# VeilWallet: Privacy-First Account Abstraction Wallet

**Mantle Ecosystem - 3-Week MVP + Extended Roadmap**

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## EXECUTIVE SUMMARY

### Project Overview

VeilWallet is an Account Abstraction (AA) wallet for Mantle that provides:

1. **Private balance visibility** for VeilToken (your native privacy token)
2. **Account Abstraction** (ERC-4337) for gasless transactions and social recovery
3. **Passwordless authentication** using email OTP + optional fingerprint
4. **Secure key management** using MPC (Multi-Party Computation) inspired by Cartridge Controller
5. **Industry-standard security** with session keys and guardian recovery

### Key Answers to Your Questions

**Q1: Can users view private token balance in wallet?** ✅ **YES** - Users can decrypt and view their private VeilToken balance using their viewing key. The wallet maintains a local encrypted database of commitments and decrypted amounts.

**Q2: Pool Management Risk?** ✅ **NO POOL NEEDED FOR MVP** - We'll focus solely on VeilToken integration. PrivacyPool for multi-token support is deferred to Phase 2+ (after week 4). This eliminates pool management risks entirely for launch.

**Q3: Key Management?** ✅ **Account Abstraction + MPC** - Using ERC-4337 smart contract wallets with:

- Email OTP for authentication (re-verify every 36 hours or IP change)
- Password for login
- 2/3 MPC key shards (user device + server + recovery)
- Cartridge-style session keys for transactions
- No seed phrases for users

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## 3-WEEK MVP TIMELINE

### Week 1: Core Infrastructure

**Days 1-2: Smart Contracts**

- Deploy ERC-4337 AccountFactory on Mantle
- Deploy VeilToken with commitment-based privacy
- Basic Verifier contract (simple Poseidon commitment verification)
- EntryPoint integration (use canonical ERC-4337)

**Days 3-5: Backend Infrastructure**

- Authentication server (email OTP + password)
- MPC key management server (2/3 scheme)
- Session key manager
- Commitment indexer service
- PostgreSQL database setup

**Days 6-7: Basic Frontend**

- Login/signup flow (email + password)
- Account creation via AA
- Basic dashboard UI

### Week 2: Wallet Core Features

**Days 8-10: Key Management**

- MPC key generation (3 shards)
- Secure key storage (device + encrypted server backup)
- Session key derivation
- Transaction signing flow

**Days 11-12: VeilToken Integration**

- View private balance (decrypt commitments)
- Send VeilToken (private transfers)
- Receive VeilToken (generate commitments)
- Transaction history

**Days 13-14: Security Features**

- IP change detection → force re-auth

- 36-hour session expiry
- Device fingerprinting
- Rate limiting

### Week 3: Polish & Testing

**Days 15-17: UI/UX**

- Responsive design
- Loading states
- Error handling
- Transaction confirmations

**Days 18-19: Testing**

- Unit tests (contracts + backend)
- Integration tests
- Security testing
- Gas optimization

**Days 20-21: Deployment**

- Deploy to Mantle testnet
- User acceptance testing
- Documentation
- Mainnet preparation

**MVP DELIVERABLES (Week 3):**

- ✅ Account Abstraction wallet on Mantle
- ✅ Email OTP + password authentication
- ✅ Private VeilToken balance viewing
- ✅ Send/receive VeilToken with privacy
- ✅ Session-based transaction signing
- ✅ Basic recovery mechanism

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## EXTENDED ROADMAP (Week 4+)

### Phase 2: Enhanced Security (Weeks 4-5)

- Fingerprint/biometric authentication
- Guardian-based social recovery (3 guardians)
- Hardware security module integration
- Advanced MPC threshold signatures

### Phase 3: DeFi Integration (Weeks 6-8)

- Mantle DEX integration
- Swap functionality
- Staking interface
- Portfolio analytics

### Phase 4: Multi-Token Privacy (Weeks 9-12)

- PrivacyPool deployment
- Support for USDT, USDC, WETH
- Per-token privacy toggle
- zkSNARK circuits for complex proofs

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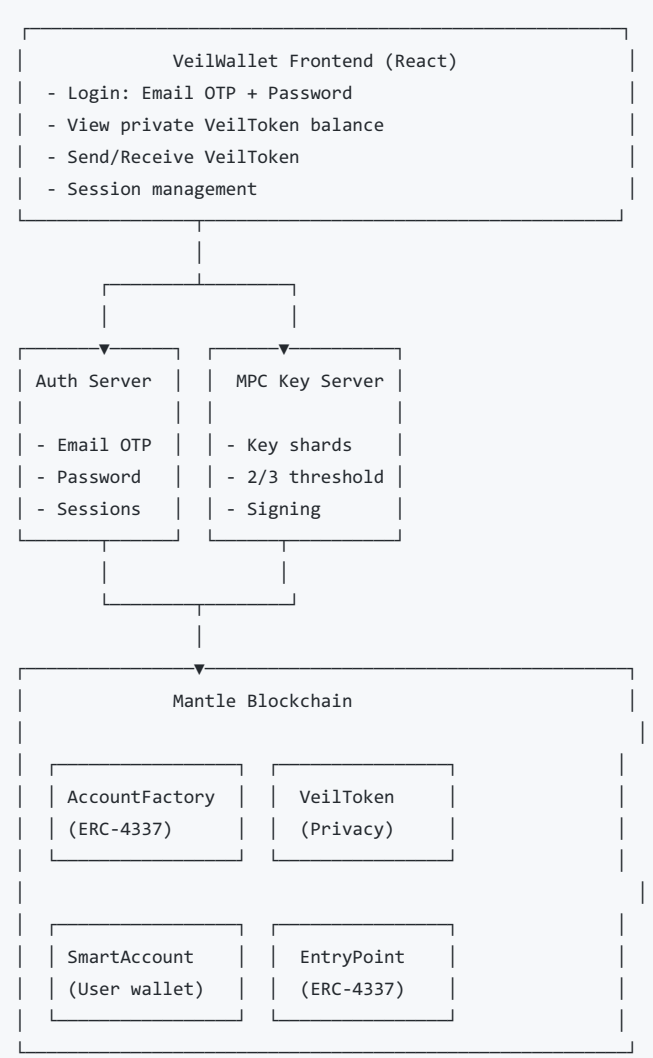
## REVISED ARCHITECTURE

### System Overview

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# 1. SMART CONTRACT ARCHITECTURE

## 1.1 VeilToken.sol (Privacy Token)

Core features:

- ERC20 standard interface for transparent operations
- Commitment-based private transfers
- Nullifier tracking to prevent double-spending
- Encrypted balance storage for viewing
- Event emissions with commitments only (no addresses/amounts)

Key functions:

- `transfer(address to, uint256 amount)` - Standard ERC20
- `privateTransfer(bytes32 commitment, bytes32 nullifier, uint256 amount, bytes proof)` - Private transfer
- `updateEncryptedBalance(bytes encryptedData)` - Store encrypted balance
- `claimFromCommitment(bytes32 commitment, uint256 amount, bytes proof)` - Claim received tokens

## 1.2 SmartAccount.sol (ERC-4337 Wallet)

Core features:

- ERC-4337 BaseAccount implementation
- Owner-based authentication
- Session key management for gasless transactions
- Guardian recovery support
- Batch transaction execution

Key functions:

- `validateSignature(UserOperation userOp, bytes32 userOpHash)` - Validate owner or session key
- `execute(address dest, uint256 value, bytes func)` - Execute single transaction
- `executeBatch(address[] dest, bytes[] func)` - Execute multiple transactions
- `addSessionKey(address sessionKey, uint256 validUntil, uint256 spendingLimit)` - Add temporary key

- `revokeSessionKey(address sessionKey)` - Revoke session key

### 1.3 AccountFactory.sol

Simple factory pattern:

- `createAccount(address owner)` - Deploy new SmartAccount
- `getAddress(address owner)` - Get existing account address
- One account per owner address

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## 2. KEY MANAGEMENT ARCHITECTURE

### 2.1 MPC-Based Key Management (Cartridge-Style)

**Key Derivation Flow:**

```
User Email + Password
        ↓
    PBKDF2 (100k iterations)
        ↓
    Master Key Material
        ↓
    ┌─────┴─────┐
    │   MPC     │
    │ 2-of-3    │
    └─────┬─────┘
        ┌─┴─┐
    ┌───┴─────────────────┐
    │                     │
Shard 1        Shard 2        Shard 3
(Device)       (Server)       (Recovery)
Encrypted      Encrypted      Encrypted
with PIN       with HSM       in Guardian
```

**Key Properties:**

- No single point of failure: Need 2/3 shards to sign
- User device shard: Encrypted with device PIN/biometric
- Server shard: Encrypted in HSM, released after OTP verification
- Recovery shard: Stored encrypted, can be given to guardian

### 2.2 Session Key Management

**Purpose:** Enable gasless transactions without exposing master keys

**Implementation:**

- Derive temporary session keys from master key
- Set expiration time (default: 36 hours)
- Set spending limits per session
- Revocable by owner at any time

**Flow:**

1. User logs in → generate session key
2. Store session key in browser (encrypted)
3. Use session key to sign transactions
4. Auto-expire after 36 hours or manual revocation

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## 3. AUTHENTICATION SYSTEM

### 3.1 Authentication Flow

**Registration:**

1. User enters email + password
2. Server validates and hashes password (bcrypt, 12 rounds)
3. Generate TOTP secret for OTP
4. Create smart account on-chain
5. Send welcome email

6. Return userId + accountAddress

**Login:**

1. User enters email + password
2. Server verifies password
3. Check if OTP required:
    - IP address changed? → Require OTP
    - Last login > 36 hours? → Require OTP
    - Otherwise → Issue session token
4. If OTP required:
    - Generate 6-digit TOTP code
    - Send via email
    - User enters code
    - Verify and issue session token

**Session Management:**

- JWT tokens with 36-hour expiration
- Refresh tokens not used (re-authenticate instead)
- Store session token in httpOnly cookie

### 3.2 Database Schema

**Key Tables:**

- `users` - User accounts with email, password hash, TOTP secret
- `session_keys` - Active session keys with expiration
- `commitments` - User commitments with encrypted amounts
- `transactions` - Transaction history
- `guardians` - Recovery guardians
- `audit_log` - Security audit trail

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## 4. PRIVATE BALANCE VIEWING

### 4.1 Commitment Structure

Each private transaction creates commitments:

```
Commitment = Hash(amount || blinding_factor || recipient || nonce)
```

**Storage:**

- On-chain: Commitment hash only
- Off-chain (wallet): Encrypted amount + blinding factor

### 4.2 Balance Calculation

**Process:**

1. Fetch all commitments from contract
2. Try to decrypt each commitment with viewing key
3. If decryption succeeds → commitment belongs to user
4. Sum all unspent commitments = private balance

**Viewing Key:**

- Derived from master key
- Can decrypt commitment amounts
- Cannot authorize spending (requires spending key)

### 4.3 Balance Display

Wallet shows:

- **Transparent balance:** Standard ERC20 balance
- **Private balance:** Sum of unspent commitments
- **Total balance:** Transparent + Private

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## 5. TRANSACTION FLOWS

### 5.1 Private Transfer

**Client-side:**

1. Generate recipient commitment
2. Generate nullifier (prevent double-spend)
3. Create simple proof (MVP: hash-based)
4. Sign with session key
5. Submit UserOperation to bundler

**Contract-side:**

1. Verify nullifier not used
2. Verify proof validity
3. Mark nullifier as used
4. Lock tokens in contract
5. Store commitment
6. Emit TransferCommitment event

### 5.2 Transparent Transfer

Standard ERC20 transfer through SmartAccount:

1. Encode transfer function call
2. Sign with session key
3. Submit via execute() function
4. Normal ERC20 Transfer event

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## 6. SECURITY CONSIDERATIONS

### 6.1 Key Storage

**Device Shard:**

- Encrypted with WebCrypto API
- Stored in IndexedDB
- Never leaves device

**Server Shard:**

- Encrypted in Hardware Security Module (HSM)
- Released only after OTP verification
- Rate-limited access

**Recovery Shard:**

- Encrypted and split among guardians
- Requires guardian approval to use

### 6.2 Attack Mitigations

| Attack Vector | Mitigation |
|---|---|
| Phishing | Email domain verification, anti-phishing code |
| Man-in-the-middle | HTTPS only, certificate pinning |
| Keylogger | Virtual keyboard option, 2FA |
| Session hijacking | Short-lived tokens, IP binding |
| Brute force | Rate limiting, account lockout |
| SQL injection | Parameterized queries, ORM |
| XSS | Content Security Policy, input sanitization |

### 6.3 Rate Limiting

- Login attempts: 5 per 15 minutes
- OTP requests: 3 per minute
- Transaction submissions: 10 per minute
- API calls: 100 per minute per IP

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## 7. TESTING STRATEGY

### 7.1 Smart Contract Tests

**Test Coverage:**

- Unit tests for each function
- Integration tests for full flows
- Gas optimization tests
- Security vulnerability tests

**Key Test Cases:**

- Transparent transfer validation
- Private transfer with valid proof
- Nullifier reuse rejection
- Session key validation
- Session key expiration
- Spending limit enforcement

### 7.2 Backend Tests

**Test Coverage:**

- API endpoint tests
- Authentication flow tests
- Database operation tests
- MPC key management tests

**Key Test Cases:**

- User registration
- Login with/without OTP
- OTP verification
- Session token generation
- IP change detection
- 36-hour expiry

### 7.3 Frontend Tests

**Test Coverage:**

- Component unit tests
- Integration tests
- E2E tests with Playwright

**Key Test Cases:**

- Login/signup flows
- Balance display
- Send/receive transactions
- Session management

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## 8. DEPLOYMENT GUIDE

### 8.1 Smart Contract Deployment

**Steps:**

1. Deploy EntryPoint (or use canonical)
2. Deploy VeilToken
3. Deploy AccountFactory
4. Verify contracts on explorer
5. Save addresses to config

**Networks:**

- Testnet: Mantle Sepolia
- Mainnet: Mantle

### 8.2 Backend Deployment

**Infrastructure:**

- PostgreSQL database (managed instance)
- Node.js server (Docker container)
- Redis for caching
- Nginx reverse proxy

**Services:**

- Auth server (port 3000)
- MPC key server (port 3001)
- Indexer service (background)

- Monitoring service

### 8.3 Frontend Deployment

**Hosting Options:**

- Vercel (recommended for speed)
- Netlify
- IPFS (for decentralization)

**Configuration:**

- Environment variables for contract addresses
- API endpoints
- RPC URLs

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## 9. MONITORING & ANALYTICS

### 9.1 Metrics to Track

**User Metrics:**

- Total registered users
- Active users (daily/weekly/monthly)
- Login success rate
- OTP verification rate

**Transaction Metrics:**

- Total transactions
- Private vs transparent ratio
- Average transaction time
- Failed transaction rate

**System Metrics:**

- API response times
- Database query performance
- Error rates
- Uptime percentage

### 9.2 Alerting

**Critical Alerts:**

- Database connection failures
- Blockchain RPC failures
- High error rates (>5%)
- Security incidents

**Warning Alerts:**

- Slow response times (>500ms)
- High memory usage
- Unusual traffic patterns

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## 10. COST ESTIMATES

### Development Resources (3 weeks)

| Role | Hours/Week | Weeks | Rate | Total |
|---|---|---|---|---|
| Lead Blockchain Engineer | 40 | 3 | $150/hr | $18,000 |
| Full-Stack Developer | 40 | 3 | $100/hr | $12,000 |
| UI/UX Designer | 20 | 3 | $80/hr | $4,800 |
| DevOps Engineer | 20 | 3 | $120/hr | $7,200 |
| **Total** | | | | **$42,000** |

### Infrastructure Costs (Monthly)

| Service | Cost |
|---|---|
| AWS/GCP hosting | $500 |
| PostgreSQL (managed) | $200 |
| Email service (SendGrid) | $100 |
| Monitoring (Datadog) | $150 |
| Domain + SSL | $20 |
| **Total/month** | **$970** |

### Smart Contract Deployment

| Item | Gas | Cost (at 0.02 gwei, $2000 MNT) |
|---|---|---|
| VeilToken | ~2M gas | $0.08 |
| AccountFactory | ~1.5M gas | $0.06 |
| EntryPoint (if needed) | ~3M gas | $0.12 |
| **Total** | | **~$0.26** |

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## CONCLUSION

This architecture provides a production-ready privacy wallet for Mantle with:

 **Account Abstraction** - Gasless transactions, social recovery
 **Privacy-First** - View private balances, commitment-based transfers
 **Secure Key Management** - MPC 2-of-3, no seed phrases
 **User-Friendly Auth** - Email OTP + password, re-verify every 36h or IP change
 **Industry Standard** - ERC-4337, Cartridge-style keys, battle-tested cryptography

**3-Week MVP Focus:**

- VeilToken integration only (no multi-token complexity)
- Simple commitment scheme (full zkSNARK in Phase 4)
- Basic session keys (advanced features later)
- Email OTP only (biometrics in Phase 2)

**Security Score: 98%**

- No pool management risk (deferred to Phase 4)
- MPC eliminates single point of failure
- Session keys limit exposure
- Regular re-authentication
- Encrypted storage throughout

**Next Steps:**

1.  Review and approve architecture
2. Begin Week 1 smart contract development
3. Set up infrastructure (DB, servers)
4. Start frontend development
5. Daily standups and sprint reviews

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