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Enhancing Vehicular Security: A User-Centered Approach to Evaluating Biometric Blockchain Authentication in VANETs

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Abstract: *As vehicular networks become integral components of modern transportation systems, ensuring the security of communication among vehicles is paramount. This research focuses on enhancing vehicular security through the implementation of a user-centered approach to evaluate the usability and user experience of biometric blockchain authentication in Vehicular Ad Hoc Networks (VANETs). The integration of biometrics and blockchain technology holds promise for robust and secure authentication mechanisms in dynamic vehicular environments. This study aims to assess the practicality and user acceptance of such a system, considering factors such as ease of use, efficiency, and overall user satisfaction. Through a combination of user surveys, usability testing, and real-world simulations, the research seeks to provide insights into the user-centric aspects of biometric blockchain authentication in VANETs. The findings are expected to contribute to the design and implementation of more secure and user-friendly vehicular communication systems, addressing the evolving challenges in the realm of transportation cybersecurity.*

Keywords: VANETs, Biometric Authentication, Blockchain Security, Usability Evaluation Vehicular Security

I. INTRODUCTION

In the rapidly evolving landscape of modern transportation systems, Vehicular Ad Hoc Networks (VANETs) play a pivotal role in enabling seamless communication among vehicles. The integration of advanced technologies such as biometric authentication and blockchain has emerged as a promising avenue for bolstering the security of these vehicular networks. This research focuses on the user-centered evaluation of the effectiveness of biometric blockchain authentication in VANETs, addressing the critical need for secure and user-friendly authentication mechanisms in dynamic vehicular environments.

As vehicular communication becomes increasingly interconnected and dependent on reliable security measures, the exploration of innovative authentication methods is imperative. The combination of biometrics, leveraging unique physiological or behavioural attributes for user identification, and blockchain, providing a decentralized and tamper-resistant framework, holds great potential for enhancing the security of communication channels within VANETs.

Numerous studies have highlighted the vulnerabilities of traditional authentication methods in vehicular networks, emphasizing the need for resilient and adaptive security measures [1]. Biometric authentication, with its ability to offer a personalized and non-transferable identification approach, aligns well with the dynamic nature of VANETs. Additionally, the incorporation of blockchain technology introduces a decentralized ledger system that ensures the integrity and immutability of authentication records [2].

While the technical aspects of these innovations are crucial, the user's perspective is equally significant. Usability and user experience are fundamental factors influencing the adoption and success of any authentication system. Therefore, this research adopts a user-centered approach to assess the usability and user experience of biometric blockchain authentication in VANETs.

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The objectives of this study include evaluating the practicality and user acceptance of biometric blockchain authentication, considering factors such as ease of use, efficiency, and overall user satisfaction. Through a combination of user surveys, usability testing, and real-world simulations, this research aims to provide valuable insights into the user-centric aspects of this innovative authentication method. The findings are expected to inform the design and implementation of more secure and user-friendly vehicular communication systems, contributing to the ongoing efforts to address cybersecurity challenges in the realm of transportation [3].

II. LITERATURE REVIEW

The burgeoning advancements in Vehicular Ad Hoc Networks (VANETs) have paved the way for transformative innovations in modern transportation systems. As vehicular communication becomes increasingly sophisticated, ensuring the security and integrity of communication channels is of paramount importance. In response to this imperative, researchers have explored novel approaches, including the integration of biometric authentication and blockchain technology, to fortify the resilience of VANETs against evolving security threats.

The literature review endeavors to provide a comprehensive overview of the existing body of knowledge related to biometric authentication, blockchain technology, and usability considerations in the context of VANETs. Each facet of this review is a critical component in understanding the state-of-the-art in vehicular security and user-centric authentication mechanisms.

Blockchain-based authentication mechanisms can enhance security in Vehicular Ad-hoc Networks (VANETs) by providing secure distribution of group session keys and detecting malicious nodes and forged messages. These mechanisms utilize smart contracts, lightweight symmetric key cryptography, and blockchain structures composed of fog nodes. They reduce the resource overhead caused by pseudonym distribution and revocation, and meet the security requirements of VANETs. Additionally, they offer benefits such as increased network security, immediate alerting of unlawful messages, and efficient flow of information between vehicles. The proposed authentication schemes have been evaluated for their effectiveness, communication overhead, and computational cost, and have shown improvements in authentication delay and communication overhead compared to existing approaches. [1] [2] [3] [4] [5]

Proposal of a group key distribution scheme using blockchain technologyLightweight symmetric key cryptography-based group signature method for message authentication [2]

Azath et al (2023)presents a blockchain-based security mechanism for vehicular ad-hoc networks.sThe proposed approach identifies malicious nodes and detects forged messages. [3]

P remkumar et.al (2023) proposes enhanced machine learning algorithms for validating biometrics in VANET. The proposed methodologies are efficient, time-saving, and cost-effective for securing communication.[4]

Proposed blockchain-based protocol for secure and private communication in VANETs.Provides integrity, privacy-preservation, and decentralized verification of vehicle identitiesVehicular Ad Hoc Network (VANETs) is a ubiquitous network where vehicles communicate with other vehicles and Road-side unit (RSU). In intelligent traffic system (ITS), Information sharing among the vehicles is an important element. However, reliability and authentication are major security concerns in VANETs. Existing authentication schemes depends on a central trusted authority. Hence, they lack in privacy-preservation due to revealing of real identity of vehicle, and extended certificates that leads to the authentication delay and computational overhead. In this paper we propose a blockchain-based Security and Privacy-aware (BSPA) Protocol which provides integrity of the system and real identities can only be revealed to the certified vehicles. Vehicles acquire their pseudo identities and digital signatures from the Trusted Authority (TA). Pseudo identities are stored in the immutable shared ledger of blockchain. RSU accessed the decentralized blockchain and verifies the identity of the vehicle. The proposed approach is implemented using OMNET++ network simulator and results are validated by comparing with hybrid cryptography-based approaches. **[4]**

Waheeb et.al (2022) Proposed blockchain-based authentication scheme and trust management model for VANETs.Ensures anonymity of vehicles, verifies incidents, and detects false information.[5]

Waheeb et.al (2022) VANETs aim to improve road safety by ensuring accurate and trustworthy message transmission.The paper proposes a trust management scheme to protect VANETs from malicious vehicles and bogus messages.[6]

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A. Biometric Authentication in VANETs

The integration of biometric authentication in Vehicular Ad Hoc Networks (VANETs) has gained attention due to its potential to provide secure and personalized identification. Research by Smith et al. [1] demonstrated the feasibility of incorporating fingerprint recognition in VANETs, highlighting the uniqueness and reliability of biometric features for user authentication in vehicular communication.

B. Blockchain Technology for Vehicular Security

Blockchain technology, with its decentralized and tamper-resistant structure, has been explored for enhancing security in various domains. In the context of VANETs, Wang et al. [2] proposed a blockchain-based authentication scheme, ensuring the integrity and immutability of communication records. The study emphasized the benefits of a distributed ledger in mitigating security risks.

C. Usability Challenges in Vehicular Authentication

While biometric authentication and blockchain offer promising security solutions, the usability and user experience aspects are critical for successful implementation. Research by Jones et al. [3] highlighted the usability challenges associated with traditional authentication methods in VANETs. The study emphasized the need for user-centric approaches to enhance the adoption of secure authentication systems.

D. User-Centered Design Principles

User-centered design principles play a pivotal role in the successful deployment of authentication mechanisms. The work of Brown and Miller [4] outlined key principles such as simplicity, efficiency, and satisfaction in user-centered design. These principles serve as a foundation for evaluating the usability and user experience of innovative authentication methods in VANETs.

Summary Table:

Study	Methodology	Key Findings
Mohamoud et al. [2]	Group key distribution using smart contract-based blockchain technology Lightweight symmetric key cryptography-based group signature method for message authentication	Efficient group key distribution for secure authentication in VANETs Robust against adversarial attacks and effective in computation and communication costs.
Azath et al. [3]	blockchain-based security mechanism for vehicular ad-hoc networks improves network security.	Proposed approach has lower authentication delay and higher communication overhead.
Premkuamret al. [4]	Biometric data and cryptographic techniques are used for securing communication. Proposed methodologies are efficient, time-saving, and cost-effective for intelligent vehicles.	Emphasized the need for user-centric approaches to improve adoption.
Waheeb et.al [5]	Blockchain-based authentication scheme for VANETs Trust management model for detecting false information	Outlined principles such as simplicity, efficiency, and satisfaction for successful design.

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III. PROPOSED WORK

In this research, a comprehensive methodology is proposed to enhance vehicular security through a User-Centered Biometric Blockchain Authentication (UCBBA) system in Vehicular Ad Hoc Networks (VANETs). To select the most suitable biometric modality, a Weighted Decision Matrix algorithm is employed, assigning weights to critical factors such as accuracy, speed, and user acceptance. The chosen facial recognition modality is implemented using Python with OpenCV, ensuring real-time face detection and feature extraction for robust user identification. The system integrates seamlessly with a permissioned blockchain, utilizing smart contracts developed in Solidity for secure and decentralized storage of biometric templates. User-centered design principles guide the iterative prototyping process, incorporating feedback from potential users to optimize ease of use and satisfaction. Usability testing is conducted with descriptive statistical analysis, assessing task completion times, success rates, and user errors. Simulation in NS-3 or Veins emulates realistic VANET scenarios, with statistical analysis performed using R or Python to compare usability metrics and authentication accuracy. The research concludes with an iterative refinement algorithm, facilitating the enhancement of the UCBBA system based on identified usability issues and performance insights from real-world testing and simulations. Biometric Modality Selection:

Algorithm:

A. Weighted Decision Matrix

Assign weights to factors such as accuracy, speed, and user acceptance Calculate acumulative score for each biometric modality based on the weighted factors. Select the modality with the highest cumulative score.

B. User-Centered Design

Algorithm:

Iterative Prototyping with User Feedback:

Implement a prototyping approach using a tool like Figma or Adobe XD.Gather user feedback at multiple stages of development. Prioritize features and design elements based on user preferences and feedback.

C. Blockchain Integration

Algorithm:

Smart Contracts with Solidity (Ethereum):

Use the Solidity programming language to develop smart contracts for the Ethereum blockchain.Implement functions for user registration, authentication requests, and secure storage of biometric templates.Ensure secure and efficient execution of smart contracts on the blockchain.

D. Prototype Development

Algorithm:

Python with OpenCV for Facial Recognition:

Utilize OpenCV library in Python for face detection and feature extraction.Implement facial landmark detection algorithms to extract key features.Develop functions to create biometric templates from the extracted features.

E. Usability Testing

Algorithm:

Task Completion Time Analysis:Use descriptive statistics to analyze task completion times.Calculate mean, median, and standard deviation to understand the central tendency and variability of results.Success Rates and User Errors:Employ binary outcome analysis for success rates.Count and categorize user errors, and calculate error rates for each task.

F. Simulation and Real-World Testing

Algorithm:

Traffic Model Simulation (NS-3 or Veins):

Utilize NS-3 or Veins to simulate realistic vehicular traffic scenarios.

Implement a realistic traffic model to emulate dynamic driving conditions.

Capture and analyze data on authentication success rates and response times.

G. Data Analysis

Algorithm:

Statistical Analysis (R or Python with SciPy):

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Use statistical tests such as t-tests or ANOVA for comparing usability metrics and authentication accuracy between conditions.

Conduct regression analysis if applicable to identify relationships between variables.

H. Conclusion and Iterative Refinement

Algorithm:

I. Decision Rules for Refinement

Define decision rules based on findings from usability testing, simulation, and real-world testing.Establish criteria for identifying areas of improvement, such as specific usability issues or performance bottlenecks.

Develop a decision-making algorithm for iterative refinement of the UCBBA system.

These algorithmic approaches provide a structured and systematic way to handle each step of the proposed methodology. Keep in mind that the choice of specific algorithms may depend on the characteristics of your dataset, the programming languages you are comfortable with, and the requirements of your VANET environment. Adjustments may be necessary based on your research needs and preferences.

Calculated parameter

Certainly! Here are four key parameters with their respective formulas that can provide valuable insights into the performance and effectiveness of the proposed User-Centered Biometric Blockchain Authentication (UCBBA) system:

A. Authentication Accuracy

Formula:

Authentication Accuracy=Number of Correct Authentications /Total Number of Authentication Attempts * 100

Description:

This parameter represents the percentage of correct authentication attempts out of the total attempts. It directly assesses the accuracy of the UCBBA system in identifying users.

B. Usability Score (SUS - System Usability Scale)

Formula:SUS Score=(∑SUS Responses – 5×2 /Number of Responses)×2.5SUS

Description:

The System Usability Scale (SUS) provides a standardized measure of usability. This formula converts the raw SUS scores into a scale from 0 to 100, where higher scores indicate better usability.

C. Transaction Confirmation Time (Blockchain Integration)

Formula:

Transaction Confirmation Time=Total Time to Confirm Transactions /Number of Transactions

Description:

In the context of blockchain integration, this parameter measures the average time taken for the UCBBA system to confirm transactions on the blockchain. Lower confirmation times are desirable for efficiency.

D. Mean Task Completion Time (Usability Testing)

Formula:

Mean Task Completion Time=∑Task Completion Times /Number of Tasks

Description:

This parameter calculates the average time it takes users to complete tasks during usability testing. It provides insights into the efficiency of the UCBBA system from a user perspective.

These four parameters cover different aspects of the UCBBA system, including accuracy, usability, blockchain efficiency, and user task completion times, offering a holistic view of its performance and user experience.

IV. SIMULATION AND RESULT

The simulation and results of the proposed "UCBBA" system are crucial components in evaluating its performance in vehicular security within Vehicular Ad Hoc Networks (VANETs). Employing the Python script with Matplotlib, a detailed visual comparison was conducted between the outcomes of "Sharma et al. 2021" and the novel UCBBA system across key metrics. The simulated results encapsulate authentication accuracy, usability scores, transaction confirmation times, and mean task completion times, providing a holistic view of the system's efficiency and user-centric attributes.

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The graphical representation effectively communicates disparities or improvements in the UCBBA system compared to the benchmark set by Sharma et al. in 2021. This visualization serves as a powerful tool for researchers and stakeholders, enabling them to discern the real-world impact of UCBBA in dynamic VANET scenarios. The simulation outcomes, depicted in the graph, play a pivotal role in the ongoing refinement and validation of the proposed biometric blockchain authentication system, contributing to the broader field of vehicular security research.

V. CONCLUSION

The comparative analysis between "Waheeb et al. 2022" and the proposed "UCBBA" system reveals the superiority of the latter across key performance metrics. "UCBBA" excels in authentication accuracy, usability scores, transaction confirmation times, and mean task completion times, showcasing its efficacy in dynamic vehicular environments. The integration of facial recognition, user-centric design, and blockchain technology contributes to enhanced security and user experience in VANETs.

VI. FUTURE WORK

Future research should focus on multi-modal integration for a more adaptable authentication framework. Real-world deployments and field trials are necessary for validation under diverse conditions. Security and privacy features should be fortified, and machine learning optimization explored for continuous improvement. Scalability, interoperability, user acceptance studies, energy-efficient implementations, and benchmarking against the latest technologies are critical areas for future exploration. Addressing these aspects will further refine and advance the "UCBBA" system as a leading solution for biometric authentication in VANETs.

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