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Enhanced Digital Identity Security Through Blockchain-Based Otp Authentication

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Abstract: Traditional authentication systems rely on trusted authorities, which often introduce security vulnerabilities such as fraud and data breaches. Blockchain technology enables a decentralized trust mechanism, ensuring secure and transparent authentication through cryptographic encryption, timestamps, and consensus mechanisms. In this paper, we propose a blockchain-based OTP authentication method, where an OTP is generated and securely transmitted to the user. The blockchain records and verifies authentication transactions, displaying block details such as timestamp, parent hash, available accounts, and gas usage for the corresponding block. Security analysis confirms that our approach effectively resists replay attacks, brute-force attempts, and OTP forgery, enhancing overall system integrity. Comparative evaluation highlights its efficiency, reduced computational overhead, and improved security over traditional OTP methods.

Index Terms **- OTP Authentication, Blockchain, Smart Contract, Decentralized Security**

I. INTRODUCTION

The exponential rise in digital services, online transactions, and cloud-based applications has heightened the need for secure, efficient, and tamper-proof authentication mechanisms. Traditional authentication methods, such as password-based systems and federated models like OpenID and OAuth, often rely on centralized servers or trusted third-party identity providers. While these systems enable seamless access to multiple services, they introduce significant vulnerabilities, including single points of failure, credential theft, phishing attacks, man-in-the-middle (MITM) attacks, and data breaches. For instance, if a centralized identity provider is compromised, attackers can gain unauthorized access to numerous services, affecting millions of users. Additionally, the lack of transparency in these systems hinders auditability, as users and service providers must blindly trust the provider's security measures, leaving malicious activities undetected for extended periods.

Blockchain technology, pioneered by Nakamoto in 2008, offers a decentralized and immutable solution some of the challenges. By leveraging a distributed ledger, blockchain eliminates the need for centralized authorities, reducing risks associated with single-point failures and insider attacks. Authentication transactions recorded on the blockchain are cryptographically secured, tamper-proof, and publicly verifiable, ensuring transparency while maintaining user privacy. Smart contracts further enhance this framework by automating authentication workflows, executing predefined rules without human intervention, and preventing fraudulent modifications through decentralized verification across multiple nodes.

Motivated by these advantages, this paper proposes a blockchain-based OTP authentication system that integrates One-Time Password (OTP) verification with blockchain technology to enhance security and transparency. OTPs, which provide temporary, single-use codes for user verification, are widely adopted in online banking, e-commerce, and secure access control, but their reliance on centralized servers limits their effectiveness. Our approach uses the blockchain as the OTP verifier, ensuring that each authentication transaction is recorded, verified, and protected from replay attacks, brute-force attempts, and forgery. The

system architecture comprises User Interaction, Backend Processing, and OTP Management components, seamlessly integrated with a blockchain network. Experimental evaluations demonstrate the system's effectiveness, highlighting its potential to provide a scalable, secure, and transparent framework for real-world applications.

II. Literature Review

The evolution of digital services has long relied on traditional authentication methods to secure user access, with password-based systems and One-Time Password (OTP) mechanisms delivered via SMS or email serving as foundational approaches. Federated authentication models, such as OpenID and OAuth, have further emerged to streamline user access across multiple platforms using a single identity. However, these centralized systems are fraught with security and reliability challenges that undermine their effectiveness in today's threat landscape. Academic research and practical observations highlight several critical disadvantages that necessitate innovative alternatives. One of the most pressing concerns is the reliance on a central authority, which introduces a single point of failure. If the central authentication server is compromised, attackers can expose multiple accounts to unauthorized access, potentially affecting millions of users simultaneously. This vulnerability is exacerbated by susceptibility to cyberattacks, including phishing, brute-force attacks, and credential stuffing, where attackers exploit weak or reused passwords to gain entry. Federated systems, while convenient, depend on trusted third-party identity providers, adding layers of risk such as insider threats and service outages.

OTP systems, a popular enhancement to password-based authentication, face additional limitations when delivered through SMS or email. These channels are prone to interception via SIM swapping, man-in-the-middle attacks, or sophisticated social engineering techniques, rendering them insecure despite their temporary nature. Moreover, authentication delays caused by network congestion or service provider failures can disrupt user experience, as highlighted in real-world incidents where users were locked out of critical services during outages. This reliability issue underscores the fragility of centralized OTP delivery mechanisms.

The centralized storage of authentication logs and user credentials poses another significant risk, amplifying the impact of data breaches. Centralized databases, often targeted by cybercriminals, can lead to the exfiltration of sensitive information, resulting in identity theft and financial fraud on a massive scale. The lack of auditability and transparency in these conventional systems further complicates matters, as users and administrators have limited visibility into authentication processes, allowing malicious activities to persist undetected for extended periods.

In response to these challenges, blockchain technology has gained attention as a decentralized alternative. The use of smart contracts for decentralized identity management showcases their ability to enforce rules without intermediaries and enhance security through immutability. However, the specific integration of blockchain with OTP authentication remains underexplored, particularly in addressing the practical limitations of traditional systems. This research builds on these foundations by proposing a blockchain-based OTP authentication system that leverages distributed consensus mechanisms and smart contracts to mitigate the disadvantages of centralized approaches, offering a promising direction for future studies.

III. Methodology

This study adopted a systematic approach to design, develop, and evaluate a blockchain-based OTP authentication system, focusing on decentralization, security, and transparency. The methodology encompassed several interconnected stages, including system design, OTP generation, blockchain integration, user verification, and transparency measures, all tailored to address the vulnerabilities of centralized authentication systems.

The research began with the design of the system architecture, structured into three core components: User Interaction, Backend Processing, and OTP Management, integrated with a blockchain network. This architecture aimed to address the limitations of centralized OTP systems by leveraging blockchain's decentralized and immutable properties. The development process included a multi-phase approach—**system initialization, OTP generation, and validation** each designed to trigger a transaction on the blockchain for enhanced security and auditability. The evaluation phase involved experimental testing to assess security, efficiency, scalability, and transparency, analyzing metrics such as transaction latency and gas usage.

A comprehensive set of tools was selected to support the development and testing phases, including a blockchain platform, a local simulation environment, a development framework, a runtime environment with

an API framework, a blockchain interaction library, and web technologies for the frontend, along with a static file server and cross-origin resource sharing for seamless communication. The evaluation phase simulated real-world scenarios to validate the effectiveness of the phased transaction process. Additionally, the methodology ensured that the timestamp-based validation process was rigorously tested to reinforce security, providing a foundation for the system's scalability and reliability in diverse applications.

IV. PROPOSED SYSTEM

To address the vulnerabilities of centralized authentication systems, this research proposes a blockchain-based OTP authentication system that leverages the decentralized and tamper-resistant properties of blockchain technology. Unlike traditional systems that rely on a single authority, this approach uses a distributed ledger to generate, validate, and store OTPs, mitigating risks such as single points of failure, data breaches, and lack of transparency. The blockchain acts as an independent OTP verifier, ensuring security, immutability, and decentralized validation, while smart contracts automate the authentication process, reducing human intervention and enhancing efficiency.

In this system, an OTP is generated and assigned to the user upon an authentication request. The system operates through three key phases—system **initialization, OTP generation, and validation** each recorded as a transaction on the blockchain, with timestamps ensuring time-sensitive security and immutability. The request and its associated details are recorded on the blockchain, ensuring transparency and auditability. Transaction logs include metadata such as the block hash and gas used, providing a verifiable record. For instance, a transaction on block number 3 recorded hash 0x3abced9a407c6cebd743b1e74ea1c976c9ba410355b691and a gas usage of 32341 units, demonstrating the system's ability to maintain detailed and transparent records. To enhance security, the system enforces a strict OTP generation policy: **if an OTP is generated but the user does not enter it and instead attempts to generate a new OTP by clicking the generate button again, the system will not produce a new OTP.** Instead, it displays an "error generating" message. This restriction ensures that only after the current OTP is entered and validated or its validity period expires can a new OTP be generated, preventing the generation of multiple OTPs concurrently and reducing the risk of unauthorized access or OTP misuse.

Advantages of the Proposed System:

The proposed system offers several significant benefits over traditional OTP authentication methods, leveraging blockchain technology to enhance security, transparency, and efficiency:

- Decentralization and Security: By eliminating reliance on a central authority, the system removes single points of failure, making it significantly harder for attackers to compromise authentication data.
- Protection Against Cyber Threats: The system resists phishing, man-in-the-middle attacks, and OTP interception through encrypted storage on the blockchain, ensuring attackers cannot alter or steal OTPs without detection.
- Tamper-Proof and Transparent Transactions: Blockchain immutability guarantees that authentication records remain unaltered, while transparency allows users and administrators to verify transactions, fostering trust.
- Efficiency Through Smart Contracts: Smart contracts automate OTP generation and verification, minimizing errors and speeding up the authentication process without compromising accuracy.
- Auditability and Traceability**:** Every authentication attempt is permanently recorded on the blockchain, enabling real-time tracking of authentication logs and detection of suspicious activities.
- Enhanced Privacy: Cryptographic techniques ensure that user data remains private during authentication, preventing unauthorized access while maintaining efficient verification.

V. SYSTEM ARCHITECTURE

The blockchain-based OTP authentication system is designed with a modular architecture to ensure seamless integration of its components, leveraging the decentralized properties of blockchain technology for secure and transparent authentication.

5.1 Components

The system comprises four key components, each playing a critical role in the authentication process:

User Interface (Client-Side): A web-based interface serves as the entry point for users, allowing them to initiate OTP requests and submit the received OTP for verification. This interface is designed for accessibility and ease of use, ensuring a smooth user experience.

OTP Generation Module: This module generates a cryptographically secure one-time password (OTP) upon request, using hash-based or time-based algorithms to ensure randomness and prevent predictability. The generated OTP is securely transmitted to the user through a protected channel.

Backend Processing: The backend acts as an intermediary between the user interface and the blockchain, handling OTP requests, coordinating with the smart contract for generation and validation, and managing transaction logging on the blockchain.

Blockchain Network: The blockchain serves as a decentralized ledger, storing OTP-related transactions and ensuring immutability and distributed verification. Each transaction is logged with metadata, such as the block hash and gas used, providing a verifiable record. For example, a transaction on block number 3 recorded a hash of 0x3abced9a407c6cebd743b1e74 ea1c976c9ba410355b6912628a9829587c0e4 and a gas usage of 32341 units.

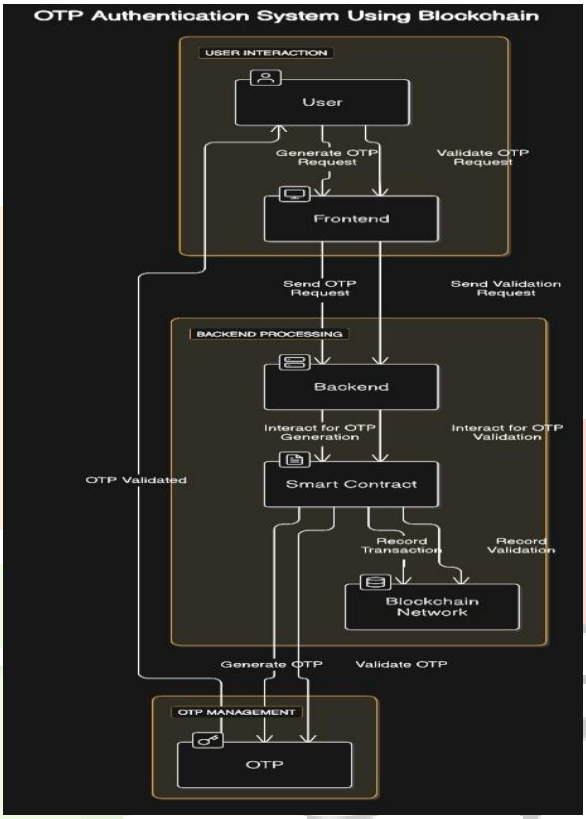

Figure 1: System Architecture

5.2 Workflow

The operational flow of the system ensures a secure and transparent authentication process, with each step recorded on the blockchain:

OTP Request & Generation: The user initiates an authentication request through the web or mobile interface. The OTP Generation Module creates a unique OTP using cryptographic functions. The generated OTP is securely sent to the user via a protected channel.

Storing OTP and Transaction Details on Blockchain: The OTP is hashed and stored on the blockchain via a smart contract, ensuring tamper resistance. Key transaction details are recorded, including the parent hash of the previous block to maintain chain integrity and the gas used for transaction execution.

OTP Verification: The user submits the received OTP through the interface. The smart contract retrieves the stored OTP hash, compares it with the user-provided OTP, and checks its validity within a predefined time window. If valid, authentication is approved; otherwise, access is denied.

Logging and Security Analysis: The blockchain ledger maintains an immutable record of all authentication attempts. Unauthorized access attempts can be audited using the blockchain's transparency, enabling real-time security analysis.

5.3 Security Features

The system incorporates several security measures to ensure a robust authentication process:

- Decentralized Authentication: Eliminates the need for a central authentication server, reducing single points of failure.
- Immutable OTP Records: Ensures OTPs cannot be altered or reused, enhancing security. Protection Against Attacks: Resists replay attacks, brute-force attempts, and OTP forgery through cryptographic safeguards and time-limited OTPs.
- Tamper-Proof Logs: Transaction history and authentication details are permanently recorded on the blockchain, ensuring auditability.

VI. IMPLEMENTATION

The system was developed using a comprehensive technology stack tailored for blockchain-based applications. Ethereum served as the foundational blockchain platform, providing a decentralized ledger for storing OTP transactions. Ganache was utilized as a local simulation environment to create a controlled blockchain network with pre-funded accounts, enabling transaction execution without real-world costs. Truffle, a development framework, managed the smart contract lifecycle, handling compilation, deployment, and interaction with the Ethereum blockchain. The compilation phase occurred when Truffle was running, initiating the first transaction on the local Ganache network to deploy the smart contract, setting the foundation for OTP management. The smart contract was designed to automate two core functions: generating a unique, time-sensitive OTP for a user based on their address and validating the submitted OTP by checking its correctness and leveraging timestamps to enhance security.

The backend was developed using Node.js as the runtime environment and Express as the API framework, connecting to the blockchain via Web3.js, a library that facilitates interaction with the Ethereum network. It manages two primary API endpoints: one for OTP generation and another for validation. When an OTP generation request is received—triggering the generation phase with another transaction on Ganache when the user clicks the Generate OTP button—the backend invokes the smart contract to create a random OTP, associating it with the user's address and recording the transaction on the blockchain with a timestamp. The OTP is then returned to the frontend for user delivery. During validation, the validation phase occurs with a third transaction when the user submits the OTP; the backend receives the submitted OTP and user details, invoking the smart contract to verify the OTP against the stored record, check its time validity using the timestamp, and log the result on the blockchain for transparency.

The frontend was developed using React, HTML, CSS, and JavaScript, enabling a dynamic and responsive interface with multiple pages: an OTP authentication page for requesting and submitting OTPs, an admin page for user management, and a block details page displaying blockchain transaction logs. The frontend was served locally using http-server, a static file server, allowing users to access the application via a web browser. Cross-Origin Resource Sharing (CORS) was implemented to ensure seamless communication between the frontend and backend.

The integration of these components results in a seamless workflow. A user initiates an OTP request through the frontend, which sends the request to the backend. The backend invokes the smart contract to generate the OTP (generation phase), which is recorded on the blockchain with a timestamp. The OTP is returned to the frontend and displayed to the user. Upon submission, the frontend forwards the OTP to the backend for validation (validation phase), where the smart contract verifies its correctness and time validity, logging the result on the blockchain. Transaction logs, accessible via the block details page, include block hashes, gas usage, and timestamps, ensuring transparency and security through the multi-phase transaction process.

The system was deployed locally, with the backend running on a Node.js server and the frontend served via http-server. This setup enabled thorough testing in a controlled environment, simulating real-world scenarios such as concurrent user requests and transaction logging across the compilation, generation, and validation phases.

VII. RESULTS

The system was tested on a simulated blockchain network to evaluate its security, efficiency, scalability, and transparency. This evaluation was conducted using Ethereum as the blockchain platform, Ganache for local simulation, Truffle for smart contract management, Node.js with Express for the backend, Web3.js for blockchain interaction, and React for the frontend interface, all served locally via http-server. The testing

environment highlighted the system's multi-phase transaction process-compilation, generation, and validation supported by timestamps for enhanced security.

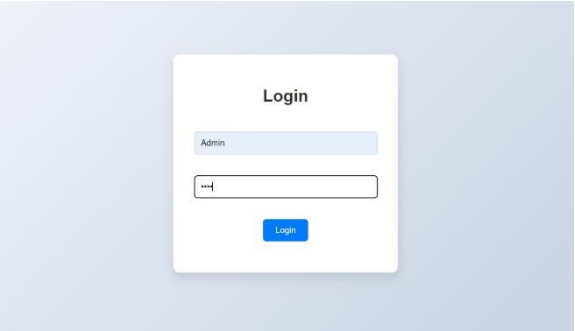

Figure 2: Admin login page

A simple login page for admin access, allowing secure entry to user management features, ensuring only authorized users can oversee the system.

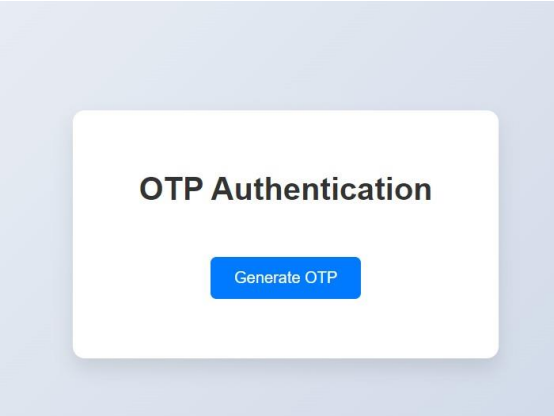

Figure 3: OTP Authentication Page

The main interface where users can initiate the generation phase by clicking the "Generate OTP" button, starting the OTP authentication process.

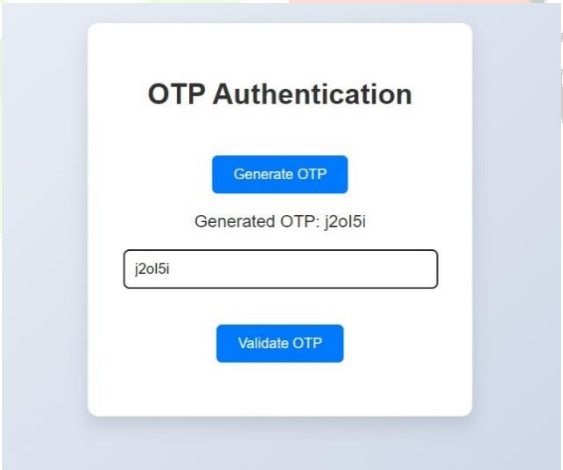

Figure 4: OTP Authentication After Validation

Shows a generated OTP, the validation input field, and a success message after the validation phase, with an option to view block details for transparency.

Figure 5: OTP Validated

Figure 6: Block Details Page

A clean interface for retrieving the latest blockchain transaction logs, displaying details like block hashes and timestamps, making authentication events transparent and auditable.

```
PS D:\otp_authentication_blockchain-main\otp_authent
ication_blockchain-main\src> node test.js
Current Block Number: 1
Available Accounts:
0: 0x11406cE33e00AbaB7715D0d8e8818DBed99F63B1
1: 0xbBE15dC3bc025E83FBc2aD36aFec667E7653D3Dc
2: 0xA9D1ab894850D71433078012305460B52475dEAc
3: 0x41E5Fd9865d21f58b3ab215a4B96a61A255748Ba
4: 0xeE36251e80f4a930984B017Ea7E7EB0b702Df3dE
5: 0x058b73Ee3958aD32BD4911E4421d8181112EE271
6: 0x9f402B7c3E311d0a2DdC60a796513BAcE9068A15
7: 0x428bEF1cd5c653f578Cf77006b3a18C239af6686
8: 0x424ee1d3b10a70EC4B5856Ec9fb26256DE6081E6
9: 0x81499B8b9E2256251c903830E4CDF18729DFA967
Balance of 0x11406cE33e00AbaB7715D0d8e8818DBed99F63B
1: 999.99646893325 ETH
Generated OTP for 0x11406cE33e00AbaB7715D0d8e8818DBe
d99F63B1: n7u9k1
Please enter the OTP to validate: n7u9k1
Validation result for OTP "n7u9k1": Valid

Details of Block Number: 3
Hash: 0xd0085ecd445d64db56164f23af7ed50600e746e15473
13873d67c287e2adecd0
Parent Hash: 0x6bf69ddeb71548c23eb6bb6bd18bd92ad4728
b09ff0521a5b387c83f27b33acd
Nonce: 0
Transactions:
  - Hash: 0x735f0de964d2620f620f49d070355281256a70cb
e034d869de4228f7935c20ca, From: 0x11406ce33e00abab77
15d0d8e8818dbed99f63b1, To: 0x807779c9c7ac899c92b776
26a90eac4965c5cf66, Value: 0 ETH
```

Figure 7: Backend Terminal Execution in VS Code

Displays the backend running on the VS Code terminal, showing the compilation phase with Truffle on Ganache, the generation phase with an OTP, the validation phase confirming it as "valid," and block details (block number 3) with transaction logs, ensuring transparency through timestamped records.

VIII. Conclusion

This research introduces a blockchain-based OTP authentication system, leveraging Ethereum, Ganache, and Truffle to create a seamless multi-phase process—compilation, generation, and validation—integrated with a React frontend and Node.js backend. The system streamlines secure authentication by automating OTP management through smart contracts, ensuring each phase is logged on the blockchain with timestamps for transparency. Its practical implementation is vividly captured in the admin login, OTP generation, validation, and block details interfaces, alongside the backend terminal in VS Code. These visuals highlight the system's intuitive design, allowing users to easily navigate the authentication process while accessing transparent transaction logs with block hashes and timestamps. This approach offers a promising, user-friendly solution for secure authentication in domains like online banking and e-commerce, paving the way for future improvements in blockchain-based security systems.

IX. Future Scope

Looking ahead, we plan to make our OTP authentication system even better by exploring faster blockchain options to speed up validation. We'll add privacy features to protect user data and test it in real-world settings like online shopping. Plus, we aim to include an AI detector to spot suspicious activities and create a more colorful interface to make it friendlier for everyone, building on its current strengths.

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