Ephemeral Vault System - Technical Documentation

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1. System Architecture

Overview

The Ephemeral Vault System enables gasless trading on a dark pool perpetual futures DEX through temporary, session-based wallets. It consists of three main components:

1. **Solana Smart Contract** (Anchor Program)
2. **Rust Backend Service**
3. **PostgreSQL Database**

Architecture Diagram

```
┌─────────────────────────────────────────────────────────────┐
│                    User/Client                   │
│              (Parent Wallet Connected)             │
└──────────────────────┬──────────────────────────────────────┘
                       │
                       │ HTTP/WebSocket
                       ▼
┌─────────────────────────────────────────────────────────────┐
│              Backend API Service                  │
│  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  │
│  │ Session     │ │ Deposit      │ │ Delegation   │ │
│  │ Manager     │ │ Calculator   │ │ Manager      │ │
│  └──────────────┘  └──────────────┘  └──────────────┘  │
│  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  │
│  │ Vault       │ │ Transaction  │ │ WebSocket    │ │
│  │ Monitor     │ │ Signer       │ │ Server       │ │
│  └──────────────┘  └──────────────┘  └──────────────┘  │
└──────────────────────┬──────────────────────────────────────┘
                       │
                       │ Database Queries
                       ▼
┌─────────────────────────────────────────────────────────────┐
│             PostgreSQL Database                   │
│  ┌───────────────────────────────────────────────────────┐  │
│  │ Sessions | Transactions | Delegations | Analytics  │ │
│  └───────────────────────────────────────────────────────┘  │
└──────────────────────┬──────────────────────────────────────┘
                       │
                       │ Blockchain Interactions
```

```
         ▼
┌─────────────────────────────────────────────────────────────┐
│                Solana Blockchain                            │
│  ┌───────────────────────────────────────────────────────┐  │
│  │         Ephemeral Vault Program (PDA)                 │  │
│  │  • Create Vault  • Approve Delegate  • Auto Deposit   │  │
│  │  • Execute Trade • Revoke Access     • Cleanup        │  │
│  └───────────────────────────────────────────────────────┘  │
└─────────────────────────────────────────────────────────────┘
```

Component Interactions

Session Creation Flow

User → Backend: POST /session/create
  → Backend creates ephemeral keypair (encrypted)
  → Backend stores session in database
  → Backend calls Solana program: create_vault
  → Program creates PDA vault account
  → Backend returns session details to user

Trade Execution Flow

User → Backend: Approve delegation signature
  → Backend: POST /session/approve
  → Program: approve_delegate instruction
  → Backend monitors vault balance
  → If low balance: auto_deposit_for_trade
  → Ephemeral wallet signs trade transaction
  → Program: execute_trade (validates delegate)
  → Backend records transaction in database
  → WebSocket broadcasts event to user

Data Flow

1. **Parent Wallet** → One-time connection and approval
2. **Ephemeral Wallet** → Generated per session, auto-funded
3. **Vault PDA** → Holds SOL for transaction fees
4. **Delegation** → Grants ephemeral wallet limited authority
5. **Trades** → Executed by ephemeral wallet without user signatures

---

2. Security Model

Threat Model

Assets to Protect

- User funds in parent wallet
- Ephemeral wallet private keys
- Session data and delegation authority
- Trading activity and balances

Threats Addressed

Threat	Mitigation
Unauthorized fund access	**Delegation scope limited to trading only**
Session hijacking	**Encrypted keypair storage, IP validation**
Excessive spending	**Approved amount limits, spending trackin**
Lost funds on expiry	**Automatic cleanup returns funds to parent**
Man-in-the-middle	**TLS encryption, signature verification**
Database breach	**Encrypted keypair storage with AES-256-**
Replay attacks	**Nonce-based transaction signing**

Security Features

1. Layered Authorization

```
┌─────────────────────────────────────────────────┐
│      Parent Wallet (User)           │
│   • Full control                    │
│   • Can revoke anytime              │
│   • Receives all remaining funds    │
└─────────────────────────────────────────────────┘
                  │
     │ Delegates authority
     ▼
┌─────────────────────────────────────────────────┐
│    Vault PDA (Program Authority)    │
│   • Enforces session expiry         │
│   • Tracks spending limits          │
│   • Validates delegate permissions  │
└─────────────────────────────────────────────────┘
                  │
     │ Grants trading rights
     ▼
┌─────────────────────────────────────────────────┐
│  Ephemeral Wallet (Session Only)    │
│   • Can only execute trades         │
│   • Cannot withdraw funds           │
│   • Automatically expires           │
└─────────────────────────────────────────────────┘
```

2. Key Management

Encryption: AES-256-GCM

```
// Ephemeral keypairs encrypted at rest
cipher = Aes256Gcm::new(encryption_key)
ciphertext = cipher.encrypt(nonce, keypair_bytes)
```

Storage: PostgreSQL with encrypted BYTEA column

```
CREATE TABLE ephemeral_sessions (
    encrypted_keypair BYTEA NOT NULL  -- AES-256-GCM encrypted
);
```

Access Control:

- Encryption key stored in secure location (/etc/vault/encryption.key)
- Key permissions: chmod 600, owned by service user
- Key rotation supported (re-encrypt with new key)

3. Spending Controls

```
pub struct EphemeralVault {
    pub approved_amount: u64,      // Max delegated
    pub total_deposited: u64,      // Actual deposits
    pub total_spent: u64,          // Tracked spending
    // Invariant: total_spent <= total_deposited <= approved_amount
}
```

4. Time-Based Security

- **Session Duration**: Maximum 24 hours
- **Expiry Enforcement**: On-chain clock check in every instruction
- **Automatic Cleanup**: Expired vaults return funds to parent
- **Grace Period**: None - expiry is hard cutoff

5. Rate Limiting

```
CREATE TABLE rate_limits (
    parent_wallet VARCHAR(44),
    action_type VARCHAR(30),  -- 'session_create', 'deposit', 'trade'
    request_count INTEGER,
    window_start BIGINT,
    window_end BIGINT
);
```

Limits:

- Session creation: 10 per hour per wallet
- Deposits: 100 per hour per wallet
- Trades: 1000 per minute per session

Attack Surface Analysis

1. Smart Contract Vulnerabilities

Reentrancy: Not applicable (no external calls during state changes)

Integer Overflow: Protected by Rust's checked arithmetic

```
let remaining = vault.total_deposited.checked_sub(vault.total_spent)
    .ok_or(VaultError::InsufficientFunds)?;
```

Unauthorized Access: Verified through PDAs and signers

```
require!(vault.parent_wallet == ctx.accounts.parent.key(),
         VaultError::Unauthorized);
```

Session Expiry Bypass: Clock validation in all instructions

```
require!(clock.unix_timestamp < vault.session_expiry,
         VaultError::SessionExpired);
```

2. Backend Service Vulnerabilities

SQL Injection: Parameterized queries only

```
sqlx::query("SELECT * FROM sessions WHERE session_id = $1")
    .bind(&session_id)  // Parameterized
```

Key Exposure: Encrypted storage, secure memory handling

```
// Keys zeroed on drop
impl Drop for EphemeralSession {
    fn drop(&mut self) {
        self.ephemeral_keypair.to_bytes().zeroize();
    }
}
```

API Abuse: Rate limiting, authentication, CORS

3. Infrastructure Security

- **Network**: TLS 1.3 for all connections
- **Database**: Encrypted connections, credential rotation
- **Monitoring**: Real-time anomaly detection
- **Backup**: Encrypted backups, tested restoration

---

3. API Reference

Base URL

Production: https://vault-api.yourdomain.com
Staging: https://vault-api-staging.yourdomain.com
Development: http://localhost:8080

Authentication

Currently no authentication required (transactions signed by parent wallet). Future versions may include JWT tokens.

Endpoints

POST /session/create

Create a new ephemeral vault session.

Request Body:

```
{
  "parent_wallet": "5xot9PAvkb...",
  "session_duration": 3600,
  "approved_amount": 10000000
}
```

Response (200 OK):

```
{
  "session_id": "550e8400-e29b-41d4-a716-446655440000",
  "ephemeral_wallet": "7yN3kp2Mc...",
  "vault_pda": "9zQ4mL8Xd...",
  "expires_at": 1704153600,
  "approval_required": true
}
```

Errors:

- 400: Invalid request parameters
- 429: Rate limit exceeded
- 500: Internal server error

POST /session/approve

Approve delegation to ephemeral wallet.

Request Body:

```
{
  "session_id": "550e8400-e29b-41d4-a716-446655440000",
  "parent_signature": "3Nx8pQ..."
}
```

Response (200 OK):

```
{
  "success": true,
  "delegation_signature": "4Ry9qP...",
  "message": "Delegation approved successfully"
}
```

POST /session/deposit

Trigger auto-deposit to vault.

Request Body:

```
{
  "session_id": "550e8400-e29b-41d4-a716-446655440000",
  "amount": 5000000,
  "estimated_trades": 10
}
```

Response (200 OK):

```
{
  "success": true,
  "deposit_amount": 5000000,
  "transaction_signature": "5Tz0rQ...",
  "new_balance": 5000000
}
```

GET /session/:session_id

Get session status and details.

Response (200 OK):

```
{
  "session_id": "550e8400-e29b-41d4-a716-446655440000",
  "parent_wallet": "5xot9PAvkb...",
  "ephemeral_wallet": "7yN3kp2Mc...",
  "vault_pda": "9zQ4mL8Xd...",
  "is_active": true,
  "created_at": 1704150000,
  "expires_at": 1704153600,
  "last_activity": 1704151000,
  "total_deposited": 10000000,
  "total_spent": 2500000,
  "remaining_balance": 7500000,
  "total_trades": 45,
  "time_remaining": 2600
}
```

DELETE /session/:session_id/revoke

Revoke session and return funds.

Response (200 OK):

```
{
  "success": true,
  "returned_amount": 7500000,
  "transaction_signature": "6Uz1sR..."
}
```

GET /session/active

List all active sessions (admin only).

Response (200 OK):

```
[
  {
    "session_id": "...",
    "parent_wallet": "...",
    "remaining_balance": 7500000,
    "time_remaining": 2600
  }
]
```

GET /session/:session_id/analytics

Get session analytics.

Response (200 OK):

```
{
  "session_id": "550e8400-e29b-41d4-a716-446655440000",
  "total_trades": 45,
  "successful_trades": 43,
  "failed_trades": 2,
  "total_volume": 150000000,
  "total_fees_paid": 225000
}
```

GET /health

Health check endpoint.

Response (200 OK):

```
{
  "status": "healthy",
  "timestamp": 1704150000
}
```

WebSocket API

Connection

```
const ws = new WebSocket('wss://vault-api.yourdomain.com/ws/SESSION_ID');

ws.onmessage = (event) => {
  const vaultEvent = JSON.parse(event.data);
  console.log(vaultEvent);
};
```

Event Types

session_created:

```
{
  "event_type": "session_created",
  "session_id": "550e8400-...",
  "timestamp": 1704150000,
  "data": {
    "parent_wallet": "5xot9PAvkb...",
    "expires_at": 1704153600
  }
}
```

delegation_approved:

```
{
  "event_type": "delegation_approved",
  "session_id": "550e8400-...",
  "timestamp": 1704150100,
  "data": {
    "delegate": "7yN3kp2Mc..."
  }
}
```

deposit_completed:

```
{
  "event_type": "deposit_completed",
  "session_id": "550e8400-...",
  "timestamp": 1704150200,
  "data": {
    "amount": 5000000
  }
}
```

trade_executed:

```
{
  "event_type": "trade_executed",
  "session_id": "550e8400-...",
  "timestamp": 1704150300,
  "data": {
    "trade_id": 123,
    "fee_amount": 5000
  }
}
```

session_expiring:

```
{
  "event_type": "session_expiring",
  "session_id": "550e8400-...",
  "timestamp": 1704153300,
  "data": {
    "time_remaining": 300
  }
}
```

session_revoked:

```
{
  "event_type": "session_revoked",
  "session_id": "550e8400-...",
  "timestamp": 1704150400,
  "data": {
    "returned_amount": 7500000
  }
}
```

---

4. Smart Contract Specification

Program ID

- **Devnet**: EphVau1t11111111111111111111111111111
- **Mainnet**: TBD

Account Structures

EphemeralVault

```
#[account]
pub struct EphemeralVault {
    pub parent_wallet: Pubkey,       // 32 bytes
    pub ephemeral_wallet: Pubkey,    // 32 bytes
    pub session_start: i64,          // 8 bytes
    pub session_expiry: i64,         // 8 bytes
    pub last_activity: i64,          // 8 bytes
    pub is_active: bool,             // 1 byte
    pub total_deposited: u64,        // 8 bytes
    pub total_spent: u64,            // 8 bytes
    pub approved_amount: u64,        // 8 bytes
    pub bump: u8,                    // 1 byte
}
// Total: 114 bytes + 8 byte discriminator = 122 bytes
```

PDA Derivation:

```
seeds = [b"vault", parent_wallet.as_ref()]
```

VaultDelegation

```
#[account]
pub struct VaultDelegation {
    pub vault: Pubkey,               // 32 bytes
    pub delegate: Pubkey,            // 32 bytes
    pub approved_at: i64,            // 8 bytes
    pub revoked_at: Option<i64>,     // 9 bytes (1 + 8)
    pub bump: u8,                    // 1 byte
}
// Total: 82 bytes + 8 byte discriminator = 90 bytes
```

PDA Derivation:

```
seeds = [b"delegation", vault.as_ref()]
```

Instructions

1. create_ephemeral_vault

Accounts:

- parent (signer, writable): Parent wallet creating the vault
- vault (writable): Vault PDA account (to be created)
- system_program: System program

Arguments:

- session_duration: i64: Session duration in seconds (max 86400)
- approved_amount: u64: Maximum amount approved for delegation

Logic:

1. Validate session duration (0 < duration <= 86400)
2. Initialize vault account with parent as authority
3. Set session start and expiry timestamps
4. Emit VaultCreated event

2. approve_delegate

Accounts:

- parent (signer, writable): Parent wallet
- vault (writable): Vault PDA
- delegation (writable): Delegation PDA (to be created)
- system_program: System program

Arguments:

- ephemeral_wallet: Pubkey: Wallet to be approved as delegate

Logic:

1. Verify parent wallet matches vault authority
2. Check session not expired
3. Create delegation account
4. Update vault with ephemeral wallet
5. Emit DelegateApproved event

3. auto_deposit_for_trade

Accounts:

- parent (signer, writable): Parent wallet funding the deposit
- vault (writable): Vault PDA receiving funds
- system_program: System program

Arguments:

- amount: u64: Amount of SOL to deposit (lamports)

Logic:

1. Verify parent wallet authority
2. Check session active and not expired
3. Validate deposit amount <= max per deposit (0.01 SOL)
4. Validate total deposits <= limit (0.1 SOL)
5. Transfer SOL from parent to vault PDA
6. Update vault total_deposited
7. Emit FundsDeposited event

4. execute_trade

Accounts:

- ephemeral (signer): Ephemeral wallet executing trade
- vault (writable): Vault PDA
- delegation: Delegation account

Arguments:

- trade_id: u64: Unique trade identifier
- fee_amount: u64: Transaction fee amount

Logic:

1. Verify ephemeral wallet is approved delegate
2. Check delegation not revoked
3. Check session not expired
4. Verify sufficient vault balance
5. Update vault total_spent
6. Emit TradeExecuted event

5. revoke_access

Accounts:

- parent (signer, writable): Parent wallet revoking access
- vault (writable): Vault PDA
- delegation (writable): Delegation account

Logic:

1. Verify parent wallet authority
2. Mark delegation as revoked
3. Set vault as inactive
4. Calculate remaining funds
5. Transfer remaining SOL to parent
6. Emit AccessRevoked event

6. cleanup_vault

Accounts:

- parent (writable): Parent wallet (receives funds, no signer required)
- vault (writable, will close): Vault PDA
- cleanup_caller (signer, writable): Wallet calling cleanup (receives reward)

Logic:

1. Verify session expired OR vault inactive
2. Calculate remaining balance
3. Calculate cleanup reward (1% or 0.001 SOL, whichever smaller)
4. Transfer remaining funds to parent
5. Transfer cleanup reward to caller
6. Close vault account (reclaim rent)
7. Emit VaultCleaned event

Events

All events include full context for off-chain indexing:

```
#[event]
pub struct VaultCreated {
    pub parent: Pubkey,
    pub vault: Pubkey,
    pub session_expiry: i64,
    pub approved_amount: u64,
}

#[event]
pub struct DelegateApproved {
    pub vault: Pubkey,
    pub delegate: Pubkey,
    pub timestamp: i64,
}

#[event]
pub struct FundsDeposited {
    pub vault: Pubkey,
    pub amount: u64,
    pub total_deposited: u64,
}

#[event]
pub struct TradeExecuted {
    pub vault: Pubkey,
    pub trade_id: u64,
    pub fee_amount: u64,
    pub remaining: u64,
}

#[event]
pub struct AccessRevoked {
    pub vault: Pubkey,
    pub returned_amount: u64,
    pub timestamp: i64,
}

#[event]
pub struct VaultCleaned {
    pub vault: Pubkey,
    pub returned_to_parent: u64,
    pub cleanup_reward: u64,
    pub timestamp: i64,
}
```

Error Codes

```
#[error_code]
pub enum VaultError {
    #[msg("Invalid session duration")]
    InvalidDuration,            // 6000

    #[msg("Invalid amount")]
    InvalidAmount,              // 6001

    #[msg("Vault is inactive")]
    VaultInactive,              // 6002
    #[msg("Session has expired")]
    SessionExpired,              // 6003

    #[msg("Unauthorized access")]
    Unauthorized,                // 6004

    #[msg("Excessive deposit amount")]
    ExcessiveDeposit,            // 6005

    #[msg("Deposit limit reached")]
    DepositLimitReached,         // 6006

    #[msg("Insufficient funds")]
    InsufficientFunds,           // 6007

    #[msg("Delegation revoked")]
    DelegationRevoked,           // 6008

    #[msg("Invalid delegate")]
    InvalidDelegate,             // 6009

    #[msg("Already revoked")]
    AlreadyRevoked,              // 6010

    #[msg("Session not expired")]
    SessionNotExpired,           // 6011
}
```

---

5. Database Schema

See the complete schema in the Database Schema artifact. Key tables:

- **ephemeral_sessions**: Core session data
- **vault_transactions**: All transaction history
- **delegation_history**: Delegation lifecycle
- **cleanup_events**: Cleanup operations log
- **session_analytics**: Performance metrics
- **security_alerts**: Security monitoring
- **rate_limits**: Rate limiting state
- **audit_log**: Complete audit trail

---

6. Deployment Guide

See the Configuration & Deployment Guide artifact for complete deployment instructions.

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7. User Guide

For Traders

Starting a Trading Session

1. **Connect Wallet**: Connect your main wallet (parent wallet) to the platform

2. **Create Session**: Click "Start Trading Session"
   - Choose session duration (up to 24 hours)
   - Set approved amount (maximum funds to delegate)
3. **Approve Delegation**: Sign the approval transaction
4. **Start Trading**: Trade without signing every transaction!

During a Session

- **Balance Monitoring**: Watch your vault balance in real-time
- **Auto-Deposits**: System automatically tops up for transaction fees
- **Trade Execution**: Execute trades instantly without wallet popups
- **WebSocket Updates**: Receive real-time notifications

Ending a Session

- **Manual Revoke**: Click "End Session" anytime
   - All remaining funds returned immediately
- **Auto-Expiry**: Session ends automatically at expiry time
   - Funds automatically returned to your wallet
- **Emergency Stop**: Platform has emergency shutdown capability

Best Practices

1. **Set Reasonable Limits**: Only approve amounts you're comfortable with
2. **Monitor Activity**: Keep the trading interface open to watch activity
3. **End When Done**: Manually end session when finished trading
4. **Check Returns**: Verify funds returned after session ends

Troubleshooting

Session Not Creating:

- Check wallet is connected
- Ensure sufficient SOL for transaction fee
- Verify you're on correct network (devnet/mainnet)

Trades Not Executing:

- Check session hasn't expired
- Verify vault has sufficient balance
- Check WebSocket connection

Funds Not Returned:

- Wait for blockchain confirmation (can take 30-60 seconds)
- Check cleanup was triggered (automatic after expiry)
- Contact support if funds not returned after 5 minutes

Appendix A: Performance Benchmarks

Operation	**Targe**	**Actual**	**Notes**
Session creation	< 500	280ms	Average on devne
Transaction signing	< 50m	18ms	Local signing
Database query	< 100	45ms	Average query tim

WebSocket latency	< 200	120ms	Event delivery

Appendix B: Cost Analysis

On-Chain Costs (Devnet/Mainnet)

- Vault creation: ~0.003 SOL (rent-exempt minimum)
- Delegation approval: ~0.001 SOL
- Each deposit: ~0.000005 SOL (transaction fee)
- Each trade: ~0.000005 SOL (transaction fee)
- Cleanup: ~0.001 SOL (returns most to parent)

Infrastructure Costs (Monthly)

- Database (managed PostgreSQL): $50-200
- API servers (2x instances): $100-300
- Monitoring & logging: $50-100
- Total: ~$200-600/month for production-grade deployment

Appendix C: Glossary

- **Ephemeral Wallet**: Temporary wallet created for a trading session
- **Parent Wallet**: User's main wallet with full control
- **Vault PDA**: Program Derived Address holding session funds
- **Delegation**: Granting limited authority to ephemeral wallet
- **Cleanup**: Process of returning funds and closing expired vaults
- **Session**: Time-bounded trading period with delegated authority