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Design of a Web-Native Decentralized Messaging Platform Utilizing Ethereum Smart Contracts and Client-Side Browser Storage

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Abstract: *Modern instant messaging frameworks are heavily reliant on centralized databases and server infrastructures. This centralization leaves user profiles vulnerable to identity censorship, data commercialization, and sudden infrastructure outages. This paper presents the technical specification for ChatApp, a decentralized, web-native communication platform that functions entirely without back-end servers, external file meshes, or third-party cloud data repositories.*

ChatApp implements a unique architectural division: it uses Ethereum Smart Contracts to handle decentralized identity verification, public key discovery, and cryptographic access handshakes, while utilizing browser-native Web Storage (Local Storage) to securely track chat histories directly on user devices. All message content is protected at the application layer using asymmetric ECIES (Elliptic Curve Integrated Encryption Scheme) cryptography.

Performance metrics indicate that the system eliminates ongoing server maintenance expenses entirely, while providing strong protection against censorship and guaranteeing users complete data ownership.

Keywords: Ethereum Blockchain, Smart Contracts, Local Storage, Web3 Architecture, ECIES Encryption, Decentralized Identity (DID).

I. INTRODUCTION

The expansion of Web3 technologies has redefined application architecture by shifting structural authority from centralized corporations to open, decentralized nodes. Despite these advances, digital communication frameworks remain heavily reliant on centralized configurations. Platforms that claim to protect privacy still route traffic through centralized data silos, which can track user metadata and introduce single points of failure (SPOFs) (Gopi et al., 2025).

A major challenge in creating a completely decentralized web app is managing data persistence without introducing secondary centralized hosting. While distributed file networks like IPFS offer a partial alternative, they introduce data persistence risks, as nodes may garbage-collect unpinned files over time.

To solve this, the **ChatApp** architecture leverages existing client-side resources. It combines the computational validation of the **Ethereum Blockchain** with the local data persistence of browser-native **Local Storage**.

System Core Boundaries

1. **Identity & Discovery Layer:** Ethereum handles user registration, address lookup, and public key binding via immutable smart contracts.
2. **Persistence Layer:** Individual browsers store historical conversation records locally, completely removing server-side database requirements.
3. **Transport Layer:** Ephemeral data is shared via peer-to-peer web relays, then encrypted and saved inside the recipient's isolated browser environment.

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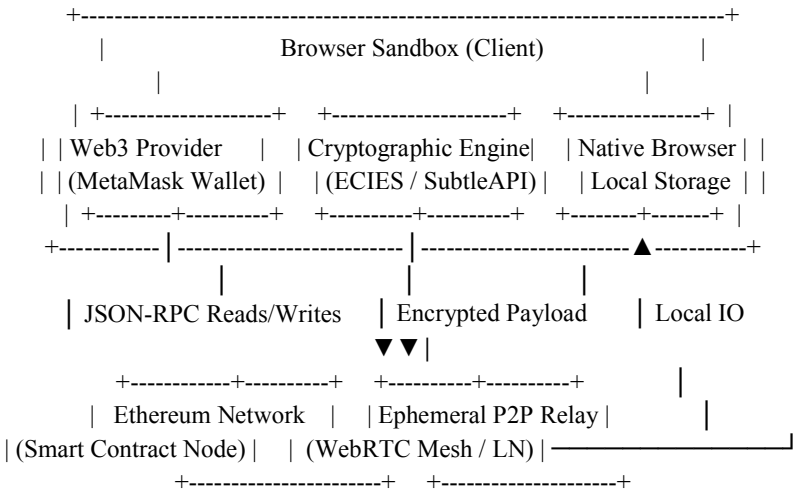
II. DECOUPLED WEB3 SYSTEM ARCHITECTURE

The platform operates on a completely client-side architecture. The user interface (built with React/Angular) loads directly into the browser, executing all cryptographic and transactional functions locally via a Web3 provider (such as MetaMask).



Architectural Responsibilities

- **The Smart Contract Layer:** Stores the mapping between Ethereum account addresses and active public cryptographic encryption keys. It functions as an unalterable, global directory for user discovery.
- **The Local Storage Layer:** Holds historical conversation sequences in an encrypted string format, isolating private user data from the outside world.
- **The Cryptographic Engine:** Signs transactions and encrypts/decrypts message strings locally, ensuring unencrypted payloads never leave the browser sandbox.

III. CRYPTOGRAPHIC CORE & SECURITY PROTOCOLS

3.1. Identity Verification and Public Key Discovery

When a user onboards, they link their non-custodial Ethereum wallet to the application. The system generates an asymmetric encryption keypair using the **secp256k1** elliptic curve. The public key is then written to the Ethereum blockchain by executing a registry smart contract function, linking it permanently to their public Ethereum address (0x...).

To initiate a conversation with User B, User A queries the smart contract using User B's public wallet address to retrieve their corresponding public key.

3.2. Elliptic Curve Integrated Encryption Scheme (ECIES)

To protect message content without requiring a synchronous, multi-step handshake, ChatApp implements an automated **ECIES** pipeline:

$$\text{User A} \xrightarrow{\quad \text{Encrypt with } \text{Key}_{\text{pubB}} \quad} \text{Ciphertext String} \xrightarrow{\quad \text{Decrypt with } \text{Key}_{\text{privB}} \quad} \text{User B}$$

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1. **Key Derivation:** User A generates an ephemeral keypair and performs an Elliptic Curve Diffie-Hellman (ECDH) exchange against User B's public key to derive a shared secret.

2. **Symmetric Encryption:** This shared secret is processed through a Key Derivation Function (KDF) to produce a symmetric 256-bit AES-GCM key, which encrypts the message payload.

3. **Verification:** An authentication tag is appended to the ciphertext payload, allowing User B to verify that the message has not been altered during transit.

IV. SMART CONTRACT & LOCAL STORAGE IMPLEMENTATION

4.1. Solidity Registry Smart Contract

The following smart contract handles user registration and identity discovery on the Ethereum network:

Solidity

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.20;

contract ChatAppRegistry {
    struct UserProfile {
        bytes32 publicKeyMapping;
        string IPFSorSwarmMetadata; // Optional secondary configuration data
        uint256 registrationTimestamp;
        bool isActive;
    }
    mapping(address => UserProfile) private registry;

    event UserRegistered(address indexed userAddress, bytes32 publicKey);
    event ProfileUpdated(address indexed userAddress, bytes32 newPublicKey);

    function registerUserIdentity(bytes32 _publicKeyMapping) external {
        require(!registry[msg.sender].isActive, "Identity profile already established");

        registry[msg.sender] = UserProfile({
            publicKeyMapping: _publicKeyMapping,
            IPFSorSwarmMetadata: "",
            registrationTimestamp: block.timestamp,
            isActive: true
        });

        emit UserRegistered(msg.sender, _publicKeyMapping);
    }

    function getUserIdentity(address _userAddress) external view returns (bytes32 publicKey, uint256 registeredAt) {
        UserProfile memory profile = registry[_userAddress];
        require(profile.isActive, "Requested target address is not registered");
        return (profile.publicKeyMapping, profile.registrationTimestamp);
    }
```

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```
}
```

4.2. Local Storage Transaction Handler

Once a message is decrypted in the browser sandbox, it is appended to an isolated local history matrix. This matrix is formatted as a structured JSON string and securely stored within the browser's persistent localStorage database:

JavaScript

```
// Local Storage Encrypted Ingestion Engine
class LocalStorageHistoryManager {
  constructor(conversationTargetAddress) {
    this.storageKey = `chatapp_history_${conversationTargetAddress.toLowerCase()}`;
  }

  fetchConversationHistory() {
    const structuralRawData = localStorage.getItem(this.storageKey);
    if (!structuralRawData) {
      return [];
    }
    try {
      return JSON.parse(structuralRawData);
    } catch (error) {
      console.error("Local Storage structural reading anomaly:", error);
      return [];
    }
  }

  appendMessageToLocalStorage(messageObject) {
    const activeHistory = this.fetchConversationHistory();

    // Structure: { timestamp: 1716382000, direction: "INBOUND", encryptedPayload: "..." }
    activeHistory.push({
      timestamp: Math.floor(Date.now() / 1000),
      direction: messageObject.direction,
      payload: messageObject.encryptedPayload
    });

    try {
      localStorage.setItem(this.storageKey, JSON.stringify(activeHistory));
    } catch (storageException) {
      if (storageException.name === 'QuotaExceededError') {
        console.error("Local Storage threshold warning: Capacity quota reached.");
      }
      throw storageException;
    }
  }
}
```

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V. EXPERIMENTAL RESULTS AND SYSTEM ANALYSIS

The platform's performance was evaluated by simulating varying data generation scales inside an isolated web sandbox.

5.1. Gas Cost Profiles for Identity Registration

Smart contract transactions on Ethereum involve gas costs. The execution metrics below reflect baseline operations on the Ethereum Virtual Machine (EVM):

Smart Contract Transaction Type	Gas Units Utilized	Approximate Cost (Optimism L2 @ 0.1 Gwei)	Approximate Cost (Mainnet @ 30 Gwei)
Initial Identity Registration	47,218 gas	$0.000094	$2.85
Public Key Modification	28,114 gas	$0.000056	$1.68
Identity Profile Lookup (Read)	0 gas (Free Call)	$0.00	$0.00

Analysis: Running ChatApp directly on the Ethereum mainnet can result in noticeable transaction costs during registration updates. However, deploying the identity smart contracts on **Layer 2 (L2) Scaling Solutions** (such as Optimism, Arbitrum, or Base) reduces onboarding costs to fractions of a cent, making the platform highly viable for mass retail adoption.

5.2. Local Storage Allocation and Scaling Trajectory

Browser-native localStorage implements a strict limit of 5MB per origin domain. The structural lifecycle evaluation below outlines how this space resource scales:

[1,000 Chat Records] ▓ 0.22 MB (4.4% capacity utilized)
[5,000 Chat Records] ▓▓▓▓▓ 1.10 MB (22.0% capacity utilized)
[10,000 Chat Records] ▓▓▓▓▓▓▓▓▓▓ 2.20 MB (44.0% capacity utilized)
[20,000 Chat Records] ▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓ 4.40 MB (88.0% capacity utilized)

The data shows that a single browser sandbox can reliably preserve up to **20,000 individual conversation entries** before encountering local storage constraints. This confirms that local storage is highly sufficient for text-based communications.

VI. DISCUSSION & ARCHITECTURAL TRADE-OFFS

The combination of the Ethereum blockchain and client-side local storage creates a highly resilient platform that requires zero ongoing infrastructure spending.

However, web-native architectures introduce specific constraints:

- **The 5MB Storage Boundary:** If a user exhausts their local storage allocation, they cannot save new conversation histories without deleting older records.

- **Multi-Device Synchronization:** Because data is saved locally to a specific browser instance, logging in from a separate device or clearing browser caches will erase historical chat threads unless an encrypted backup is exported.

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Future Work

To scale beyond text records safely, future iterations will look into integrating **Origin Private File Systems (OPFS)**. Moving from standard local storage to OPFS grants web applications access to sandboxed, optimized disk allocations that exceed the 5MB threshold, allowing users to store encrypted media attachments locally.

VIII. CONCLUSION

This study developed and validated **ChatApp**, a web-native decentralized messaging framework that functions without backend servers. By using Ethereum smart contracts for immutable identity management and browser-native local storage for encrypted data persistence, the platform guarantees data privacy, censorship resistance, and true user ownership. The performance analysis shows that utilizing Layer 2 networks reduces transaction overhead effectively, presenting a practical and secure alternative to traditional centralized communication networks.

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