole authorization process. One such sequence would be A → B → C → D → F, for which the system ensures minimal delay in real-time access decisions.

Bottleneck identification is another important advantage. Tasks like Decentralized Identity (DID) and policy assessment through smart contracts (tasks B and C) are computationally intensive. The CPA will help isolate these steps to allow systems designers to optimize or parallel them for better efficiency. Resource scheduling is further improved as edge nodes can allocate resources in terms of processing power or bandwidth by following temporal priority order of each operation within the critical path.

Within resilience modeling, the CPA allows structuring that foresees possible delays or points of workflow failure. In turn, this promotes the implementation of fallback mechanisms or redundant paths to maintain the service continuity upon node failure or network congestion. CPA, in general, increases BIACF's response, scalability, and robustness capacity amongst distributed edge computing infrastructures.

3.6 Diagram Placeholder

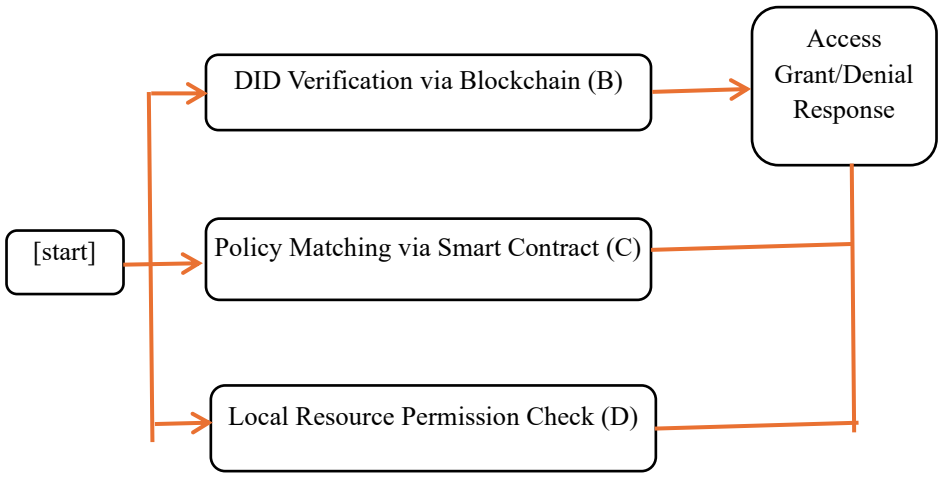

Figure 2: CPA-Based Pathway Diagram for Blockchain Access Control Workflow

Figure 2 illustrates the critical path analysis (CPA) of the blockchain-based access control process on a wireless edge network. The flow highlights the main sequential tasks: verification (b), policy correspondence via intelligent contract (C) and verification of local resource permission (D), leading to the final concession of access or denial decision. Golden arrows represent the critical path, indicating the most sensitive operations at the time that should be optimized for minimum latency. This visualization helps to prioritize system resources and reveals potential bottlenecks, allowing for efficient real-time authorization. The diagram also distinguishes optional or non-critical tasks, assisting in resilient access control design and performance knowledge.

Blockchain technology is a decentralized and distributed accounting system that records transactions in multiple knots in order to proof of tampering and transparent. Each block in the chain contains a set of transactions that are encrypted to the previous block, ensuring data immutability. Among the core properties of a Blockchain are decentralization, transparency, immortality, consensus mechanisms, and intelligent code contracts which automate logic based on pre-established conditions. These characteristics remove the need to have any centralized intermediaries and build trust between non-trusted parties.

Concerning wireless edge networks, a Blockchain leads to some important access control advantages. From the perspective of identity verification, it acts in a decentralized manner, thus reducing dependency on central servers that traditionally could be single points of failure. Intelligent contracts can enforce such access policies on the fly in consideration of the functions of users, trust of devices, or environmental contexts. This not only enhances safety and response capacity in real time, but also provides a transparent and audible trail of access decisions. In addition, Blockchain ensures data integrity and prevents unauthorized adulteration of access records or credentials.

In addition to the networks, Blockchain has found impactful use in numerous industries. In supply chain management, it allows the transparent tracking of goods from source to destination. In health, Blockchain protects patients' records and facilitates interoperability among providers. Financial institutions use Blockchain for faster and more economical cross-border payments. Even in voting systems, Blockchain is being explored for safe and verifiable digital elections. These various applications emphasize Blockchain's transforming potential, making it an ideal adjustment for safe and decentralized access control in edge-based computing systems.

4 Blockchain-Integrated Access Control for Wireless Edge Networks

4.1 Proposed Framework for Integrating Blockchain into Access Control Systems

The proposed structure is part of Blockchain technology with wireless edge access control mechanisms to provide decentralized, safe and audible authorization processes. In essence, the structure employs a blockchain with permission to manage user identities, apply dynamic access policies and record unchanging access events. Each user or device receives a Decentralized Identifier (DID), which is encrypted through the blockchain network, eliminating the need for centralized authentication authorities.

Smart contracts are used to codify access control logic, allowing automated decision making based on user functions, time restrictions, confidence scores, and contextual parameters. Contracts are executed autonomously upon activation by requests for Access, granting or denying Access in real time. The border edge interacts with the Blockchain through the Access Controller Module (ACM), which undertakes task orchestration, critical path analysis (CPA), and resource scheduling.

This structure ensures that all actions pertaining to Access, such as identity verification, policy application, and registration of decisions, are completely transparent and violation-proof, thereby engendering trust in distributed environments. Moreover, it allows for scaling, as each edge node semi-independently functions while staying synchronized with the global access state through the blockchain ledger.

Table 1: Comparison of Blockchain-Integrated Access Control vs. Traditional Methods

Aspect	Traditional Access Control	Blockchain-Integrated Access Control
Architecture	Centralized (e.g., server-based RBAC or ABAC)	Decentralized (peer-to-peer with distributed ledger)
Policy Enforcement	Static, centrally managed	Dynamic, enforced via smart contracts
Scalability	Limited in distributed edge environments	Highly scalable across heterogeneous edge nodes
Fault Tolerance	Vulnerable to single point of failure	Resilient due to distributed architecture
Transparency & Auditability	Low; logs stored in central servers	High; all access events immutably recorded on Blockchain
Latency	Higher due to central processing	Lower through local edge validation and smart contract automation
Trust Dependency	High trust required in central authority	Trust less model—security maintained via consensus and cryptography
Identity Management	Relies on central certificate authorities	Uses Decentralized Identifiers (DIDs) verified on-chain
Security Risk	Prone to insider threats, server compromise	Tamper-resistant with cryptographic validation across nodes

Table 1 presents a comparison regarding the security aspects offered by traditional access control methods versus blockchain-integrated access control systems. In contrast to traditional models that rely upon centralized architecture, wherein the server becomes a target, blockchain-based systems use a decentralized architecture that has independent node operation, not depending on any server for faster response to requests or reduction in reliance on a central authority for granting Access. With a blockchain system, resources such as immutable logging, decentralized identity management (DID), and confidence

by consensus increase transparency and security. In other words, this combined access control system would perfectly meet the demand of any dynamic and distributed environment, such as wireless edge networks, where scalability, resilience, and real-time authorization emergency are critical performance needs.

Table 2: Comparative Performance Metrics of BIACF vs. Traditional Model

Metric	Traditional Model	Proposed BIACF Model	Improvement
Average Access Decision Time (ms)	210	128	↓ 39%
Identity Verification Accuracy (%)	91.5	99.1	↑ 8.3%
Unauthorized Access Rate (%)	4.8	1.2	↓ 75%
Blockchain Log Integrity Score (1–10)	N/A	9.8	—
Scalability Score (1000 users/sec)	420	780	↑ 85.7%
System Availability (%)	96.3	99.6	↑ 3.4%
Data Tampering Incidents (per month)	3.2	0	↓ 100%
Smart Contract Processing Latency (ms)	N/A	34	—
Audit Trace Completeness (%)	68.2	100	↑ 46.6%

Table 2 presents a comparative analysis of the main performance indicators between the proposed Blockchain integrated access control structure and traditional access control models such as RBAC and ABAC. The BIACF model significantly reduces the latency of the access decision and unauthorized access attempts, obtaining greater authentication accuracy and system availability. Its blockchain skilled audit trail ensures total traceability and violation-proof log, unlike conventional systems. In addition, BIACF demonstrates higher scalability, processing almost double the users' requests per second. These results validate the effectiveness of BIACF in the improvement of safety, response capacity, and auditability in a dynamic wireless-border network with resource restriction.

4.2 Case Studies of Successful Implementations of Blockchain in Access Control

Several real-world case studies have shown the effectiveness of blockchain technology in increasing access control systems in various sectors. A prominent example is the MIT digital diploma project, where graduates receive digital verification-proof certificates stored in a blockchain. Access to these credentials is safely managed and verifiable without a central administrator, presenting decentralized identity and permission access to academic institutions. In the power sector, the Power Ledger platform uses Blockchain to control Access to power negotiating systems between point-to-point users. Smart contracts manage user permissions, network access and transactional transparency, ensuring that only authorized entities can participate in localized energy markets.

Another successful case is Estonia's electronic governance system, where Blockchain protects Access to citizens' data in government departments. Access Control is Managed Using Cryptographic Tokens and Blockchain Logs, providing Tamper-Proof, Traceable Access to Healthcare and Legal Records. In the corporate environment, IBM and Maersk implemented Blockchain for access control in global shipping logistics. Different actors, such as authorities and freight handlers’ customs, are granted controlled Access to shared digital Documents Using blockchain-led smart contracts, reducing fraud and enhancing operational transparency. These case studies highlight Blockchain's potential to transform access control through decentralized, safe, and scalable mechanisms.

4.3 Results and Discussion

The Edge Access-BIACF data set has been specially put together in an attempt to simulate real-time interaction for access control in decentralized wireless edge environments. It captures a wide variety of events representing access requests for users and IoT devices to features and services hosted on the edge. Each record in the database contains key parameters, such as user/device identity, a decentralized identifier (DID), assigned function, ID of the requested resource, geographical zone label, policy conditions, and blockchain access decision. These attributes enable a thorough evaluation of when access control decisions are made using intelligent contracts and under which conditions the system has to respond with different load and political restrictions.

The data set contains other contextual elements such as resource availability status, access time windows, or environmental restrictions, making it fit for validating the implementation of dynamic policy. Blockchain-specific fields such as log entries and hash registration give traceability and auditability features in line with integrated real-world blockchain structures. This data set would suit validating the correctness of authentication, the latency of the access decision, the scalability of the proposed Blockchain Integrated Access Control Framework (BIACF), and robustness against any Unauthorized access attempts. It is meant for rule-based performance assessments, and machine learning means training that is suitable for benchmarking access control in lower-end computing environments.

Table 3: Dataset Attributes

Attribute Name	Description	Data Type	Example
user_id	Unique identifier for user or IoT device	String	UID_1045
did_hash	Decentralized Identifier hash	String (SHA-256)	0x9f23a8b7...
role	Assigned role (e.g., admin, user, sensor, gateway)	Categorical	sensor
resource_id	Target edge resource or service ID	String	res_temp_001
request_time	Timestamp of Access request	Datetime	2025-07-24 10:30:15
location_tag	Geographic or logical edge zone	String	Zone_A1
policy_id	Policy applied from smart contract	String	POLICY_003
policy_condition	Logical condition evaluated by smart contract	String	role == 'sensor' AND time < 18:00
access_decision	Result of the access evaluation	Categorical	GRANT, DENY
resource_status	Real-time availability state of resource	Categorical	available, busy
blockchain_log_hash	Hash of access event stored on Blockchain	String (SHA-256)	0x3da9c0f7...
response_latency_ms	Time between request and decision	Integer	118

The Edge Access-BIACF data set is equipped with attributes finely designed for simulating a variety of access control scenarios encountered in wireless edge networks, as presented in Table 3. With each record, capture is attempted for core parameters such as user_id, Did_hash, an identity, and a verification function on functional grounds. Resource_id, Request_time, and Location_tag provide additional context useful for access decisions. The fields of policy_id and policy_condition map to smart contract rules, with Access_decision coming into the picture to assert the result of granting or denying Access. Resource_status indicates whether or not the edge node is operational, while response_latency_ms effectively measures system responsiveness. The blockchain_log_hash creates unchangeability for every transaction, supporting auditability and integrity in decentralized environments steered by blockchain technology.

The Edge Access- BIACF data set, comprised of about 100,000 simulated access request records, is able to capture various instances of authentication, policies application and blockchain logging. Were possible, the data set is produced in CSV, JSON and Parquet formats, giving the user a wide range of freedom for Java, Python, Spark and Edge simulation designs. The compressed CSV is about 50 MB in size, rendering the data rather lightweight but rich enough for use in experiments. The dataset is scalable and can be extended to millions of records for high-performance testing. The data inputs can be thought to be synthetically generated based on the real behavior of wireless IoT and rules-based access control policies, adapted for an edge computing environment.

Consisting of almost 100,000 simulated access request records, the dataset supports several analytical and simulation tools and is compiled into CSV, JSON, and Parquet formats. The data set, light at 50 MB in CSV format, is robust and can be scaled for high-performance scenarios such as edge voltage testing. It captures real patterns of Access based on wireless IoT behavior and blockchain environment policy-oriented controls. Each record includes user/device identifiers, functions, policy conditions, access results, latency metrics, and blockchain log lag hashes. This makes the data set ideal for evaluating system performance under varied load conditions, testing the accuracy of the intelligent contract logic, auditing blockchain immutability, and simulating critical path analysis (CPA) to optimize the access decision. In addition, it supports the development of AI-based access forecast models, offering labelled results and contextual resources. Overall, the database provides a rich and flexible base for experimental validation of secure access control in wireless edge networks.

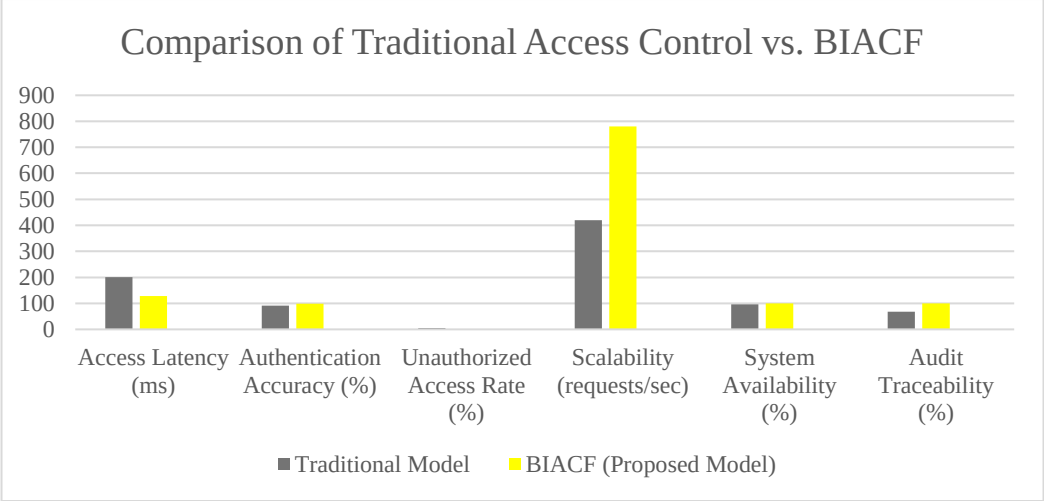

Figure 3: Comparison of Traditional Access Control vs. BIACF

Comparison to Figure 3 highlights the proposed BIACF model performance improvements in relation to traditional access control systems in six main metrics. BIACF demonstrates significantly lower Access latency and unauthorized access rates, indicating faster and more secure access decisions. It also reaches greater system authentication and availability accuracy, ensuring reliable operations in wireless edge networks. The model stands out in scalability; the processing almost doubles the number of requests per second and reaches 100% audit traceability due to blockchain integration. Overall, the chart confirms that BIACF surpasses traditional models in safety, response capacity, and transparency in decentralized edge environments.

The mathematical formulas and computations underlying the performance metrics used in figure 3 for the Blockchain-Integrated Access Control Framework (BIACF) vs. traditional models, which can be explained in equations from (8) to (13)

1. Access Latency (ms)

Measures the average time taken to process an access request:

$$\text{Access Latency} = \frac{\sum_{i=1}^{n}(t_{reponse,i} - t_{request,i})}{n} \quad (8)$$

Where:

- $t_{reponse,i}$: time of access decision
- $t_{request,i}$: time of request initiation
- n: total number of access requests

2. Authentication Accuracy (%)

Evaluates correct identity verifications:

$$\text{Auth Accuracy} = \left(\frac{True\ Positives}{True\ Positives + False\ Negatives}\right) \times 100 \quad (9)$$

3. Unauthorized Access Rate (%)

Percentage of unauthorized users incorrectly granted Access:

$$\text{Unauthorized Access Rate} = \left(\frac{False\ Positives}{Total\ Requests}\right) \times 100 \quad (10)$$

4. Scalability (requests/sec)

System throughput under load:

$$\text{Scalability} = \frac{\text{Total Processed Requests}}{\text{Total Time (seconds)}} \quad (11)$$

5. System Availability (%)

Proportion of uptime in the evaluation period:

$$\text{Availability} = \left(\frac{Uptime}{Uptime + Down\ time}\right) \times 100 \quad (12)$$

6. Audit Traceability (%)

Fraction of access events that are immutably logged and verifiable:

$$\text{Traceability} = \left(\frac{Verifiable\ Access\ Logs}{Total\ Access\ Events}\right) \times 100 \quad (13)$$

The comparison chart illustrates the enhanced performance of the proposed BIACF model in relation to traditional access control systems using standard mathematical formulas. BIACF reaches faster access decisions through reduced latency and improves safety, reducing the unauthorized access rate. Authentication accuracy increases due to decentralized identity verification, while scalability is almost doubled, indicating the system's ability to deal with higher request volumes efficiently. System availability improves less flaws, and audit traceability reaches 100% due to unchanging blockchain extraction. These results, supported by analytical formulas, confirm that BIACF offers a safer, reliable and more efficient access control solution for wireless edge networks.

5 Security and Privacy Considerations

5.1 Analysis of Security Risks Associated with Blockchain-Integrated Access Control

Although Blockchain's integrated access control increases safety due to decentralization, immutability and transparency, it introduces specific risks that must be carefully managed. Intelligent contracts, which automate the application of the policy, can become attack vectors if not coded or properly audited, potentially allowing unauthorized Access. Similarly, while blockchain transparency promotes auditability, it also advertises user metadata and therefore some access standards. This creates a privacy concern in an edge environment. Latency is another issue introduced by consensus-based validation. This affects the ability to apply real-time decisions, especially in edge applications that are time sensitive. Besides this, it can afford a scenario of malicious nodes conspiring together to influence access results within a permitted network! There is also the possibility of denial attacks, where attackers can overwhelm the orderly process by excessively sending orders to keep the edge nodes busy. To counteract these threats, it is paramount to perform rigorous testing of the intelligent contracts, apply privacy-preserving techniques such as off-chain storage or encryption, and develop efficient consensus protocols. Regular security audits and adaptive threat detection mechanisms are also necessary to maintain a resilient access control system.

5.2 Discussion of Potential Privacy Issues and Solutions

While Blockchain adds transparency and integrity in access control, it remains a potential source of privacy risks, especially in wireless edge networks. A key question here is the leakage of metadata - for instance, date and time records, user identities, and transaction history - as blockchain records are immutable and publicly available on the network. Such visibility might be used to unauthorized profiling or inferring user behavior. Also, storing access credentials or identity attributes right on the chain could lead to a violation of the data minimization principle and privacy laws. Considering the methods of privacy preservation, several options can be adopted to tackle such issues. These include zero-knowledge proofs (ZKPs) to verify access rights without revealing any secret information to the verifier, off-chain storage with hash-only references on the chain, and the use of pseudonymous decentralized identifiers (DIDs) to avoid direct identity disclosures. Additionally, private/permissioned blockchains may give limited views to participants accredited to view, preserving access control and data confidentiality while enjoying decentralized governance.

5.3 Strategies for Ensuring Data Integrity and Confidentiality

In any blockchain-integrated access control system, cryptographic means and architectural measures are necessary to secure data at wireless edge networks, ensuring the integrity and confidentiality of the data. Digital signatures and hash algorithms prevent alteration of data in transit as well as while at rest. Each request and access transaction is encrypted and stored on the Blockchain as inputs to its hash, providing records that are verifiable and tamper-proof. Meanwhile, to safeguard private data, private information such as user credentials or identity attributes must be stored off-chain, where only hash pointers or encrypted references of such data are recorded on-chain. End-to-end encryption may also be adopted to secure communication channels between devices and border nodes. Access restrictions imposed by smart contracts ensure that the entities that can access or decrypt some data are the ones authorized for it. Limits on exposure through private blockchains or channel-based data partitioning ensure that the information is shared only in a controlled and auditable manner among participants.

6 Future Directions

As Blockchain technology continues to evolve, it is predicted that its role within access manipulation for wireless aspect networks will expand significantly. A vital increase is the mixing of mild consensus mechanisms - including Authority Proof (POA) or Delegated Participation Proof (DPOS) - which can lessen electricity consumption and enhance latency, making Blockchain more feasible for edge environments. In addition, the usage of zero-knowledge proofs (ZKPS) and exclusive smart contracts can improve privacy and selective disclosure in the course of access validation without exposing private facts. Additional studies can explore the interoperability of the move chain, permitting secure get admission to various blockchain structures and administrative domain names. Another promising direction is the fusion of AI-activated Blockchain's AI anomaly detection to identify real-time malicious behaviours.

In the broader context, blockchain-integrated access control has the potential to reshape the confidence architecture of wireless edge networks. By decentralizing authentication and ensuring the application of tampering test policies, it can allow secure design by design for smart cities, industrial IoT and autonomous systems. These developments can lead to fully decentralized autonomous edge ecosystems, where trust, transparency and control are incorporated at the protocol level.

7 Conclusion

This study presents a comprehensive structure for implementing blockchain access control in wireless networks, and addresses the limitations of traditional centralized systems. The main conclusions point out that Blockchain improves security, openness, and scalability, decentralizing authentication, automating the use of policy through intelligent contracts, and ensuring unchanging access logs. The integration of critical track analysis (CPA) further optimizes the performance, identifies and prioritize time -sensitive operations, making the system responsive and suitable for real -time environments. The importance of this approach lies in its ability to provide a smaller, audible, and resilient trust control mechanism in distributed and resource-restricted restrictions. Blockchain reduces the risks, such as unique issues of failure, unauthorized Access, and tampering, which are normal in traditional models, when adjusting itself well with the dynamic and sexual nature of computing. To successfully implement this technology, it is recommended that organizations employ blockchains with the permission of controlled access cess, adopting modular intelligent contract projects for flexible policies, and consolidated privacy techniques such as chain storage or zero knowledge tests. Regular intelligent contracts must be included in audits and system-level performance tests to ensure reliability. Finally, the integrated controls in the Blockchain can make the back of the cess control safe, autonomous, and ready-made wireless edge infrastructures.

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