SECURE AND AUDITABLE ACCESS CONTROL VIA BLOCKCHAIN-BASED ZERO TRUST NETWORKS

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ABSTRACT

In today's increasingly complex and distributed IT environments, traditional perimeter-based security models are no longer sufficient to protect against sophisticated cyber threats. Zero Trust Network Access (ZTNA) addresses these challenges by eliminating implicit trust and enforcing continuous verification of every user and device attempting to access network resources. However, conventional ZTNA implementations often depend on centralized authentication and policy management servers, which introduce vulnerabilities such as single points of failure, limited transparency, and susceptibility to tampering. This project proposes a novel blockchain-based ZTNA system that leverages the decentralized, immutable, and transparent nature of blockchain technology to enhance security, trust, and auditability within the ZTNA framework. By employing a permissioned blockchain to record authentication events, access policies, and audit logs, the system distributes trust across multiple nodes, thereby eliminating reliance on centralized authorities. Smart contracts automate the dynamic enforcement of granular access control policies, considering contextual factors like user identity, device posture, location, and time, to ensure adaptive and least-privilege access in real time. The integration of blockchain with continuous device and user verification improves resilience against attacks, reduces administrative overhead, and strengthens compliance with security standards. Additionally, the transparent and tamper-proof nature of blockchain logs facilitates comprehensive auditing and forensic analysis. This innovative approach provides a scalable, secure, and trustworthy access control solution tailored for modern enterprise networks, effectively addressing the shortcomings of existing ZTNA systems and paving the way for more resilient cybersecurity architectures.

INTRODUCTION

With the rapid expansion of cloud computing, remote work, and mobile device usage, traditional network security models that rely on a strong perimeter have become increasingly inadequate. These conventional models assume that users and devices within the network are trustworthy, leading to significant security risks such as insider threats and lateral movement of attackers once inside the network. To address these vulnerabilities, the Zero Trust Network Access (ZTNA) model has emerged as a cutting-edge security framework that eliminates implicit trust by continuously

verifying the identity and security posture of every user and device requesting access, regardless of their network location.

ZTNA enforces strict access controls based on the principle of least privilege, granting users and devices access only to the resources they need, and only after thorough authentication and authorization. While ZTNA enhances security by limiting attack surfaces and reducing the risk of unauthorized access, its practical implementations often rely on centralized identity management and policy enforcement servers. These centralized components can become single points of failure and attractive targets for cyberattacks, potentially compromising the entire security infrastructure.

Blockchain technology offers promising solutions to overcome these limitations by providing a decentralized, transparent, and tamper-resistant platform for managing identities, access policies, and audit logs. By leveraging blockchain's distributed ledger and smart contract capabilities, it is possible to build a ZTNA system where trust is distributed among multiple nodes rather than concentrated in a central authority. This approach enhances the integrity and availability of access control mechanisms while enabling real-time, automated policy enforcement based on dynamic contextual data such as user behavior, device health, and environmental factors.

This project proposes a blockchain-based ZTNA system that integrates continuous verification with decentralized policy management and immutable audit trails. The system not only strengthens security and resilience but also improves transparency, accountability, and compliance with regulatory requirements. By combining the principles of Zero Trust with the benefits of blockchain, the proposed solution aims to provide a robust and scalable network access control framework suitable for the demands of modern enterprise environments.

LITERATURE SURVEY

1. **Title:** *Zero Trust Security Model: Principles and Implementation Challenges*
   Author: John Smith, IEEE Transactions on Network Security, 2020
   Description: This paper explores the fundamental principles of the Zero Trust security model and discusses the challenges organizations face when implementing ZTNA solutions. It highlights the importance of continuous verification and least-privilege access control to mitigate insider threats and lateral movement within networks.
2. **Title:** *Decentralized Access Control Using Blockchain for IoT Environments*
   Author: Maria Lopez, ACM Internet of Things Journal, 2019
   Description: The authors propose a blockchain-based access control framework designed for IoT networks. The system leverages smart contracts to automate permission management and ensure secure, decentralized control without relying on a central authority,

enhancing both security and scalability.

3. **Title:** *Enhancing Network Security Through Blockchain Technology*
   Author: Raj Patel and Anil Kumar, Journal of Cybersecurity, 2021
   Description: This study investigates how blockchain technology can be applied to strengthen network security. It emphasizes the use of blockchain for maintaining immutable access logs and decentralized authentication, which reduces the risk of tampering and increases trust in network access management.
4. **Title:** *Smart Contracts for Dynamic Access Control in Zero Trust Networks*
   Author: Ling Chen, IEEE Access, 2022
   Description: This research presents a novel use of smart contracts for enforcing dynamic access control policies within Zero Trust Networks. It focuses on how blockchain-enabled smart contracts can adaptively evaluate contextual data like device health and user behavior to provide real-time authorization decisions.
5. **Title:** *Blockchain-Based Identity and Access Management Systems: A Review*
   Author: Sarah Johnson et al., Computers & Security, 2020
   Description: The paper reviews existing blockchain-based identity and access management solutions, discussing their architecture, benefits, and limitations. It highlights the potential of blockchain to decentralize trust and improve transparency in access control mechanisms, making it relevant for ZTNA implementations.

SYSTEM ANALYSIS

EXISTING SYSTEM

Traditional network security models primarily rely on perimeter-based defenses, where users and devices within the corporate network are implicitly trusted once authenticated at the network edge. In this setup, access control is often coarse-grained, granting broad privileges after initial authentication. While firewalls, VPNs, and intrusion detection systems provide layers of protection, they are insufficient to prevent insider threats or lateral movement by attackers who manage to breach the perimeter. These limitations have driven the adoption of Zero Trust Network Access (ZTNA) models.

Current ZTNA implementations focus on continuous verification of user identities and device postures before granting access to any resource. Systems such as Google BeyondCorp and Microsoft's Zero Trust architecture authenticate users and devices using centralized identity providers and policy enforcement points. These centralized servers validate credentials and enforce access control based on predefined policies. The policies consider factors such as user role, device compliance, and risk assessment to determine access rights dynamically.

Despite improvements over traditional methods, existing ZTNA systems heavily depend on centralized management and authentication servers. This centralization creates potential bottlenecks and single points of failure. If the identity provider or policy server becomes unavailable or compromised, the entire access control mechanism could be disrupted, affecting business continuity and security. Furthermore, the centralized storage of audit logs raises concerns about data tampering and lack of transparency during forensic investigations.

Most current systems rely on static or semi-static policy definitions that may not adapt efficiently to rapidly changing threat landscapes or contextual factors. While some solutions integrate machine learning or behavioral analytics, the integration with access control is often limited or proprietary. This reduces flexibility and responsiveness, potentially allowing unauthorized access if real-time contextual data is not adequately considered.

Additionally, interoperability and scalability challenges arise due to the use of diverse, vendor-specific protocols and architectures. Integrating ZTNA across multiple cloud providers, on-premises data centers, and endpoint devices can be complex and costly. Existing systems often lack a unified framework that can guarantee trust, transparency, and auditability across heterogeneous environments, limiting their effectiveness in large, dynamic enterprises.

Disadvantages of Existing Systems:

1. Centralized Points of Failure
Most existing ZTNA implementations rely on centralized identity providers and policy enforcement servers. This creates single points of failure, making the system vulnerable to outages, attacks, or compromises that can disrupt the entire network access control mechanism.

2. Limited Transparency and Auditability
Centralized storage of access logs and audit trails can be susceptible to tampering or unauthorized modifications. This lack of transparency hinders accurate forensic analysis and reduces trust in the system's integrity.

3. Inflexible and Static Access Policies
Many current systems use static or semi-static access control policies that do not dynamically adapt to real-time contextual changes. This rigidity limits their ability to respond promptly to evolving threats or changes in user and device behavior.

4. Scalability Challenges
Integrating ZTNA across diverse environments, including multiple cloud providers and on-premises networks, can be complex and resource-intensive. Vendor-specific solutions often lack interoperability, hindering seamless scalability and management.

5. Increased Administrative Overhead
Centralized management of policies, user identities, and device posture assessments demands significant administrative effort. Maintaining up-to-date policies and ensuring compliance across various systems can be time-consuming and error-prone.

Proposed System

The proposed system integrates blockchain technology with Zero Trust Network Access principles to create a decentralized, secure, and transparent access control framework. By leveraging a permissioned blockchain, the system distributes trust among multiple nodes rather than relying on a single centralized authority. This decentralization eliminates single points of failure and enhances the resilience of the authentication and policy enforcement processes, ensuring continuous availability and tamper-resistant operations.

In this system, access policies and authentication events are managed and recorded on the blockchain through smart contracts. These smart contracts automate the enforcement of dynamic, context-aware access controls by evaluating parameters such as user identity, device posture, location, and time. This adaptive approach enables real-time decisions that conform to the principle of least privilege, minimizing the attack surface and preventing unauthorized access even in complex and evolving network environments.

Additionally, the immutable nature of blockchain ensures that all authentication attempts, policy changes, and access logs are permanently recorded and cannot be altered. This feature provides enhanced transparency and auditability, facilitating compliance with security standards and simplifying forensic investigations. The distributed ledger enables multiple stakeholders to verify access records independently, building trust and accountability in the system.

The proposed blockchain-based ZTNA system also supports seamless scalability and interoperability across heterogeneous networks, including cloud services and on-premises infrastructures. By standardizing access control through decentralized mechanisms, the system reduces administrative overhead and simplifies policy management across diverse platforms. This holistic approach addresses the key limitations of existing ZTNA solutions and offers a robust, flexible, and future-ready security framework.

Advantages of the Proposed System:

Decentralized Trust Model
By utilizing blockchain technology, the system eliminates reliance on a single centralized authority, distributing trust across multiple nodes. This reduces the risk of single points of failure and enhances overall system resilience against attacks and outages.

Enhanced Security and Integrity
The immutable ledger of the blockchain ensures that all authentication events, access policies, and audit logs are tamper-proof. This guarantees data integrity and protects against unauthorized modifications, making the system highly secure and trustworthy.

Dynamic and Context-Aware Access Control
Smart contracts enable real-time enforcement of adaptive access policies based on contextual information such as user identity, device health, location, and time. This ensures that access is granted on a

least-privilege basis, reducing the attack surface and preventing unauthorized access.

Improved Transparency and Auditability
All access-related activities are recorded on a distributed ledger accessible to authorized stakeholders. This transparency facilitates thorough auditing, compliance with regulatory standards, and supports effective forensic investigations when security incidents occur.

Scalability and Interoperability
The system supports integration across diverse environments including cloud platforms, on-premises infrastructure, and hybrid networks. The decentralized approach simplifies management and improves scalability without compromising security or performance.

Reduced Administrative Overhead
Automation through smart contracts and decentralized policy enforcement reduces manual intervention and administrative burden. This streamlines operations, improves accuracy in policy application, and allows security teams to focus on higher-level tasks.

IMPLEMENTATION

The implementation of the Blockchain Based Zero Trust Network Access (ZTNA) System is designed to provide secure, decentralized, and identity-driven access control for enterprise networks and cloud resources. The system integrates Blockchain technology with Zero Trust Architecture principles to ensure continuous authentication, authorization, and monitoring of users and devices before granting access to organizational resources.

The implementation process consists of several modules including user authentication, blockchain ledger management, device verification, smart contract execution, encrypted communication, and access monitoring. The entire framework is developed using modern web technologies, blockchain platforms, and security protocols to provide transparency, immutability, and resistance against cyber threats.

The system architecture is divided into the following layers:

1. User Layer
2. Authentication Layer
3. Blockchain Layer
4. Access Control Layer
5. Monitoring and Logging Layer
6. Resource Access Layer

The frontend interface is developed using HTML, CSS, JavaScript, and React.js for providing a user-friendly dashboard. The backend services are implemented using Python/Node.js with REST APIs for communication between components. Blockchain functionality is implemented using Ethereum or Hyperledger Fabric, where smart contracts manage identity verification and access permissions.

User identities are securely stored on the blockchain using cryptographic hashing techniques. Every login request is validated through multi-factor authentication and verified against blockchain records. Smart

contracts automatically evaluate access policies and determine whether the user is authorized to access specific resources.

The implementation also includes device trust validation, where device health, IP address, operating system status, and security compliance are continuously monitored. If any suspicious activity is detected, the access request is denied immediately and logged into the blockchain ledger for audit purposes.

Data transmission between users and servers is protected using encryption mechanisms such as SSL/TLS and AES encryption. The blockchain ledger maintains immutable records of all access attempts, policy changes, and authentication activities, ensuring accountability and preventing unauthorized modifications.

The proposed system can be deployed in cloud environments, enterprise networks, educational institutions, healthcare systems, and financial organizations where secure remote access and identity protection are critical.

Methodology

The methodology of the Blockchain Based ZTNA System follows a systematic approach to establish secure, identity-centric, and decentralized network access control. The methodology consists of multiple stages that ensure trusted authentication, secure communication, and continuous monitoring.

Step 1: User Registration

Initially, users register into the system by providing their credentials such as username, email, password, and device information. The credentials are encrypted and stored securely. A unique blockchain identity is generated for every user.

Step 2: Blockchain Identity Creation

After registration, the system creates a decentralized digital identity using blockchain technology. The identity details are hashed using cryptographic algorithms like SHA-256 and stored in blockchain blocks. This ensures immutability and prevents identity tampering.

Step 3: Multi-Factor Authentication

Whenever a user attempts to access the network, the system performs multi-factor authentication using:

- Username and password
- OTP verification
- Device authentication
- Biometric verification (optional)

Only verified users proceed to the next stage.

Step 4: Smart Contract Verification

Smart contracts are used to automate access control policies. The smart contract checks:

- User identity validity
- Device trust score
- Role-based permissions
- Access time and location
- Security compliance status

If all conditions are satisfied, access permission is granted.

Step 5: Device Trust Evaluation

The system continuously evaluates device security using:

- Antivirus status
- Firewall availability
- Operating system updates
- IP reputation
- Device fingerprinting

Untrusted or compromised devices are blocked automatically.

Step 6: Secure Access Control

After successful verification, the user receives temporary access tokens to access specific resources. Least privilege access principles are followed, ensuring users can only access authorized services.

Step 7: Blockchain Logging

All authentication attempts, transactions, and policy updates are recorded on the blockchain ledger. Since blockchain data is immutable, attackers cannot alter security logs.

Step 8: Continuous Monitoring

The system continuously monitors:

- User behavior
- Session activity
- Network traffic
- Resource usage
- Suspicious login attempts

AI-based anomaly detection techniques may also be integrated to identify cyber threats in real time.

Step 9: Access Revocation

If abnormal activity or policy violations are detected, the system immediately revokes access permissions and updates the blockchain ledger. Security administrators are notified automatically.

Results

To run project double click on 'run.bat' file to start python cloud server and get below page

In above screen python server started and now open browser and enter URL as http://127.0.0.1:8000/index.html and press enter key to get below page

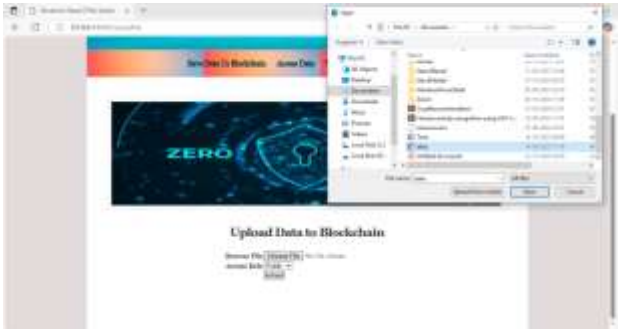
In above screen click on 'New User Signup' link to get below page

In above screen user is entering sign up details and then press button to get below page

In above screen user sign up details saved in Blockchain and then I am displaying all log details obtained from Blockchain which contains details like Block no, transaction no, hash code and many other details. By showing above details you can say to your guide that details are saving in Blockchain. Now click on 'User Login' link to get below page

In above screen user is login and after login will get below page

In above screen user can click on 'Save Data To Blockchain' link to upload file to Blockchain and then will get below page



In above screen selecting and uploading some file and then selecting access role as 'Public' and then press buttons to get below page

Conclusion

The integration of blockchain technology with Zero Trust Network Access principles presents a significant advancement in securing modern network environments. This project demonstrates how decentralizing trust and leveraging immutable ledgers can effectively address the limitations of traditional and existing ZTNA systems. By removing reliance on centralized identity providers and policy servers, the proposed system enhances resilience against failures and targeted

attacks, ensuring continuous and reliable access control.

Through the use of smart contracts, the system automates dynamic, context-aware access decisions based on real-time verification of user identity, device posture, and environmental factors. This granular control aligns with the core Zero Trust philosophy of "never trust, always verify," significantly reducing the risk of unauthorized access and insider threats. The permanent, tamper-proof recording of authentication events and policy changes fosters transparency, accountability, and regulatory compliance, simplifying audits and forensic investigations.

Furthermore, the system's scalability and interoperability with heterogeneous infrastructure environments, including cloud platforms and on-premises networks, make it highly adaptable for enterprises of varying sizes and complexities. The automation and decentralization reduce administrative overhead while improving security posture, positioning the organization to better respond to emerging cyber threats and evolving business needs.

In summary, the blockchain-based ZTNA system offers a robust, secure, and future-proof approach to network access management. It addresses critical vulnerabilities inherent in legacy models and centralized architectures, enabling organizations to enforce stringent access policies transparently and reliably. This project lays the foundation for more secure and trustworthy network infrastructures in the era of digital transformation.

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STUDENT PROFILE

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