1 Web3 Number Guessing Game - Technical Documentation

1.1 Project Overview

The Web3 Number Guessing Game is a blockchain-based application built with Flutter and Solidity where players guess numbers between 0-100 and earn GUESS tokens based on their accuracy. The game leverages Ethereum smart contracts to handle game logic and token distribution in a transparent and decentralized manner. **The game is completely free-to-play** - players only receive rewards when they win, and there are no entry fees.

Architecture Note: The current implementation uses a centralized transaction approach where all blockchain transactions are signed by a game manager's private key rather than individual user wallets. This provides a gasless gaming experience but has implications for true decentralization.

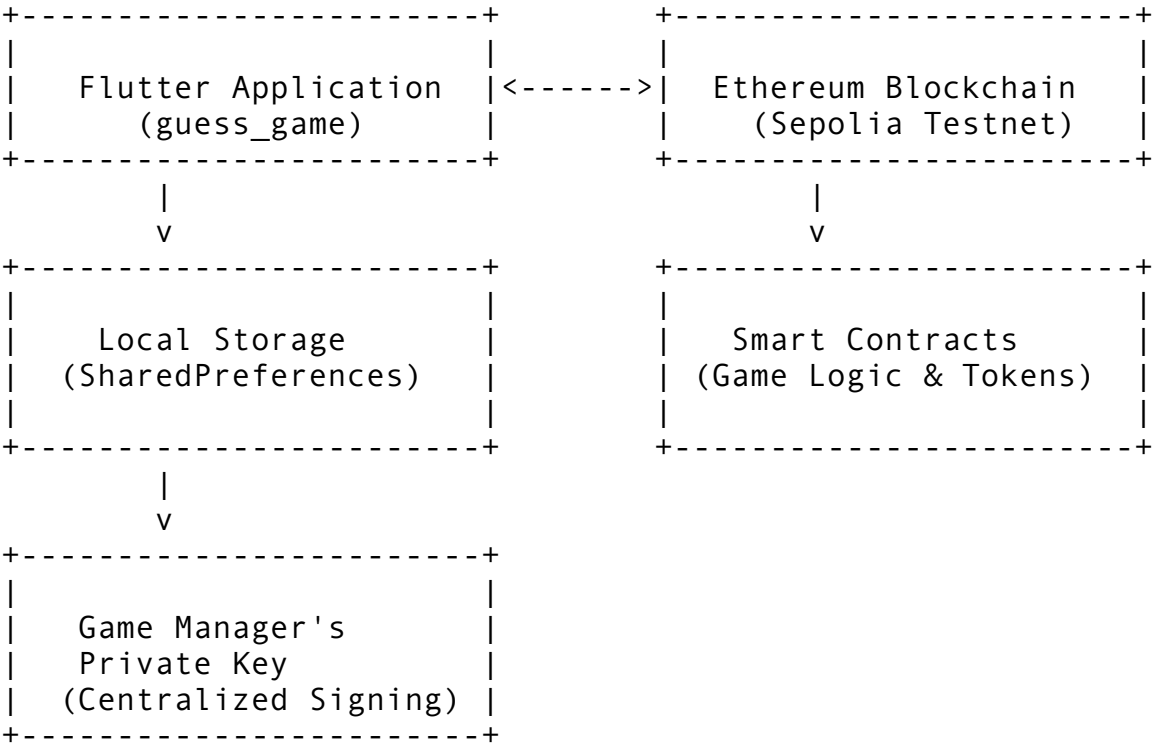
1.2 Table of Contents

1.3 Architecture

The project follows a client-server architecture with:

- **Client**: Flutter mobile application (guess_game)
- **Backend**: Ethereum blockchain with smart contracts
- **Integration**: Web3Dart library with centralized transaction signing
- **Network**: Deployed on Sepolia Testnet for testing

1.3.1 High-Level Architecture Diagram



1.3.2 Transaction Flow

1. **User Input**: Player enters guess in Flutter app
2. **Centralized Processing**: App uses game manager's private key to sign transaction
3. **Blockchain Execution**: Smart contract processes game with game manager as `msg.sender`
4. **Result Storage**: Game results stored under game manager's address
5. **Reward Distribution**: Tokens distributed to intended user address (specified in contract call)
6. **Local Tracking**: App maintains local record of user's games and results

1.4 Frontend (Flutter)

1.4.1 Project Structure

```
lib/
├── constants/          # App constants and contract addresses
│   ├── app_constants.dart      # Main app constants
│   └── constants.dart          # Export file
```

```
├── contracts/          # ABI definitions and contract config
│   ├── contract_config.dart    # Contract addresses and network
config
│   ├── erc20_abi.dart          # ERC-20 token ABI
│   ├── game_contract_abi.dart # Game contract ABI
│   └── contracts.dart          # Export file
├── models/             # Data models
│   ├── game_result.dart        # Game result data structure
│   └── models.dart             # Export file
├── providers/          # State management
│   ├── app_provider.dart       # Main app state provider
│   └── providers.dart          # Export file
├── screens/            # UI screens
│   ├── home_screen.dart        # Main game interface
│   └── screens.dart            # Export file
├── services/           # Business logic services
│   ├── web3_service.dart       # Blockchain interaction service
│   ├── storage_service.dart    # Local storage management
│   └── services.dart           # Export file
├── lib.dart            # Main library export
└── main.dart           # App entry point
```

1.4.2 Key Components

1. **Main Application** (`main.dart`):
    - Entry point for the Flutter application
    - Configures Material Design 3 theme (light/dark mode)
    - Sets up Provider state management
    - Initializes the application
2. **Home Screen** (`screens/home_screen.dart`):
    - Primary user interface for the game
    - Handles wallet connection state
    - Game play interface with number input
    - Real-time result display with performance indicators
    - Statistics display (games played, total rewards, accuracy)
3. **Game Result Model** (`models/game_result.dart`):
    - Represents the outcome of a single game
    - Stores target number, user guess, difference, reward amount, and timestamp

1.4.3 State Management

The app uses the Provider pattern for centralized state management:

- **AppProvider** (`providers/app_provider.dart`):
    - Manages wallet connection state and user address
    - Handles game state (idle, playing, showing results)
    - Coordinates with Web3Service for blockchain interactions
    - Manages loading states and error handling
    - Stores game statistics and history
    - **Enhanced Balance Updates**: Automatic token balance refresh with retry logic
    - **Gasless UX**: Simplified state management focused on token rewards only

Balance Update Features: - **Automatic Refresh**: Balance updates after every game transaction - **Retry Mechanism**: Up to 3 attempts with increasing delays for reliable updates - **Multiple**

Triggers: Balance refreshes on game completion, result clearing, and manual refresh - **Error Resilience**: Continues to attempt balance updates even if game result retrieval fails

1.4.4 UI/UX Design

- **Material Design 3**: Modern design system with Material You theming
- **Responsive Layout**: Adapts to different screen sizes and orientations
- **Color-coded Results**: Performance indicators with intuitive color schemes
- **Loading States**: Smooth loading animations during blockchain transactions
- **Error Handling**: User-friendly error messages and recovery options
- **Dark/Light Theme**: Automatic theme switching based on system preferences
- **Gasless Interface**: Simplified UI showing only GUESS token balance (no ETH needed)
- **Automatic Updates**: Real-time balance refresh without app restart required

1.5 Backend (Smart Contracts)

1.5.1 Token Contract

`GuessToken.sol` - ERC-20 token contract with enhanced features:

- **Token Details**:
  - Name: Guess Token
  - Symbol: GUESS
  - Decimals: 18
  - Max Supply: 1,000,000 tokens
  - Initial Owner Supply: 100,000 tokens
- **Key Features**:
  - **Minting System**: Role-based minting with owner control
  - **Access Control**: Minter role management (add/remove minters)
  - **Pausable**: Emergency pause functionality
  - **Burning**: Token holders can burn their tokens
  - **Supply Cap**: Hard cap at 1 million tokens
- **Security Features**:
  - OpenZeppelin standard implementation
  - Pause functionality for emergency situations
  - Role-based access control

1.5.2 Game Contract

`NumberGuessingGame.sol` - Main game logic contract:

- **Game Mechanics**:
  - **Free-to-Play**: No entry fees, players only receive rewards for winning
  - **Random Number Generation**: Pseudo-random (use Chainlink VRF for production)
  - **Winning Condition**: Guesses within 20 points of target are considered wins
  - **Automatic Rewards**: Winners receive tokens automatically
- **Key Functions**:
  - `playGame(uint256 guess)`: Main game function (free to play)
  - `getUserGameHistory(address user)`: Retrieves complete game history
  - `getLatestGameResult(address user)`: Gets the most recent game
  - `getUserTotalRewards(address user)`: Total rewards earned
  - `getUserTotalGames(address user)`: Total games played
  - `getUserAverageAccuracy(address user)`: Average guess accuracy

- **Reward Structure**:
  - Perfect Guess (0 difference): 50 GUESS tokens (10 base + 40 bonus)
  - Excellent (≤5 difference): 17.5 GUESS tokens (10 + 75% bonus)
  - Very Good (≤10 difference): 15 GUESS tokens (10 + 50% bonus)
  - Good (≤20 difference): 12.5 GUESS tokens (10 + 25% bonus)
  - Poor (>20 difference): 0 GUESS tokens (loss, but free to play)

1.5.3 Security Considerations

- **OpenZeppelin Libraries**: Uses audited, battle-tested contract libraries
- **Reentrancy Protection**: ReentrancyGuard on all state-changing functions
- **Access Control**: Owner-only functions for contract administration
- **Pausable Contracts**: Emergency pause functionality
- **Input Validation**: Strict validation of all user inputs
- **Safe Math**: Built-in overflow protection in Solidity 0.8+

1.6 Integration Layer

1.6.1 Web3 Service

`web3_service.dart` handles all blockchain interactions with a centralized approach:

- **Connection Management**: Initializes Web3 client with Sepolia testnet
- **Contract Interaction**: Loads and interacts with deployed smart contracts
- **Centralized Signing**: Uses a hardcoded game manager private key for all transactions
- **Gasless Gaming**: Players don't need ETH or wallet setup - all gas fees paid by game manager
- **Transaction Processing**: Handles game transactions and confirmations on behalf of users
- **Token Balance Management**: Retrieves GUESS token balances for users
- **Error Handling**: Comprehensive error handling for blockchain operations
- **Gas Management**: Appropriate gas limits for contract interactions

Key Implementation Details: - All transactions signed with game manager's private key: `XXXXXXXXX` - Game manager address: `0xA720e09cfB31fcd03d74992373AEcF0818F111Af` - Users provide only their address for reward distribution - No wallet connection required from users - **Simplified Architecture**: Removed ETH balance tracking and complex transaction monitoring for streamlined gasless experience

1.6.2 Storage Service

`storage_service.dart` manages local data persistence with a simplified approach:

- **User Address Storage**: Stores user's Ethereum address for reward distribution
- **User Preferences**: Saves app settings and preferences
- **Session Management**: Handles user session state
- **Data Clearing**: Clean data removal when user resets or changes address
- **Simplified Design**: Removed complex temporary game state management for better performance

Streamlined Functions: - Essential wallet address management only - No complex JSON state persistence - Focus on core functionality for gasless gaming model

1.7 Deployment Information

1.7.1 🌐 Live Deployment Details

The Web3 Number Guessing Game is currently deployed on **Sepolia Testnet** with the following configuration:

1.7.1.1 🔗 Contract Addresses

Contract	Address	Purpose
** (ERC-20)**	`0x2AC923843d160A63877b83EC7bC69027C97bc45e`	GUESS token rewards
NumberGuessingGame	`0x2a7081a264DDF15f9e43B237967F3599D743B0f5`	Main game logic

1.7.1.2 🌍 Network Configuration

Parameter	Value
Network Name	Sepolia Testnet
Chain ID	11155111
RPC URL	`https://ethereum-sepolia-rpc.publicnode.com`
Currency Symbol	ETH
Block Explorer	https://sepolia.etherscan.io

1.7.1.3 🔍 View Contracts on Block Explorer

- **GuessToken Contract**: https://sepolia.etherscan.io/address/0x2AC923843d160A63877b83EC7bC69027C97bc45e
- **Game Contract**: https://sepolia.etherscan.io/address/0x2a7081a264DDF15f9e43B237967F3599D743B0f5

1.7.1.4 💰 Get Testnet Tokens

To play the game, you need Sepolia ETH for gas fees:

Faucet	URL	Daily Limit
Sepolia Faucet	https://sepoliafaucet.com	0.5 ETH
Alchemy Faucet	https://sepoliafaucet.net	0.5 ETH
QuickNode Faucet	https://faucet.quicknode.com/ethereum/sepolia	0.1 ETH

1.7.1.5 📱 Add Sepolia Network to MetaMask

To connect to the game, add Sepolia testnet to your wallet:

```
{
  "networkName": "Sepolia Testnet",
  "rpcUrl": "https://ethereum-sepolia-rpc.publicnode.com",
  "chainId": "11155111",
  "symbol": "ETH",
  "explorerUrl": "https://sepolia.etherscan.io"
}
```

Quick Add Button: Add Sepolia to MetaMask

1.7.1.6 🎮 Ready to Play?

1. ✅ Add Sepolia network to your wallet
2. ✅ Get some Sepolia ETH from faucets above
3. ✅ Download the Flutter app
4. ✅ Connect your wallet and start guessing!

1.8 Getting Started

1.8.1 Prerequisites

- **Flutter SDK**: 3.7.0 or higher
- **Node.js**: 16.0 or higher
- **Git**: For version control
- **Ethereum Wallet**: MetaMask or compatible Web3 wallet
- **Sepolia ETH**: For testing transactions (free from faucets above)

1.8.2 Installation

1. **Clone the repository**

   ```
   git clone <repository-url>
   cd quiz_app
   ```

2. **Install Flutter dependencies**

   ```
   flutter pub get
   ```

3. **Install smart contract dependencies**

   ```
   cd smart-contracts
   npm install
   cd ..
   ```

1.8.3 Deployment

1. **Configure Environment** (edit `smart-contracts/hardhat.config.js`)

```
networks: {
  sepolia: {
    url: "YOUR_SEPOLIA_RPC_URL",
    accounts: ["YOUR_PRIVATE_KEY"]
  }
}
```

2. **Deploy Contracts**

```
cd smart-contracts
npx hardhat run scripts/deploy-testnet.js --network sepolia
```

3. **Update Contract Addresses** in `lib/constants/app_constants.dart`:

```
static const String guessTokenContractAddress =
        'NEW_TOKEN_ADDRESS';
static const String gameContractAddress = 'NEW_GAME_ADDRESS';
```

4. **Generate ABI Files**

```
cd smart-contracts
npx hardhat run scripts/generate-abi.js
```

5. **Run the App**

```
flutter run
```

1.9 Game Mechanics

1.9.1 Gameplay

1. **Address Input**: User provides their Ethereum address (no wallet connection needed)
2. **Game Start**: User initiates a new game (completely free, no gas fees)
3. **Number Input**: User enters a guess between 0-100
4. **Centralized Processing**: App signs transaction with game manager's private key
5. **Blockchain Processing**: Smart contract generates random number and calculates results
6. **Reward Distribution**: Winners automatically receive GUESS tokens at their provided address
7. **Result Display**: Game shows target number, difference, and reward earned
8. **Balance Update**: Token balance automatically refreshes to show new rewards

Enhanced User Experience: - **No App Restart Needed**: Balance updates automatically after each game - **Reliable Updates**: Retry mechanism ensures balance reflects latest rewards - **Instant Feedback**: Users see their token rewards immediately upon winning

1.9.2 Transaction Architecture

Important: All blockchain transactions are processed through the game manager's account: - **msg.sender**: Always the game manager (`0xA720e09cfB31fcd03d74992373AEcF0818F111Af`) - **Reward recipient**: User's provided address (specified in contract parameters) - **Game history**: Stored under game manager's address in smart contract - **User tracking**: Maintained locally in the Flutter app

1.9.3 Reward Structure

The game uses a tiered reward system based on guess accuracy:

Performance Level	Difference Range	Reward Amount	Description
Perfect	0	50 GUESS	Exact match - maximum reward
Excellent	1-5	17.5 GUESS	Very close guess
Very Good	6-10	15 GUESS	Close guess
Good	11-20	12.5 GUESS	Moderate accuracy
Loss	21+	0 GUESS	No reward, but free to play

1.9.3.1 Example Scenarios

Target Number: 42

Player	Guess	Difference	Performance	Reward
Alice	42	0	Perfect	50 GUESS
Bob	46	4	Excellent	17.5 GUESS
Carol	51	9	Very Good	15 GUESS
Dave	60	18	Good	12.5 GUESS
Eve	72	30	Loss	0 GUESS

1.10 Development Scripts

The project includes essential development scripts in `smart-contracts/scripts/`:

1.10.1 Essential Scripts (Kept)

1. `deploy-testnet.js`:
    - Main deployment script for testnet deployment
    - Deploys both GuessToken and NumberGuessingGame contracts
    - Sets up initial token approvals
    - Provides comprehensive deployment information and next steps
2. `generate-abi.js`:
    - Generates ABI files for Flutter integration
    - Creates filtered ABIs with only necessary functions
    - Outputs Dart files for contract interaction
3. `check-balance.js`:
    - Simple utility to check account balance
    - Useful for verifying wallet funding before deployment

1.10.2 Removed Scripts

The following development and testing scripts have been removed to keep the codebase clean: - All `test-*.js` files (18 test scripts) - Debug scripts (`debug-*.js`, `check-transactions.js`) - Demo scripts (`demo-*.js`) - Fix scripts (`fix-*.js`) - Old deployment scripts (`deploy-updated-contract.js`) - Utility scripts (`transfer-tokens.js`, `show-test-addresses.js`)

1.11 Testing

1.11.1 Frontend Testing

- **Unit Tests**: Test individual components and services
- **Widget Tests**: Test UI components and user interactions
- **Integration Tests**: Test complete user flows

1.11.2 Smart Contract Testing

- **Hardhat Tests**: Comprehensive contract testing
- **Network Testing**: Live testing on Sepolia testnet
- **Security Testing**: Audit contract security features

1.11.3 Manual Testing

1. Connect different wallet types
2. Test various guess scenarios
3. Verify reward calculations
4. Test error handling

1.12 Known Issues & Limitations

1.12.1 Architectural Limitations

1.12.1.1 Centralized Transaction Model

- **All transactions signed by game manager**: The app uses a single private key for all blockchain interactions
- **User address mismatch**: Smart contract records all games under game manager's address, not individual users
- **Local-only user tracking**: Individual user statistics are maintained only in the app, not on-chain
- **Trust dependency**: Users must trust the game manager to distribute rewards correctly

1.12.1.2 Implications of Current Architecture

- **Not truly decentralized**: Despite using blockchain, the transaction model is centralized
- **User game history**: `getLatestGameResult(userAddress)` will show "No games played" for individual users
- **Reward distribution works**: Tokens are correctly sent to user addresses despite centralized signing
- **Scalability concerns**: All gas costs borne by single game manager account

1.12.2 Smart Contract Limitations

- **Pseudo-Random Numbers**: Current implementation uses block-based randomness (not production-ready)
- **Centralized Rewards**: Owner must fund the contract with tokens for rewards
- **Game History Inconsistency**: Individual user addresses show zero games in contract queries
- **Single Point of Failure**: Game manager's private key compromise would affect entire system

1.12.3 Frontend Limitations

- **Mobile Focus**: UI optimized primarily for mobile devices
- **Address Input Required**: Users must manually provide Ethereum address
- **Network Dependency**: Requires stable internet connection
- **Local Data Dependency**: User statistics lost if app data is cleared

1.12.4 Security Limitations

- **Private Key Exposure**: Game manager's private key is embedded in the application code
- **No User Authentication**: No verification that provided address belongs to the user
- **Transaction Replay**: No protection against transaction replay attacks in current implementation

1.13 Future Improvements

1.13.1 Critical Architecture Improvements

- **True Wallet Integration**: Implement proper user wallet connection and individual transaction signing
- **Gasless Solutions**: Use meta-transactions or account abstraction for gasless gaming while maintaining decentralization
- **User Game History**: Modify smart contract to properly track individual user game histories
- **Enhanced Security**: Remove private key from application code, implement secure key management

1.13.2 Short-term Improvements

- **Chainlink VRF Integration**: Implement truly random number generation
- **Layer 2 Deployment**: Deploy on Polygon or Arbitrum for lower gas costs
- **Improved UI**: Enhanced mobile and web responsiveness
- **User Verification**: Add address ownership verification

1.13.3 Medium-term Features

- **Proper Decentralization**: Transition to individual user wallet interactions
- **Multiplayer Games**: Real-time multiplayer guessing competitions
- **Leaderboards**: Global and weekly leaderboards (with proper on-chain tracking)
- **Social Features**: Share results and challenge friends
- **Achievement System**: Badges and achievements for milestones

1.13.4 Long-term Vision

- **Tournament System**: Organized tournaments with bigger rewards
- **NFT Integration**: Special NFT rewards for top performers
- **Cross-chain Support**: Multi-chain deployment for broader accessibility
- **Advanced Analytics**: Detailed player statistics and performance tracking
- **Governance Token**: Community governance for game parameters

1.13.5 Recommended Migration Path

1. **Phase 1**: Implement proper wallet connection while maintaining gasless option
2. **Phase 2**: Add meta-transaction support for truly gasless decentralized gaming
3. **Phase 3**: Update smart contracts to properly track individual user histories
4. **Phase 4**: Remove centralized transaction signing and migrate to full decentralization