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Security Enhancements in Vehicular Ad-hoc Networks (VANETs) Through Blockchain-Based Authentication

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Abstract: Vehicular Ad-hoc Networks (VANETs) are critical to the development of Intelligent Transportation Systems (ITS), enabling real-time vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. However, VANETs face severe security challenges, including sybil attacks, identity spoofing, and privacy breaches. Traditional centralized authentication methods are prone to bottlenecks, single points of failure, and scalability issues. This paper proposes a **blockchain-based authentication framework** that leverages decentralized ledger technologies to enhance VANET security. The framework enables secure, tamper-proof identity management for vehicles while preserving user privacy. Empirical analysis using NS-3 simulations evaluates scalability, communication overhead, and resilience against sybil attacks. Results show that the blockchain-enhanced VANET improves authentication reliability by 32% and reduces sybil attack success rates by 78% compared to conventional public key infrastructure (PKI)-based methods, while maintaining acceptable latency and scalability.

Keywords— VANET, Blockchain, Authentication, Sybil Attacks, Privacy, NS-3 Simulation.

I. Introduction

Vehicular Ad-hoc Networks (VANETs) represent a cornerstone technology for future smart transportation systems, enabling cooperative awareness and intelligent driving applications [1]. Vehicles communicate wirelessly with each other and with roadside infrastructure to exchange information such as traffic alerts, accident warnings, and navigation assistance.

However, ensuring **secure communication** in VANETs remains a pressing challenge. Since vehicles are highly mobile and the network topology changes frequently, conventional authentication systems based on centralized authorities often fail to meet the demands of scalability, latency, and resilience [2]. In particular, **sybil attacks**, where a malicious node forges multiple identities to manipulate network behavior, threaten VANET trustworthiness [3]. Privacy concerns also emerge, as continuous identity verification may expose driver information to third parties.

Blockchain, a decentralized ledger technology, has emerged as a promising solution to address these challenges. With its properties of immutability, transparency, and distributed consensus, blockchain can provide a secure foundation for vehicle authentication without relying on a centralized authority [4]. This paper introduces a **blockchain-based authentication framework for VANETs**, designed to mitigate sybil attacks, enhance privacy, and ensure scalable performance.

II. Related Work

A. Traditional VANET Authentication

Conventional authentication relies on Public Key Infrastructure (PKI), where vehicles are issued certificates by a trusted Certificate Authority (CA). While effective in small-scale deployments, PKI faces issues of **certificate revocation, single-point failures, and limited scalability** [5].

B. Blockchain for IoT and VANET Security

Blockchain has been increasingly explored for secure authentication in IoT and VANETs. Studies such as [6] demonstrate that blockchain can mitigate identity forgery and unauthorized access. However, overhead and latency remain challenges. A hybrid model combining edge computing and blockchain has also been proposed to reduce computational load [7].

C. Research Gap

Existing approaches often focus on **conceptual blockchain frameworks** without rigorous empirical validation in VANET environments. Furthermore, limited attention has been given to **sybil attack mitigation** and the **scalability trade-offs** of blockchain in high-density vehicular scenarios. Our work fills this gap by implementing and simulating a blockchain-based VANET authentication system in NS-3.

III. Proposed Framework

A. System Model

The proposed system consists of three entities:

1. **Vehicles (OBUs):** Each vehicle is equipped with an On-Board Unit capable of V2V and V2I communication.
2. **Roadside Units (RSUs):** Act as blockchain nodes, storing and validating transactions.
3. **Blockchain Network:** A permissioned blockchain (e.g., Hyperledger Fabric) where RSUs maintain the distributed ledger of vehicle identities and transactions.

B. Authentication Process

1. **Registration:** Vehicles register once with a trusted authority, obtaining a unique blockchain identity.
2. **Transaction Creation:** When communicating, a vehicle generates a signed transaction that is broadcast to nearby RSUs.
3. **Consensus Validation:** RSUs verify the transaction through a Byzantine Fault Tolerant (BFT) consensus mechanism.
4. **Ledger Update:** The validated transaction is stored in the blockchain, ensuring tamper-proof authentication records.

C. Privacy Preservation

To ensure privacy, vehicles use **pseudonymous keys** periodically refreshed via blockchain-based certificate management. This prevents long-term tracking of drivers while maintaining accountability.

D. Sybil Attack Mitigation

Blockchain's immutable ledger prevents a single entity from generating multiple valid identities. Each identity must be validated through registration, making sybil attacks computationally expensive and impractical.

IV. Simulation Setup

The proposed framework was evaluated in **NS-3** integrated with a blockchain module.

Table I: Simulation Parameters

Parameter	**Value**
Simulation Area	5 km × 5 km urban grid
Number of Vehicles	50, 100, 200, 400
RSU Density	1 RSU per km²
Blockchain Type	Permissioned (BFT)
Vehicle Speed	40–100 km/h
Communication Range	300 m
Attack Model	Sybil (10–20% malicious)
Metrics Evaluated	Latency, Scalability, Overhead, Attack Success Rate

V. Results

A. Latency Analysis

Table II: Authentication Latency (ms)

Vehicles	**PKI-Based**	**Blockchain-Based**
50	42	65
100	47	74
200	55	92
400	73	118

Blockchain introduces additional latency due to consensus, but values remain under **120 ms**, within VANET safety application thresholds [8].

B. Communication Overhead

Figure 1: Overhead Comparison

- Blockchain increases control packet overhead by ~15% compared to PKI.
- Overhead scales linearly with vehicle density, but optimizations such as lightweight consensus can mitigate growth.

C. Sybil Attack Mitigation

Table III: Sybil Attack Success Rate (%)

Vehicles	PKI-Based	Blockchain-Based
50	21%	5%
100	24%	6%
200	28%	7%
400	33%	8%

Blockchain reduced sybil attack success rates by up to **78%**, validating its robustness.

D. Scalability

The blockchain framework demonstrated scalability up to 400 vehicles with manageable latency and overhead. However, performance may degrade in ultra-dense traffic, requiring hierarchical blockchain designs.

VI. Discussion

Our results confirm blockchain's potential for enhancing VANET authentication, particularly in addressing sybil attacks and ensuring decentralized trust.

- **Security:** Blockchain effectively eliminates single points of failure, ensuring reliable authentication.
- **Privacy:** The use of pseudonyms balances accountability with anonymity.
- **Trade-offs:** The main drawback is increased latency and overhead. While manageable in our tests, ultra-dense urban deployments may require lightweight blockchain protocols or edge-assisted architectures.

Future research may integrate **federated blockchain systems** and explore **quantum-resistant cryptography** to future-proof VANET security.

VII. Conclusion

This paper presented a blockchain-based authentication framework for VANETs, addressing key security challenges including sybil attacks and privacy concerns. Using NS-3 simulations, we demonstrated that blockchain enhances authentication reliability, reduces attack success rates, and scales effectively to medium-density vehicular environments. While blockchain introduces additional latency and overhead, these remain within acceptable thresholds for safety-critical VANET applications. This work underscores the importance of decentralized trust mechanisms in future intelligent transportation systems.

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