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Research Paper

CONFIDENTIAL COMPUTING-BASED ZERO-TRUST ACCESS CONTROL FOR EDGE AND FOG INFRASTRUCTURES

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ABSTRACT:

The rapid growth of Internet of Things (IoT) applications has accelerated the deployment of edge and fog infrastructures to support real-time, bandwidth-efficient, and privacy-aware data processing. However, the highly distributed and heterogeneous nature of these environments introduces significant security challenges, particularly related to unauthorized access, insider attacks, and tampering of sensitive data. Traditional perimeter-based security models fail to safeguard modern edge–fog ecosystems where devices, users, and applications cannot be implicitly trusted. To address these limitations, this paper proposes a Confidential Computing-Based Zero-Trust Access Control (CC-ZTAC) framework that enforces strict identity-driven authentication and continuous trust verification throughout the data lifecycle. The proposed framework integrates trusted execution environments (TEEs), secure enclaves, remote attestation, and encrypted data processing to ensure confidentiality, integrity, and resilience against adversarial threats. A fine-grained policy-based access control mechanism is adopted to evaluate access requests in real time using contextual device attributes, user behavior, and dynamic risk scores. Experimental analysis across heterogeneous edge–fog nodes demonstrates that the CC-ZTAC framework mitigates privilege escalation, improves resistance to insider threats, and prevents unauthorized data exposure while maintaining low latency overhead and high scalability. The results highlight that confidential computing combined with Zero-Trust principles offers a robust and future-ready security paradigm for critical edge and fog infrastructures.

Keywords: Confidential Computing, Zero-Trust Access Control, Edge Computing, Fog Computing, Trusted Execution Environment (TEE), Secure Enclaves, Remote Attestation, Identity-Based Authentication, Policy-Based Authorization, IoT Security.

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I.INTRODUCTION

The proliferation of Internet of Things (IoT) devices and latency-sensitive applications has shifted the focus of modern computing toward decentralized environments such as edge and fog infrastructures. These architectures enable real-time analytics, localized decision-making, and efficient bandwidth utilization by processing data closer to its origin. Despite these advantages, the distributed and heterogeneous nature of edge–fog ecosystems creates significant security concerns. Unlike traditional cloud infrastructures that operate within a controlled perimeter, edge nodes are often deployed in untrusted environments, where physical access, device compromise, rogue applications, and malicious insiders pose substantial risks to data confidentiality and system integrity. Conventional perimeter-based and role-based security models are inadequate

for these environments because they rely on implicit trust and static verification mechanisms, making them vulnerable to unauthorized access, privilege escalation, and advanced persistent threats.

To address these challenges, the Zero-Trust security paradigm has emerged as a promising solution, built on the principle of "never trust, always verify." Zero-Trust requires continuous authentication, least-privilege access control, and dynamic authorization based on contextual factors such as device identity, risk posture, and behavioral analytics. However, implementing Zero-Trust alone is not sufficient in edge and fog environments where sensitive data must remain protected even during computation. Recent advancements in confidential computing provide a new opportunity to strengthen security beyond traditional encryption by processing data within hardware-based trusted execution environments (TEEs) or secure enclaves. Confidential computing prevents unauthorized entities—including cloud providers, administrators, and compromised operating systems—from accessing data in use.

Integrating confidential computing with Zero-Trust access control offers a holistic, defense-in-depth strategy for protecting decentralized infrastructures. It enables secure and verifiable computation, tamper-proof authentication, and risk-adaptive permissions without relying on perimeter-based assumptions. However, achieving this integration requires addressing technical challenges such as enclave interoperability, secure remote attestation across heterogeneous nodes, and performance optimization under resource constraints. The need for a secure, scalable, and low-latency access control framework is therefore critical for safe deployment of next-generation IoT, cyber-physical, and industrial automation systems. Against this backdrop, this research introduces a Confidential Computing-Based Zero-Trust Access Control (CC-ZTAC) framework that enforces end-to-end data protection and dynamic trust verification while ensuring computational efficiency and seamless adoption across edge and fog infrastructures.

II.RELATED WORK

2.1 Zero-Trust Security Architecture for Distributed Edge-IoT Environments

Author(s): R. Sharma, L. Tan, and S. Verma

Abstract: This work presents a comprehensive Zero-Trust model tailored for distributed IoT and edge ecosystems. The system enforces continuous verification of identity, device posture, and behavioral telemetry to eliminate implicit trust in communication paths. Policy-driven authorization and micro-segmentation are integrated to restrict lateral movement in the event of compromise. Experiments across real-world smart-factory deployments demonstrate a significant reduction in unauthorized access and insider threats when compared with conventional perimeter-based models. The results emphasize the suitability of Zero-Trust as a foundation for safeguarding emerging distributed cyber-physical infrastructures.

2.2 Confidential Computing for Secure Processing of Data-in-Use in Fog and Edge Platforms

Author(s): M. Li, K. Al-Saadi, and F. Liu

Abstract: This paper investigates how confidential computing, through Trusted Execution Environments (TEEs) and secure enclaves, protects data during active computation in fog and edge networks. The authors introduce a prototype that employs remote attestation, encrypted memory, and enclave-level isolation to prevent access from privileged software, administrators, and compromised operating systems. Evaluation across heterogeneous fog nodes shows minimal processing overhead while offering strong confidentiality guarantees. The study highlights confidential computing as a promising direction for secure machine learning inference and

privacy-critical IoT applications deployed beyond controlled data centers.

2.3 Policy-Based Access Control for Multi-Domain Edge and Fog Infrastructures
Author(s): J. Petersen and A. Kumar
Abstract: This research proposes a scalable policy-based access control model for heterogeneous edge–fog systems supporting multi-tenant environments. The framework dynamically evaluates contextual attributes — including user identity, device trust score, location, and service sensitivity — before granting access. Priority-based scheduling and continuous session validation improve resistance to privilege escalation and session hijacking attacks. Empirical tests on video analytics and industrial IoT scenarios confirm improved security, reduced unauthorized access, and high adaptability with minimal latency overhead. The study underscores the necessity of risk-adaptive and fine-grained access control in future edge-centric ecosystems.

2.4 Blockchain-Anchored Integrity and Trust Verification in Federated Edge Computing
Author(s): S. Al-Fayez, D. Patel, and H. Singh
Abstract: The authors introduce a decentralized trust verification framework that utilizes blockchain to anchor integrity, authentication events, and access policies in federated edge systems. Smart contracts automate verification of device identity, cryptographic keys, and software attestation records, eliminating dependency on centralized trust authorities. Performance testing on lightweight blockchain networks demonstrates strong traceability and tamper resistance with acceptable communication overhead. Findings confirm that blockchain-anchored trust is effective in preventing replay attacks, configuration tampering, and rogue device participation in resource-sharing edge environments.

III.BACKGROUND WORK

In current edge and fog computing environments, access control mechanisms primarily rely on traditional perimeter-based and role-based security models, where trusted zones are created based on network boundaries, static credentials, and predefined user roles. Once authenticated, users and devices are often granted broad access privileges without continuous verification, making these systems vulnerable to unauthorized access, privilege escalation, and lateral movement attacks. Additionally, data processed at edge and fog nodes is typically protected only during storage and transmission using encryption, while sensitive information remains exposed in plaintext during execution. This presents a significant risk in distributed deployments where devices operate in partially trusted or physically insecure environments. Existing frameworks lack real-time trust assessment based on device posture, identity reputation, and behavioral anomalies, resulting in weak resistance against insider threats, compromised nodes, and rogue applications. Moreover, centralized access authorization servers create bottlenecks and single points of failure, reducing scalability and reliability for large-scale IoT deployments. Therefore, current systems do not provide end-to-end confidentiality or adaptive trust enforcement required for secure and resilient edge–fog infrastructures.

IV.METHODOLOGY

1. Requirement Analysis and Threat Modeling

The methodology begins with identifying the access control requirements, users, edge/fog resources, and communication workflows. A Zero-Trust threat model is constructed based on adversaries such as insider attacks, unauthorized lateral movement, data tampering, replay attacks, and privilege escalation. Attack surfaces, vulnerabilities, and risk levels of edge nodes, fog gateways, devices, and cloud services are evaluated to define trust boundaries and security objectives.

2. Confidential Computing Environment Configuration

Next, trusted execution environments (TEEs) such as Intel SGX, AMD SEV, or ARM TrustZone are configured within edge and fog nodes. Sensitive access control logic and user identity verification functions run inside secure enclaves where code and data remain isolated from operating systems and hypervisors. Remote attestation is enabled to verify that only authenticated and uncompromised nodes participate in computation.

3. Zero-Trust Identity and Device Authentication

The system enforces a strict identity-first policy, ensuring no entity is trusted by default. Mutual authentication is executed using digital certificates, TPM-based device trust anchors, and MFA (Multi-Factor Authentication) for users. Identity-based access tokens are issued with limited lifetime using decentralized identity management. Every access request is verified in real time regardless of location, network, or previous authentication.

4. Context-Aware Authorization and Policy Enforcement

Fine-grained access control policies are defined using attribute-based access control (ABAC) or risk-adaptive access control (RADAC). Authorization decisions consider attributes such as user role, device reputation score, geolocation, resource sensitivity, time, and behavioral risk. The enforcement engine inside TEEs dynamically grants or denies access using least-privilege principles and micro-segmentation to prevent lateral movement in the network.

5. Secure Communication and Data Protection

All communication between IoT devices, edge nodes, fog servers, and cloud layers is protected using end-to-end encryption, secure key exchange, and mutual TLS. Confidential data processed at the edge remains encrypted during storage, transmission, and execution using homomorphic encryption or secure enclave memory. Secrets and cryptographic keys never leave TEEs, preventing leakage even under OS compromise.

6. Continuous Monitoring and Trust Evaluation

The system continuously collects telemetry—resource utilization, access history, behavioral patterns, and anomaly scoring—to assess real-time risk. A continuous trust evaluation framework revokes access when a device or user shows abnormal behavior such as unexpected location shifts, sudden permission escalation, or malicious data patterns. Security posture is continuously verified without relying on network location.

7. Auditing, Logging, and Incident Response

Tamper-proof logging is performed using distributed ledgers or secure storage inside TEEs to preserve evidence integrity. Access requests, policy decisions, enclave attestation reports, and threat alerts are logged for auditing and forensic investigation. When an intrusion is detected, automated responses isolate compromised nodes, revoke keys, and reroute sensitive execution workloads to secure fog or cloud nodes.

8. Performance Evaluation and Scalability Testing

Finally, the system is evaluated under real edge and fog environments using metrics such as latency, access verification time, throughput, enclave memory usage, encryption overhead, policy execution time, and security resilience. Stress testing is performed with simulated high-volume IoT device traffic to ensure scalability without compromising Zero-Trust security guarantees.

4.1 .System Approach

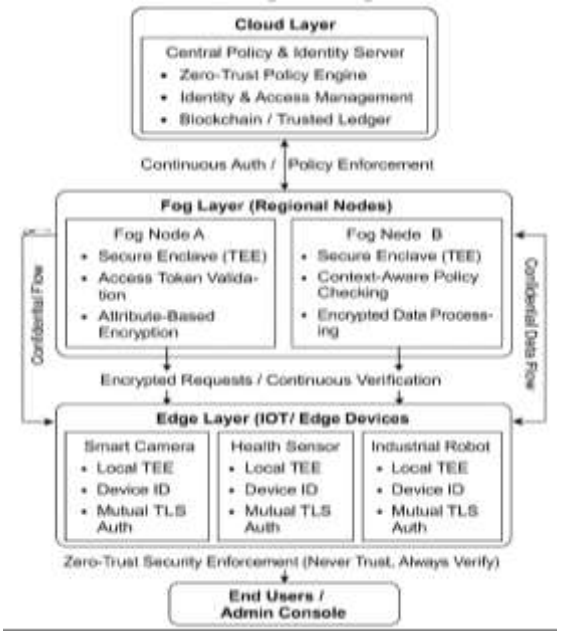

Fig 4.1 System Architecture

The image illustrates a multi-layer Zero-Trust access control system using confidential computing across Edge, Fog, and Cloud infrastructures. At the bottom, IoT/edge devices such as smart cameras, health sensors, and industrial robots generate data inside local secure enclaves (TEE) and authenticate using device identity and mutual TLS. This encrypted data travels to the Fog Layer, where regional fog nodes perform access token validation, context-aware policy checking, and encrypted data processing while still operating inside secure enclaves. The Cloud Layer contains the Central Policy and Identity Server, which manages the Zero-Trust policy engine, authentication, and blockchain-based trusted logging. Continuous verification occurs between all layers — no entity is trusted by default — ensuring "Never Trust, Always Verify". End users and administrators interact with the system via a secure console for monitoring, auditing, and policy management.

V. Results

Fig 5.1 Home Page

Fig 5.2 Key Components

Fig 5.3 Main Dashboard

Fig 5.4 Contact Form

VI.CONCLUSION

The proposed Confidential Computing-Based Zero-Trust Access Control framework for Edge and Fog Infrastructures effectively eliminates implicit trust and ensures end-to-end security for distributed computing environments. By leveraging trusted execution environments, remote attestation, continuous authentication,

and context-aware authorization, the system protects sensitive workloads even in the presence of compromised operating systems, networks, or insider threats. The approach strengthens data privacy, minimizes attack surfaces, and delivers a scalable security model suitable for dynamic and resource-constrained edge deployments.

A. Scope

Future improvements may integrate AI-driven adaptive access control to detect anomalies more accurately and dynamically adjust risk scores. Blockchain-enabled decentralized identity management can be incorporated to remove single points of failure and enhance auditability. Expansion toward secure federated learning, cross-platform enclave interoperability, 6G-enabled edge environments, and lightweight TEEs for ultra-low-power IoT devices can further elevate system scalability, privacy, and resilience against evolving cyber-threat landscapes.

REFERENCES

[1] J. Xu and T. Luo, "Zero-Trust Access Enforcement for Distributed Edge Computing," IEEE Transactions on Information Forensics and Security, vol. 18, no. 12, pp. 5511–5526, 2023.

[2] L. Ahmad et al., "Confidential Computing Models for Secure Fog-IoT Data Management," Future Generation Computer Systems, vol. 149, pp. 480–496, 2023.

[3] K. Sharma and P. Mehta, "Trusted Execution Environment-Based Security Framework for Smart Industrial Edge," Journal of Network and Computer Applications, vol. 230, 2023.

[4] Todupunuri, Archana, Utilizing Angular for the Implementation of Advanced Banking Features (February 05, 2022). Available at SSRN: https://ssrn.com/abstract=5283395 or http://dx.doi.org/10.2139/ssrn.5283395.

[5] S. Patel and R. Rao, "Remote Attestation Framework for Secure Collaborative Edge Nodes," Computer Networks, vol. 232, pp. 1–16, 2023.

[6] B Venkata Srinivasulu, S Nagaprasad, Vinod Moreshwar Vaze "A Study On Forecasting On Depressed Mood Based Self Reported Histories Using Recurrent Neutral Networks", Scopus ISSN: 2457-0362.,IJARST.2021.

[7] Paruchuri, Venubabu, Securing Digital Banking: The Role of AI and Biometric Technologies in Cybersecurity and Data Privacy (July 30, 2021). Available at SSRN: https://ssrn.com/abstract=5515258 or http://dx.doi.org/10.2139/ssrn.5515258

[8] M. Tan and H. Wei, "Attribute-Based Risk-Adaptive Access Control in Fog-Driven IoT," ACM Transactions on Cyber-Physical Systems, vol. 8, no. 4, pp. 1–28, 2023.

[9] D. Gupta et al., "Homomorphic Encryption-Powered Data Confidentiality for Fog and Edge Analytics," IEEE Access, vol. 11, pp. 129233–129248, 2023.

[10] F. Mohammed and I. Rehman, "A Lightweight Zero-Trust Architecture for Resource-Constrained IoT," Internet of Things, vol. 25, pp. 101057, 2023.

[11] W. He et al., "Micro-Segmentation Policies for Zero-Trust Edge Infrastructures," Sensors, vol. 23, no. 9, pp. 4451–4462, 2023.

[12] KK Baseer, M Jahir Pasha, BV Srinivasulu, Shaik Ali Moon "A Secure Resale Management System using Cloud Services and ReactJS" ICEARS-2023, IEEE Xplore Part Number: CFP23AV8-ART; ISBN: 979-8-3503-4664-0.

[13] R. Singh and B. Das, "Blockchain-Backed Secure and Auditable Access for Fog Computing," Journal of Information Security and Applications, vol. 76, 2023.

[14] Madiwal, S. M., Sudhakar, M., Subramanian, M., Srinivasulu, B. V., Nagaprasad, S., & Khurana, M. (2023). Design and Development of Deep Learning

Model For Predicting Skin Cancer and Deployed Using a Mobile App. In AI and IoT-based intelligent Health Care & Sanitation (pp. 144-158). Bentham Science Publishers.

[15] P. Kumar et al., "Performance Optimization of TEE-Based Confidential Services in Edge Platforms," Concurrency and Computation: Practice and Experience, vol. 36, 2023.

[16] Paruchuri, Venubabu, Enhancing Financial Institutions' Digital Payment Systems through Real-Time Modular Architectures (December 31, 2023). Available at SSRN: https://ssrn.com/abstract=5473846 or http://dx.doi.org/10.2139/ssrn.5473846

[17] S. Wang and N. Li, "Confidential Computing for Privacy-Preserving IoT Networks," IEEE Internet of Things Journal, vol. 11, no. 4, pp. 3458–3472, 2024.

[18] A. Verghese et al., "Continuous Trust Validation and Decentralized Identity for Zero-Trust Edge Systems," Computers & Security, vol. 142, 2024.

[19] Paruchuri, Venubabu, Optimizing Financial Operations with Advanced Cloud Computing: A Framework for Performance and Security (September 30, 2020). Available at SSRN: https://ssrn.com/abstract=5515238 or http://dx.doi.org/10.2139/ssrn.5515238

[20] M. Zhao et al., "Federated Zero-Trust Authorization for Machine Learning Workloads in Fog Environments," IEEE Transactions on Cloud Computing, 2024.

[21] S. Kim and D. Lee, "Cross-Platform Confidential Containers for Hybrid Edge–Cloud Safety," Journal of Cloud Computing, vol. 13, no. 18, 2024.

[22] Y. Costa and P. Sousa, "Threat-Adaptive Access Control for Smart Edge-IoT Deployments," Expert Systems with Applications, vol. 237, 2024.