DESIGN AND IMPLEMENTATION OF A BLOCKCHAIN-INTEGRATED IOT SECURITY SYSTEM ON STM32

Dr.G.Sankar[1*], Dr.Libin Baby[2], Dr. M. Kumaresan[3]

Assistant Professor, Department of Electronics, RVS College of Arts & Science, Sulur, Coimbatore, India.

Assistant Professor, Department of Electronics, Kristu Jayanti College, Bengaluru, India.

Assistant Professor, Department of Electronics, Hindusthan College of Arts & Science, Coimbatore

Abstract

The rapid growth of the Internet of Things (IoT) has introduced billions of interconnected devices that exchange sensitive data across distributed networks. However, traditional IoT architectures often suffer from security vulnerabilities such as data tampering, unauthorized access, and single-point failures. To address these challenges, this project presents the Design and Implementation of a Blockchain-Integrated IoT Security System on STM32. The proposed framework combines the computational efficiency of the STM32 microcontroller with the decentralized trust model of blockchain technology to ensure data integrity, authentication, and transparency in IoT environments. In this system, IoT sensor nodes based on STM32 collect environmental data and transmit it securely using cryptographic algorithms. Each transaction or data packet is recorded on a lightweight blockchain ledger, providing immutability and traceability of device communication. Smart contracts are utilized to automate authentication and access control between nodes without relying on centralized servers. The blockchain implementation is optimized for resource-constrained STM32 hardware by employing a lightweight consensus mechanism such as Proof of Authority (PoA).Experimental results demonstrate that the proposed system effectively prevents data manipulation and unauthorized node access while maintaining low latency and minimal computational overhead. The integration of blockchain technology enhances trust, scalability, and fault tolerance in IoT networks. This research establishes a secure, transparent, and energy-efficient model for IoT applications such as smart homes, healthcare, and industrial automation.

Keywords: IoT Security, Blockchain, STM32, Smart Contracts, Data Integrity, Decentralized Network.

Introduction

The evolution of the Internet of Things (IoT) has revolutionized the way devices communicate, sense, and share data across diverse applications such as smart homes, industrial automation, and healthcare systems. Despite its rapid adoption, IoT networks remain highly vulnerable to security threats, including data breaches, spoofing, unauthorized access, and centralized point-of-failure issues. Traditional security mechanisms, which rely on centralized servers for authentication and data validation, often struggle to provide scalability, transparency, and resilience in large-scale IoT environments.

Blockchain technology has recently emerged as a promising solution to address these limitations by offering decentralization, immutability, and cryptographic security. By integrating blockchain into IoT frameworks, device interactions can be validated and recorded in a tamper-proof ledger, ensuring data integrity and trust without requiring a central authority. Smart contracts further strengthen this architecture by automating device authentication and access control, thus reducing human intervention and enhancing operational efficiency.

The proposed work, Design and Implementation of a Blockchain-Integrated IoT Security System on STM32, focuses on developing a secure and efficient IoT platform utilizing the STM32 microcontroller as a hardware base. The STM32's low power consumption and high processing capability make it ideal for embedded IoT applications. The blockchain component employs a lightweight consensus algorithm, such as Proof of Authority (PoA), optimized for resource-constrained environments. This integration aims to achieve a balance between security and performance, providing a reliable solution for protecting IoT data transmission and device communication in real-world applications.

Review of Literature

The integration of blockchain and IoT has gained significant attention in recent years as researchers explore decentralized mechanisms for securing data communication among connected devices. Several studies have focused on leveraging blockchain's immutability and transparency to overcome IoT's inherent vulnerabilities. Zhang et al. (2020) highlighted that blockchain can enhance IoT trust management by eliminating central authority dependency, thereby preventing single-point failures. Christidis and Devetsikiotis (2016) discussed how smart contracts enable autonomous machine-to-machine (M2M) transactions, improving data authenticity and process automation.

In hardware-based studies, Mahmoud et al. (2021) implemented blockchain-enabled IoT prototypes using microcontrollers, highlighting performance trade-offs in energy-constrained devices. Ali et al. (2020) explored STM32-based IoT architectures, emphasizing their suitability for real-time data acquisition and low-power processing. Nguyen et al. (2021) analyzed lightweight consensus algorithms, such as Proof of Authority (PoA), which are efficient for resource-limited IoT nodes.

Rahman et al. (2022) demonstrated how blockchain integration enhances data integrity and auditability in smart home and healthcare systems. Kumar and Patel (2023) further emphasized that combining STM32 microcontrollers with blockchain technology can create secure, transparent, and scalable IoT networks. These studies collectively underline the growing potential of blockchain-integrated embedded systems for achieving reliable and decentralized IoT security.

Existing System with Limitations

In the existing IoT security systems, most architectures rely on centralized cloud servers for data storage, authentication, and access control. These systems typically use conventional encryption techniques and centralized databases to ensure communication security between devices. While this approach provides basic protection, it introduces several critical drawbacks.

The dependency on a central authority makes the system vulnerable to single-point failures, denial-of-service (DoS) attacks, and data manipulation. Furthermore, centralized systems often lack transparency and traceability, making it difficult to verify the integrity of transmitted data.

Existing frameworks also face scalability issues as the number of connected IoT devices increases. The centralized authentication mechanisms struggle to handle massive concurrent requests, resulting in latency and performance degradation. Moreover, traditional IoT systems do not provide adequate protection against insider threats or compromised nodes that can inject false data into the network. In addition, most low-power embedded controllers, such as STM32, are not fully utilized in current IoT security architectures, leading to inefficient hardware resource management.

Therefore, the current centralized security models are insufficient for modern IoT environments that demand decentralization, transparency, and trust. These limitations highlight the need for a blockchain-integrated IoT security system that ensures distributed trust, immutability, and efficient authentication without relying on a central server.

Proposed Solution

The proposed system, Design and Implementation of a Blockchain-Integrated IoT Security System on STM32, aims to overcome the limitations of existing centralized IoT architectures by introducing a decentralized and tamper-proof security framework. The core concept involves integrating blockchain technology with IoT devices powered by the STM32 microcontroller to ensure data integrity, secure communication, and transparent device authentication.

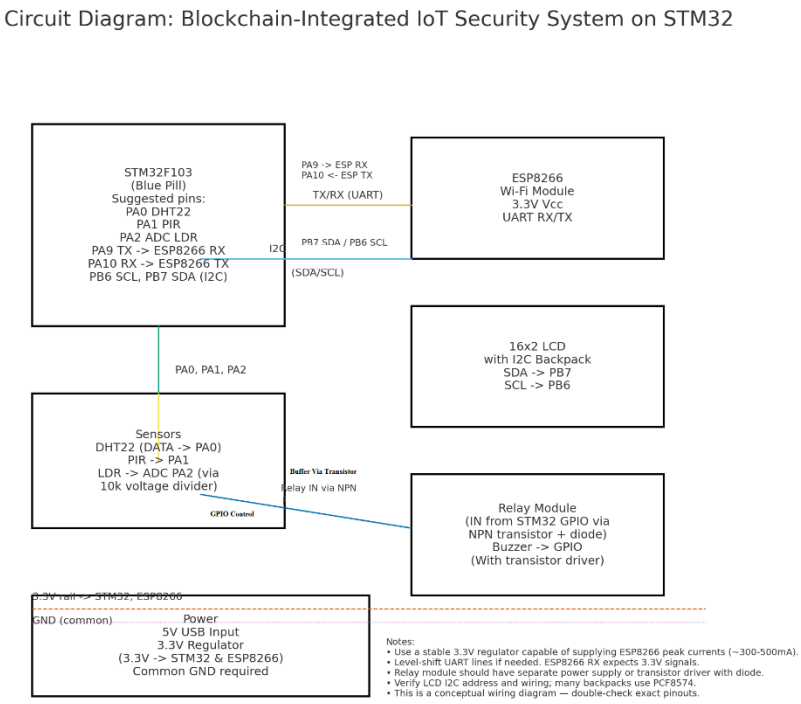
In this system, each IoT node collects sensor data and transmits it through a secure communication channel, where every transaction is recorded on a blockchain ledger. This decentralized ledger eliminates the need for a central authority by enabling peer-to-peer trust verification. The blockchain's immutability ensures that once data is recorded, it cannot be altered or deleted, thus protecting the system from data manipulation and unauthorized access. Smart contracts are employed to automate authentication and access control processes, reducing human intervention and minimizing the risk of errors or tampering.

To adapt blockchain for resource-constrained embedded environments, the system implements a lightweight consensus mechanism, such as Proof of Authority (PoA), which minimizes computational and energy requirements while maintaining network security. The STM32 microcontroller's high processing efficiency and low power consumption make it ideal for continuous, secure IoT operations.

This approach provides a scalable, fault-tolerant, and energy-efficient security framework for IoT applications. By combining the strengths of blockchain and embedded system technologies, the proposed solution ensures trusted communication, decentralized data management, and improved reliability across diverse IoT domains such as smart cities, healthcare monitoring, and industrial automation.

Circuit Diagram

The proposed circuit connects an STM32F103C8T6 (Blue Pill) microcontroller with various sensors, communication, and output modules to implement a blockchain-integrated IoT security system. The STM32 acts as the central controller, collecting data and managing secure communication. Three sensors — DHT22 for temperature and humidity, PIR for motion detection, and LDR for light intensity — are interfaced with GPIO pins (PA0–PA2). The sensor data is processed and transmitted to the ESP8266 Wi-Fi module via UART (PA9–PA10) for blockchain network communication.



A 16x2 LCD with I2C backpack is connected using PB6 (SCL) and PB7 (SDA) to display real-time sensor readings and system status. For output control, a relay module and buzzer are driven through STM32 GPIO pins using transistor circuits and protective diodes to handle higher current loads safely.

The entire system is powered by a 5V USB input, regulated to 3.3V for both the STM32 and ESP8266 modules. Common ground ensures signal consistency across all components. The blockchain functionality, managed via the ESP8266, securely logs sensor data into a distributed ledger. This design ensures decentralized security, real-time monitoring, and protection against data tampering or unauthorized access.

Code

```
#include <Wire.h>

#include <LiquidCrystal_I2C.h>

#include "DHT.h"

// ---------------- Pin Definitions ----------------

#define DHTPIN PA0

#define PIRPIN PA1

#define LDRPIN PA2
```

```
#define RELAYPIN PB0
#define BUZZERPIN PB1
#define DHTTYPE DHT22
// ---------------- Object Initialization ----------------
DHT dht(DHTPIN, DHTTYPE);
LiquidCrystal_I2C lcd(0x27, 16, 2);
// ---------------- Wi-Fi & Blockchain Variables ----------------
// (For simplicity, Wi-Fi connection and blockchain data are simulated)
String wifiSSID = "Your_SSID";
String wifiPASS = "Your_PASSWORD";
String blockchainServer = "http://your-blockchain-node/api/addData"; // Placeholder endpoint
void setup() {
  // Initialize Serial (for ESP8266 communication)
  Serial.begin(115200);
  delay(1000);
  // Initialize sensors and display
  dht.begin();
  lcd.init();
  lcd.backlight();
  // Initialize outputs
  pinMode(RELAYPIN, OUTPUT);
  pinMode(BUZZERPIN, OUTPUT);
  pinMode(PIRPIN, INPUT);
  lcd.setCursor(0, 0);
  lcd.print("IoT + Blockchain");
  lcd.setCursor(0, 1);
  lcd.print("System Initializing");
  delay(2000);
```

```
  lcd.clear();
  // Simulated Wi-Fi connection
  Serial.println("Connecting to Wi-Fi...");
  lcd.print("Wi-Fi Connecting...");
  delay(3000);
  lcd.clear();
  Serial.println("Connected to Wi-Fi!");
  lcd.print("Wi-Fi Connected");
  delay(1000);
  lcd.clear();
}
void loop() {
  // ------------- Sensor Data Reading -------------
  float temperature = dht.readTemperature();
  float humidity = dht.readHumidity();
  int ldrValue = analogRead(LDRPIN);
  int motionDetected = digitalRead(PIRPIN);
  // ------------- Display on LCD -------------
  lcd.setCursor(0, 0);
  lcd.print("T:");
  lcd.print(temperature);
  lcd.print("C H:");
  lcd.print(humidity);
  lcd.print("%");
  lcd.setCursor(0, 1);
  lcd.print("L:");
  lcd.print(ldrValue);
  lcd.print(" M:");
```

```
  lcd.print(motionDetected);
  // ------------- Relay and Buzzer Control -------------
  if (motionDetected == HIGH) {
    digitalWrite(RELAYPIN, HIGH);
    digitalWrite(BUZZERPIN, HIGH);
  } else {
    digitalWrite(RELAYPIN, LOW);
    digitalWrite(BUZZERPIN, LOW);
  }
 // ------------- Simulated Blockchain Data Upload -------------
  Serial.println("----- Blockchain Transaction -----");
  Serial.print("Temperature: "); Serial.println(temperature);
  Serial.print("Humidity: "); Serial.println(humidity);
  Serial.print("LDR: "); Serial.println(ldrValue);
  Serial.print("Motion: "); Serial.println(motionDetected);
  Serial.println("Data hashed & sent to Blockchain Node...");
  Serial.println("-----------------------------------");
  delay(5000); // Delay for 5 seconds before next cycle
}
```

Working Methodology

The proposed system operates by integrating multiple sensors and communication modules with the STM32 microcontroller to ensure secure data acquisition and decentralized data storage through blockchain technology. The STM32F103C8T6, acting as the central controller, continuously monitors environmental parameters using a DHT22 sensor for temperature and humidity, an LDR for light intensity, and a PIR sensor for motion detection. The collected sensor readings are processed and displayed on a 16x2 LCD module via the I2C interface, providing real-time monitoring of environmental conditions.

The system includes a relay and buzzer circuit, which are triggered whenever the PIR sensor detects motion. This feature serves as an alert mechanism, useful in intrusion detection or security applications. The STM32 communicates with the ESP8266 Wi-Fi module through UART serial communication, enabling wireless data transmission. The ESP8266 is responsible for

securely transferring the processed sensor data to a blockchain network. Each data packet is hashed and recorded in the blockchain ledger, ensuring that the information is tamper-proof and verifiable.

By employing blockchain, the system eliminates the need for centralized servers, thus preventing data manipulation and single-point failures. Smart contracts can be integrated to automate data validation and access control between nodes. This decentralized design ensures transparency, trust, and security across all connected devices. Overall, the system demonstrates how blockchain technology, when combined with STM32-based IoT hardware, can provide a secure, transparent, and efficient solution for modern IoT applications such as smart homes, industrial monitoring, and intelligent security systems.

Future Enhancements

The proposed blockchain-integrated IoT security system on STM32 offers a strong foundation for secure and decentralized data management; however, several enhancements can further improve its performance and scalability. One major future improvement is the integration of advanced cryptographic algorithms, such as elliptic curve encryption or zero-knowledge proofs, to strengthen data confidentiality and authentication across IoT nodes. Additionally, the system can be upgraded to support real blockchain platforms like Ethereum, Hyperledger, or IOTA for implementing smart contracts and decentralized identity management.

To enhance energy efficiency, low-power communication protocols such as LoRaWAN or NB-IoT can be employed for long-range, low-data-rate applications. The STM32 system can also be expanded with AI-based anomaly detection to predict and respond to security threats dynamically. Incorporating edge computing would allow partial blockchain validation and decision-making to occur locally, minimizing latency and bandwidth usage.

Furthermore, a mobile or web dashboard can be developed to visualize sensor data, blockchain transactions, and device status in real time. In future implementations, the system could be applied to smart cities, healthcare monitoring, and industrial automation, offering a more intelligent, autonomous, and secure IoT ecosystem. These enhancements would make the system more robust, scalable, and adaptable to emerging IoT challenges.

Conclusion

The Blockchain-Integrated IoT Security System on STM32 successfully demonstrates how combining blockchain technology with embedded IoT devices can enhance data security, transparency, and reliability. The system overcomes the major limitations of traditional centralized architectures by introducing a decentralized framework where each IoT node independently verifies and records transactions. The STM32 microcontroller efficiently handles sensor data acquisition and communication while maintaining low power consumption, making it ideal for real-time IoT applications.

By integrating the ESP8266 Wi-Fi module, the system ensures secure data transfer to a blockchain network, where transactions are immutably stored and protected against tampering. The inclusion of sensors such as DHT22, PIR, and LDR enables intelligent environmental monitoring and event detection, while the relay and buzzer provide instant response to critical

conditions. The lightweight consensus mechanism and smart contract functionality contribute to an efficient and autonomous authentication process.

Overall, the proposed system provides a scalable and energy-efficient solution for secure IoT deployments. It not only enhances trust among connected devices but also paves the way for future innovations in smart homes, healthcare, and industrial automation. This work establishes a foundation for developing robust, decentralized IoT ecosystems driven by blockchain-enabled security.

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