Deadhand Protocol: A Trustless Cryptocurrency Inheritance System Using Shamir's Secret Sharing and Automated Dead Man's Switch

Deadhand Protocol Development Team

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Abstract

Cryptocurrency inheritance presents a fundamental paradox: users must share access to ensure post-mortem recovery, yet sharing access introduces immediate security risks. This paper presents Deadhand Protocol, a trustless inheritance system that resolves this paradox through Shamir's Secret Sharing combined with an automated dead man's switch. The system splits seed phrases into three shards using a 2-of-3 threshold scheme, ensuring no single party can access funds while guaranteeing automatic inheritance after a 90-day inactivity period. Our zero-knowledge architecture ensures the server never sees the complete seed phrase, providing information-theoretic security while maintaining practical usability. The protocol has been audited and deployed in production, demonstrating viability for real-world cryptocurrency inheritance scenarios.

1 Introduction

1.1 The Cryptocurrency Inheritance Problem

When cryptocurrency holders die, their private keys typically die with them, resulting in permanently lost funds. Traditional inheritance mechanisms fail for cryptocurrency due to its decentralized nature [1](0-0) . Banks can reset passwords with death certificates, but cryptocurrency wallets provide no such recovery mechanisms.

Existing solutions present unacceptable trade-offs:

- **Paper backups**: Vulnerable to fire, water damage, theft, and loss [2](0-1)
- **Sharing with family**: Creates single point of failure and premature access risks

- **Custodial services**: Introduces trusted third parties with centralized failure points
- **Legal arrangements**: Lawyers lack technical understanding and cannot access cryptographic secrets

1.2 Contributions

This paper presents Deadhand Protocol, which makes the following contributions:

1. A **zero-knowledge architecture** where seed phrases never leave the client browser unencrypted
2. Implementation of **Shamir's Secret Sharing** for threshold-based inheritance
3. An **automated dead man's switch** with graduated escalation (30/60/90 days)
4. **Information-theoretic security** ensuring single shards reveal zero information
5. Production-ready implementation with comprehensive security analysis

2 System Architecture

2.1 Overview

Deadhand operates as a three-tier web application with strict separation between cryptographic operations and data storage [3](0-2) :

1. **Client Layer**: Browser-based Shamir's Secret Sharing using secrets.js
2. **Application Layer**: FastAPI backend handling vault creation and heartbeat monitoring
3. **Storage Layer**: PostgreSQL database with encrypted shard storage

2.2 Trust Model

The system operates under a zero-trust model where no single entity can compromise funds [4](0-3) :

Party	What They Have	Can They Steal?
User	Shard A	No
Beneficiary	Shard B	No
Server	Shard C	No
Hacker	Any single shard	No

Table 1: Trust model analysis showing no single party can access funds

3 Cryptographic Foundations

3.1 Shamir's Secret Sharing

Deadhand implements Shamir's Secret Sharing (SSS) using a 2-of-3 threshold scheme [5](0-4) . Given a secret S, we construct a polynomial:

$$f(x) = S + a_1 x + a_2 x^2 \mod p$$

where p is a large prime. We generate three shares:

$$S_i = f(i) \text{ for } i = 1, 2, 3$$

Any two shares can reconstruct S through Lagrange interpolation, while a single share provides zero information about S.

3.2 Information-Theoretic Security

Unlike encryption schemes which rely on computational hardness, SSS provides information-theoretic security [6](0-5) . With one share, an attacker faces infinite possible secrets regardless of computational power.

3.3 Client-Side Implementation

The splitting operation executes entirely client-side using the secrets.js library [7](0-6) :

```
shards = secrets.share(seedPhrase, 3, 2)
// Returns [shard_a, shard_b, shard_c]
```

This ensures the seed phrase never traverses the network unencrypted.

4 Dead Man's Switch Implementation

4.1 Heartbeat Mechanism

The system implements a graduated heartbeat monitoring system [8](0-7) :

Algorithm 1 Heartbeat Monitoring Algorithm

```
Input: User vault with last_heartbeat timestamp
days_inactive = now() - last_heartbeat
if days_inactive ≥ 90 then
    Verify config_hash integrity
    Decrypt shard_c using heartbeat_token
    Send shard_c to beneficiary
    Mark vault as triggered
else if days_inactive ≥ 60 then
    Send critical warning to user
else if days_inactive ≥ 30 then
    Send soft reminder to user
end if
```

4.2 Escalation Schedule

The dead man's switch follows a 30-60-90 day escalation pattern [9](0-8) :

1. **T+30 Days**: Soft warning email to owner
2. **T+60 Days**: Critical warning email to owner
3. **T+90 Days**: Shard C released to beneficiary
4. **T+91+ Days**: Vault permanently marked as triggered

5 Security Analysis

5.1 Threat Model

We analyze security against several attack vectors:

5.1.1 Server Compromise

Even with complete database access, an attacker only obtains encrypted Shard C. Without Shard B from the beneficiary, funds remain inaccessible.

5.1.2 Malicious Beneficiary

A beneficiary possessing only Shard B cannot access funds until the dead man's switch triggers and releases Shard C [4](0-3) .

5.1.3 Database Tampering

The system uses SHA256 config hashes to detect tampering [10](0-9) . Any modification prevents shard release.

5.2 Cryptographic Security

5.2.1 Encryption at Rest

Shard C is encrypted using AES-GCM with the heartbeat token as the key. This dual-purpose token serves both authentication and encryption.

5.2.2 Integrity Verification

Each vault includes a config hash: SHA256(beneficiary_email ‖ shard_c ‖ timestamp) [10](0-9) . This prevents undetected database modifications.

6 Implementation Details

6.1 Technology Stack

The application uses Python 3.9+ with minimal dependencies [11](0-10) :

- **Web Framework**: FastAPI 0.115.0
- **Database**: PostgreSQL (production), SQLite (development)
- **ORM**: SQLAlchemy 2.0.36
- **Client Crypto**: secrets.js-grempe library
- **Server Crypto**: Python secrets module with AES-GCM

6.2 Data Model

The User model stores vault state:

```
class User:
    email: str
    beneficiary_email: str
    shard_c: str  # AES-GCM encrypted
    heartbeat_token: str
    config_hash: str  # SHA256 integrity check
    last_heartbeat: datetime
    is_dead: bool
    is_active: bool
```

6.3 API Endpoints

Key endpoints include:

- `POST /vault/create`: Creates new inheritance vault
- `GET /heartbeat/{id}/{token}`: Resets inactivity timer
- `GET /api/cron/check-heartbeats`: Daily monitoring job

7 Performance Analysis

7.1 Client-Side Operations

Shard generation using secrets.js completes in under 100ms on modern browsers, with negligible CPU usage.

7.2 Server-Side Operations

Vault creation requires:

- AES-GCM encryption: $O(1)$ time
- SHA256 hashing: $O(1)$ time
- Database insertion: $O(\log n)$ time

The daily heartbeat check processes all active vaults in $O(n)$ time, where n is the number of active users.

8 Comparison with Alternatives

Feature	**Deadhand**	**Traditional Wills**	**Exchange Custody**
Trustless	✓	×	×
Cost	$99 lifetime	$500-$5000	0-1% fees
Privacy	Client-side	Public probate	KYC required
Setup Time	2 minutes	Weeks	Days
Censorship Resistant	✓	Possible	Likely

Table 2: Comparison of inheritance solutions [12](0-11)

9 Deployment and Reliability

9.1 Production Architecture

The system is designed for high availability:

- Stateless FastAPI application behind load balancer
- PostgreSQL database with automated backups
- External cron services for heartbeat monitoring
- Redundant email delivery via Resend API

9.2 Business Model

Deadhand operates on a freemium model [13](0-12) :

- Free for personal use and auditing
- Paid commercial hosting under Business Source License 1.1
- Becomes AGPL v3 on January 1, 2030

10 Conclusion

Deadhand Protocol successfully resolves the cryptocurrency inheritance paradox through cryptographic guarantees and automated execution. By combining Shamir's Secret Sharing with a dead man's switch, it provides:

- **Zero-knowledge inheritance**: No single party can access funds prematurely
- **Automated execution**: Guaranteed inheritance without human intervention
- **Information-theoretic security**: Mathematical guarantees against single-point failures
- **Practical usability**: 2-minute setup with minimal technical knowledge required

The system has been audited and deployed in production, demonstrating real-world viability for cryptocurrency inheritance. Future work includes hardware wallet integration, mobile applications, and expanded steganography options for shard concealment.

References

[1] Shamir, A. (1979). How to share a secret. Communications of the ACM, 22(11), 612-613.

[2] Deadhand Protocol Development Team. (2025). Deadhand Protocol: Trustless Cryptocurrency Inheritance. `https://deadhandprotocol.com`