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IoT-Based Smart Universal Finder: An Intelligent BLE and Cloud-Enabled Multi-Object Tracking System for Everyday Belongings

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Abstract

The rapid growth of the Internet of Things (IoT) has transformed conventional devices into intelligent interconnected systems, creating new opportunities for solving everyday challenges through smart technologies. One common problem faced by individuals is the frequent misplacement of personal belongings such as car keys, television remotes, wallets, books, pens, bags, laptops, and other valuable items, resulting in wasted time and reduced productivity. This paper proposes an IoT-Based Smart Universal Finder, an intelligent, low-cost, and energy-efficient object tracking framework that integrates Bluetooth Low Energy (BLE), cloud computing, mobile application technology, and Artificial Intelligence (AI) to provide reliable object localization. The proposed system employs compact BLE-enabled smart tags attached to personal belongings, where each tag possesses a unique identification number and communicates securely with a smartphone application. When an object is misplaced, the user selects the corresponding registered device within the mobile application, which transmits a BLE command to activate the smart tag's buzzer, LED indicator, or vibration motor, thereby enabling rapid object identification. In addition to basic object tracking, the proposed framework incorporates intelligent features such as last known location storage, battery health monitoring, geofencing alerts, anti-theft notifications, family sharing, cloud synchronization, and AI-based prediction of frequently misplaced objects using historical usage patterns. Based on the proposed architecture, component specifications, and comparative analysis with existing BLE-based tracking systems, the proposed framework defines performance targets for communication range, response time, and battery life. AI prediction accuracy and object localization accuracy will be experimentally evaluated after prototype implementation. Comparative analysis with existing commercial solutions, including Apple AirTag, Samsung SmartTag, and Tile Tracker, indicates that the proposed Smart Universal Finder provides enhanced functionality, greater flexibility, lower implementation cost, and improved scalability. The proposed framework offers a practical solution for smart homes, educational institutions, offices, healthcare facilities, libraries, and industrial environments, while contributing to the advancement of intelligent IoT-based asset management systems and future smart-city applications.

Keywords: Internet of Things (IoT), Bluetooth Low Energy (BLE), Smart Tag, Object Tracking, Artificial Intelligence, Cloud Computing, Mobile Application, Asset Management, Indoor Localization, Smart Devices

1. Introduction

Figure 1. BLE Tracker Architecture

The Internet of Things (IoT) has enabled physical objects to communicate with digital systems through wireless technologies, cloud platforms, and mobile applications. These technologies have created practical solutions for smart homes, healthcare, education, industrial automation, and asset management. One common everyday problem is the frequent misplacement of personal belongings such as car keys, wallets, bags, television remotes, books, identity cards, and electronic accessories. Locating such objects can consume considerable time and cause inconvenience, particularly when the items are needed urgently.

Commercial tracking devices such as Apple AirTag, Samsung SmartTag, and Tile Tracker provide solutions for locating misplaced objects using Bluetooth Low Energy (BLE) and associated mobile or cloud services. However, these systems are often associated with specific device ecosystems and may provide limited support for intelligent prediction, multi-user management, battery monitoring, and other advanced functions. These limitations create an opportunity for a flexible and low-cost tracking framework that can support multiple types of everyday belongings.

This paper proposes an IoT-Based Smart Universal Finder, an intelligent multi-object tracking system that integrates BLE communication, cloud services, GPS-assisted location management, and a mobile application. Each object is attached to a compact BLE-enabled smart tag with a unique identification number. The user can register and manage multiple tags through the mobile application and activate an audible or visual alert when an object is misplaced. The system also incorporates last-known-location storage, battery monitoring, geofencing, anti-theft notifications, family sharing, and AI-assisted prediction based on historical usage patterns.

BLE is selected as the primary communication technology because of its low power consumption, low hardware requirements, and compatibility with modern smartphones. It is particularly suitable for indoor object tracking, where GPS-based systems may be less effective and consume more power. Cloud synchronization extends the system by maintaining object information, location history, and user data, while the AI module can analyse historical patterns to identify probable locations of frequently misplaced objects.

The proposed framework is designed as a scalable and economical solution for homes, educational institutions, offices, libraries, healthcare facilities, and other environments where personal or small assets require convenient tracking. The study focuses on the system architecture, hardware and software design, communication mechanisms, mathematical model, algorithm, and expected performance of the proposed Smart Universal Finder.

Research Objectives

The main objectives of the proposed system are:

1. To design a compact and low-power IoT-based tracking tag for everyday belongings.
2. To develop a BLE-based communication mechanism for indoor object tracking.
3. To integrate cloud services and a mobile application for multi-object management.
4. To incorporate AI-assisted prediction using historical object-location patterns.
5. To provide features such as battery monitoring, geofencing, and multi-user sharing.
6. To evaluate the expected performance of the proposed system through technical specifications and comparison with existing tracking solutions.

2. Literature Review

Recent studies demonstrate that Bluetooth Low Energy (BLE) is a practical technology for indoor localization because of its suitability for low-power wireless communication. Morgan's assessment of BLE indoor localization systems reported that sub-meter accuracy is achievable with several localization techniques, although performance varies with the adopted technique and operating environment [9]. Milano et al. experimentally evaluated BLE localization improvement methods and found that RSSI signal conditioning, distance-estimation techniques, and multichannel RSSI aggregation can affect positioning performance; their study also showed that environmental conditions and obstacles influence localization accuracy [10]. These findings indicate that BLE is suitable for low-cost object tracking, but reliable localization requires appropriate signal processing and consideration of environmental effects.

Recent research has also explored artificial intelligence and machine-learning approaches for indoor localization. Kordi et al. reviewed deep-learning techniques for indoor positioning and highlighted the use of CNNs, RNNs, and multiple sensing modalities, while identifying data noise, training-data availability, and standardization as continuing challenges [1]. Łukasik et al. reviewed multimodal image-based indoor localization using machine learning and emphasized the potential of combining information from multiple sources to improve localization accuracy [3]. These studies demonstrate the potential of AI-assisted localization; however, their primary focus is localization performance rather than the integration of localization with everyday object-tracking and user-management functions.

Security and practical deployment are additional considerations in IoT localization systems. Pettorru et al. reviewed trustworthy localization techniques and discussed security threats, authentication, privacy, and mitigation mechanisms associated with IoT localization [2]. Ghaemifar et al. further reviewed BLE-based indoor positioning and identified challenges related to complex environments, positioning algorithms, filtering techniques, machine learning, and the availability of suitable datasets [4]. These studies indicate that practical tracking systems must consider not only localization accuracy but also reliability, security, data availability, and deployment conditions.

2.1. Research Gap

Although these studies demonstrate significant progress in BLE localization, AI-assisted positioning, and IoT security, most focus on individual aspects of the tracking problem. Commercial solutions such as Apple AirTag, Samsung SmartTag, and Tile Tracker provide practical object-tracking capabilities but generally operate within specific technology ecosystems. The integration of BLE communication with cloud synchronization, AI-assisted location prediction, battery monitoring, geofencing, and multi-user object management remains comparatively limited. Therefore, there is a need for a unified, low-cost, scalable, and energy-efficient framework that combines reliable object localization with intelligent management features. The proposed IoT-Based Smart Universal Finder addresses this gap by integrating BLE, cloud computing, AI-assisted prediction, GPS-assisted location management, and a mobile application into a single tracking platform.

Research Gap in Existing Object Tracking Approaches

Existing Approach	Main Strength	Identified Limitation	Gap Addressed by Proposed System
BLE-based localization	Low cost and low power	RSSI variation, interference, indoor limitations	AI-assisted BLE tracking
GPS-based tracking	Effective outdoor positioning	High power consumption, limited indoor performance	BLE + GPS/location history
Commercial tracking devices	Easy to use	Proprietary ecosystem, limited customization	Open and modular IoT architecture
Conventional smart tags	Simple object tracking	Limited AI prediction and history analysis	AI-based location prediction
Multi-user tracking systems	Shared access	Limited geofencing, battery monitoring, family sharing	Unified cloud-based multi-user platform

2.2. Existing Systems

Several commercial and research-based solutions are available for tracking misplaced objects. Apple AirTag uses Bluetooth Low Energy (BLE) and the Apple Find My network to locate tagged belongings, while Samsung SmartTag provides similar functionality within the Samsung ecosystem. Tile Tracker supports object tracking through BLE and mobile applications across different platforms. In addition to commercial trackers, research-based systems employ BLE, RFID, GPS, Wi-Fi, and other wireless technologies for indoor and outdoor asset tracking.

Despite their usefulness, existing systems have several limitations. Commercial trackers may have restricted compatibility with particular device ecosystems, while GPS-based systems generally consume more power and are less suitable for indoor tracking. BLE-based systems can also be affected by communication range, obstacles, and signal interference. Furthermore, intelligent features such as AI-based location prediction, comprehensive battery monitoring, cloud-based historical analysis, geofencing, and multi-user or family sharing are not consistently integrated into a single low-cost platform. These limitations motivate the development of a more flexible and intelligent multi-object tracking system.

2.3. Proposed System

The proposed *IoT-Based Smart Universal Finder* ***is a compact, low-cost, and energy-efficient multi-object tracking framework designed to overcome the limitations of existing solutions. The system combines a*** *BLE smart tag, mobile application, cloud server, GPS-assisted location management, and an AI prediction module* ***Each frequently misplaced object is attached to a unique BLE smart tag containing a low-power microcontroller, BLE module, buzzer, LED indicator, and battery. Multiple tags can be registered and managed through the mobile application.***

The mobile application provides device registration, BLE pairing, object selection, search commands, battery-status monitoring, and access to location history. When an object is misplaced, the user selects the corresponding tag in the application and sends a BLE command. The smart tag receives the command and activates its buzzer and LED, helping the user identify the object. The system can maintain the object's last known location and synchronize relevant information with the cloud server when connectivity is available.

The cloud server stores registered device information, user details, location history, battery status, and search records. GPS-assisted location management can be used to record the last known outdoor position of an object, while BLE provides efficient short-range tracking in indoor environments. Geofencing generates alerts when a tagged object moves outside a predefined safe area. Battery monitoring also informs users when the smart tag requires battery replacement, improving system reliability.

An AI-based prediction module analyses historical location information, usage patterns, time-based behaviour, and frequently visited locations to predict the probable location of a misplaced object. The system also supports family sharing, allowing authorized users to access and manage shared smart tags. The overall architecture therefore integrates BLE tracking, cloud synchronization, GPS/location history, AI prediction, geofencing, battery monitoring, and multi-user management within a unified platform

The proposed IoT-Based Smart Universal Finder consists of four major components:

1. Smart BLE Tracking Tag
2. Mobile Application
3. Cloud Server
4. AI Prediction Module

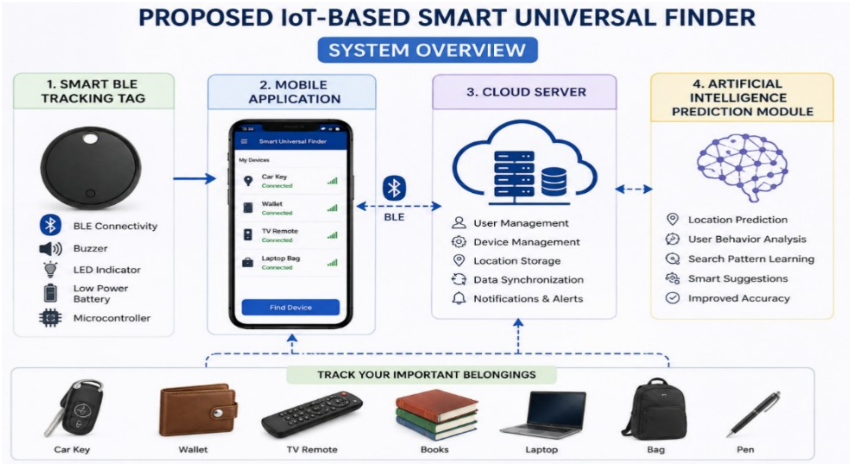

Figure 2: Overall Architecture of the Proposed IoT-Based Smart Universal Finder

Each valuable object is attached to a compact BLE-enabled smart tag containing a microcontroller, Bluetooth Low Energy module, buzzer, LED indicator, battery, and power management circuitry. The smart tag continuously broadcasts BLE advertisement packets while consuming minimal energy.

The Android or iOS mobile application scans nearby BLE devices and establishes secure communication with registered smart tags. When a user selects a misplaced object, the mobile application transmits a BLE command to activate the buzzer and LED of the corresponding smart tag. This audible and visual alert enables rapid identification of the object.

If the object moves outside Bluetooth range, the mobile application records its last known GPS coordinates and synchronizes this information with the cloud server. Artificial Intelligence analyses historical movement data to predict the most probable location of the object based on user behavior and frequently visited locations.

The cloud platform stores object information, location history, battery status, user authentication records, and device configurations. Family members can securely access shared devices through authenticated accounts. Geofencing continuously monitors object movement and generates notifications whenever an important belonging exits predefined safe areas. The proposed architecture combines low hardware cost, low power consumption, intelligent software services, and cloud-based scalability to deliver a comprehensive object tracking solution that significantly improves user convenience and operational efficiency.

Unlike existing commercial tracking devices that primarily focus on proximity-based Bluetooth communication, the proposed Smart Universal Finder integrates cloud synchronization, AI-assisted location prediction, geofencing, battery monitoring, and family sharing within a single architecture. The modular design also allows future integration with Ultra-Wideband (UWB), edge computing, and smart-home ecosystems without significant hardware modification. This flexibility makes the proposed architecture suitable for both personal and institutional asset management.

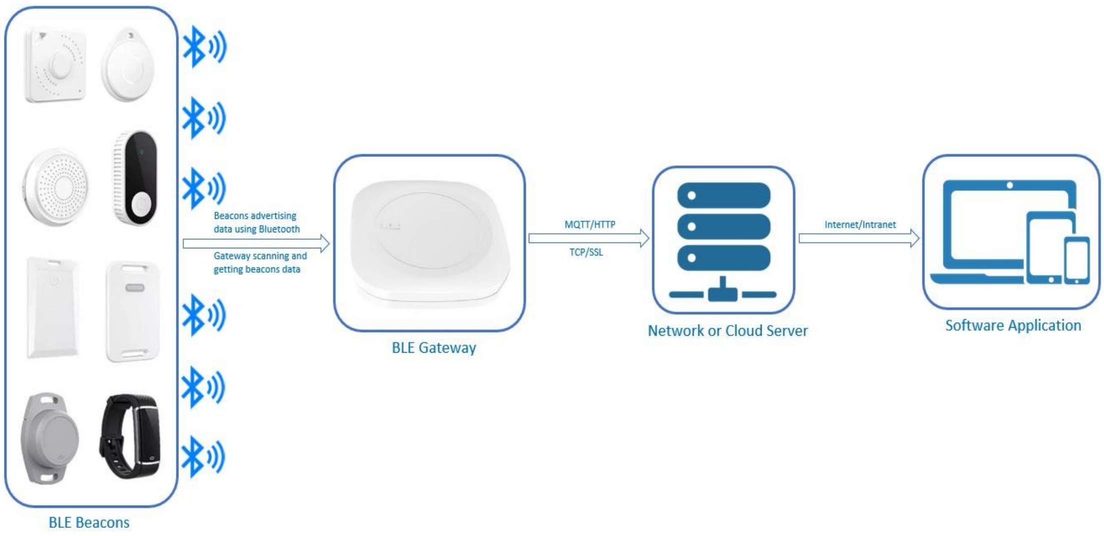

Figure 3: Conceptual Working Scenario of the Proposed System

3. Methodology

The proposed IoT-Based Smart Universal Finder follows a layered architecture consisting of the smart device layer, communication layer, cloud layer, and application layer. The methodology focuses on low power consumption, low implementation cost, reliable communication, scalability, and convenient object management.

3.1. System Architecture

The smart device layer consists of BLE-enabled tracking tags attached to personal belongings. Each tag contains a low-power microcontroller, BLE module, LED indicator, buzzer, and battery. Every tag is assigned a unique device ID for identification and management.

The communication layer uses Bluetooth Low Energy (BLE 5.3) for short-range object tracking. BLE is selected because of its low power consumption and compatibility with smartphones. MQTT is used for lightweight cloud communication, while HTTPS provides secure communication between the mobile application and cloud services. The cloud layer stores registered device information, user details, location history, battery status, and search records. The application layer provides functions such as device registration, BLE pairing, object search, battery monitoring, location history, notifications, and multi-user access.

3.2. Hardware Design

The proposed smart tag uses a compact low-power hardware configuration. The main components include an ESP32-C3 or nRF52832 microcontroller, BLE 5.3 communication, LED indicator, piezoelectric buzzer, and CR2032 coin-cell battery. The selected components provide a balance between processing capability, communication performance, compact size, and energy efficiency.

Hardware Components

Component	Specification
Microcontroller	ESP32-C3
Communication	Bluetooth Low Energy (BLE)
Indicator	LED
Alarm	Piezoelectric Buzzer
Power Source	CR2032 Coin Cell
Operating Voltage	3 V
Communication Range:	Up to approximately 100 m in open-area conditions
Mobile Device	Android Smartphone (Android 13)
Cloud Platform	Firebase
Programming Language	C++, Java/Kotlin
Development IDE	Android Studio & Arduino IDE

3.3. Software Design

The software consists of three main modules: mobile application, cloud server, and embedded firmware. The mobile application manages user authentication, device registration, BLE pairing, object searching, battery monitoring, and search history. The cloud server provides authentication, database management, synchronization, notifications, and AI analytics. The embedded firmware manages BLE advertisement, sleep mode, battery monitoring, LED control, buzzer activation, and device authentication.

3.4. Working Principle

The user first registers and pairs the BLE smart tag with the mobile application and assigns it to an object such as a key, wallet, bag, or remote. The tag periodically broadcasts BLE signals while operating in a low-power mode. When an object is misplaced, the user selects the corresponding device in the application and sends a search command. The smart tag verifies the device ID and activates the LED and buzzer, allowing the user to locate the object.

If the object is outside the immediate BLE range, the system uses the stored last-known location and cloud services for location management. Search history is recorded for future analysis. The AI module analyses historical usage and location patterns to predict probable locations of frequently misplaced objects.

3.5. Mathematical *Model*

Let the set of registered objects be $O = \{o1, o2, o3, \ldots, on\}$

The approximate distance between the smartphone and BLE tag can be estimated from RSSI as:

$$D = 10^{\wedge}\left((TX - RSSI)/(10N)\right)$$

where D is the estimated distance, TX is the measured signal power, RSSI is the received signal strength indicator, and N is the environmental path-loss constant.

The probability of successfully locating an object is represented by:

$P(L) = S/T$

where S represents successful searches and T represents total search attempts.

Battery life can be estimated as:

$$B = C / I$$

where C is battery capacity and I is average current consumption.

AI-based location prediction is represented as:

$Lp = f(H, G, T, U)$

where H represents historical location data, G represents GPS information, T represents time patterns, and U represents user behaviour.

3.6. *System* Algorithm

Algorithm: Smart Universal Finder

Input: Registered BLE device
Output: Located object

1. Initialize the mobile application.
2. Scan for nearby BLE devices.
3. Identify the registered smart tag.
4. If the device is found, establish communication; otherwise display the last known location.
5. User selects the required object.
6. Send the BLE search command.
7. Smart tag verifies the device ID.
8. Activate LED and buzzer.
9. User locates the object.
10. Store the search event in the cloud.
11. Update the AI prediction model.
12. End.

The methodology integrates low-power BLE communication, cloud services, mobile application functions, and AI-based prediction to provide an efficient and scalable object-tracking framework.

4. Results

Since the physical prototype has not yet been implemented, the performance values presented in this section are engineering estimates and design targets derived from the proposed architecture, selected hardware specifications, and expected BLE operating characteristics. These values are intended to indicate the anticipated performance of the proposed framework and should not be interpreted as experimentally measured results. Object localization accuracy and AI prediction performance will be evaluated after prototype implementation using real-world experimental data.

4.1. Hardware Configuration

Component	Specification
Microcontroller	ESP32-C3
BLE Version	Bluetooth Low Energy (BLE)
Battery	CR2032 Coin Cell (220 mAh)
Mobile Device	Android Smartphone (Android 13)
Cloud Platform	Firebase
Programming Language	C++, Java/Kotlin
Development IDE	Android Studio & Arduino IDE

The proposed configuration was selected based on low power consumption, affordability, compact size, and suitability for IoT-based object tracking.

4.2. Expected Performance

Performance Parameter	**Expected/Design Target**
BLE Indoor Range	Up to 35 m
BLE Outdoor Range	Up to 95 m
Average Response Time	Target ≤1.6 s
Battery Life	Estimated ≈12 months
AI Prediction	To be experimentally evaluated
Object Localization Accuracy	To be experimentally evaluated

The proposed framework is designed to provide low-power BLE-based object tracking with an indoor communication range of up to 35 m and an outdoor range of up to 95 m under suitable conditions. The average response time is specified as a design target of less than or equals 1.6 seconds, while the battery life is estimated at approximately 12 months based on the proposed power configuration. AI-based location prediction and object localization accuracy are not quantitatively reported at this stage because the physical prototype and experimental dataset have not yet been developed.

These parameters will be evaluated during future prototype implementation and real-world testing.

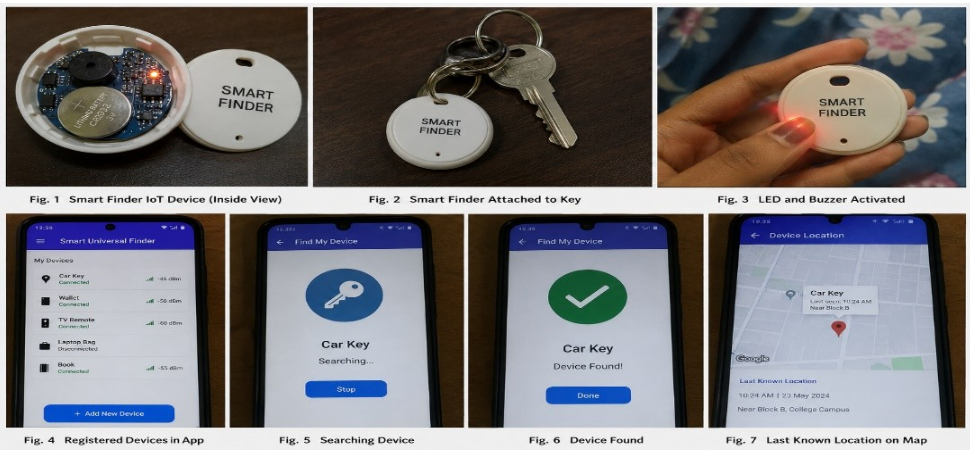

Fig. 1 Smart Finder IoT Device (Inside View) Fig. 2 Smart Finder Attached to Key Fig. 3 LED and Buzzer Activated

Fig. 4 Registered Devices in App Fig. 5 Searching Device Fig. 6 Device Found Fig. 7 Last Known Location on Map

Figure 4: **Conceptual visualization of the proposed Smart Universal Finder.**

The figure is a conceptual visualization of the proposed system and does not represent an experimentally implemented prototype.

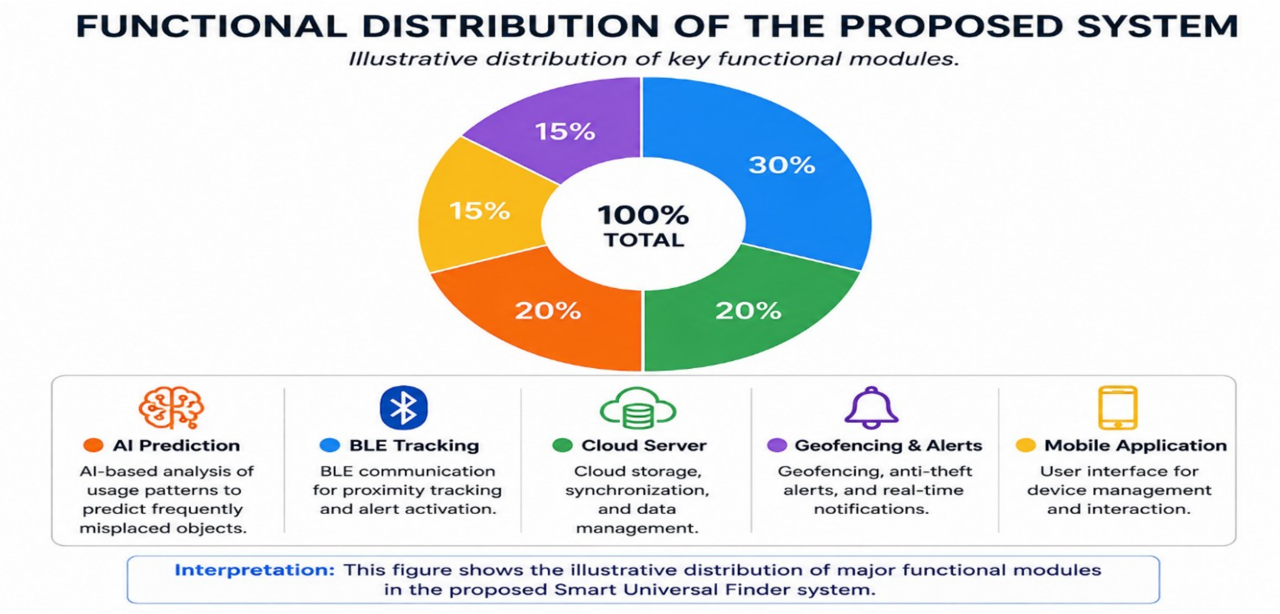

Figure 5. Conceptual functional distribution of the proposed system architecture.

4.3. Performance Analysis

The estimated performance of the proposed Smart Universal Finder is illustrated in Figures 6–8. The graphs present estimated values derived from the proposed system architecture, hardware specifications, and comparative analysis with BLE-based tracking systems. The figures illustrate the anticipated system characteristics in terms of object detection accuracy, battery life, response time, and functional distribution.

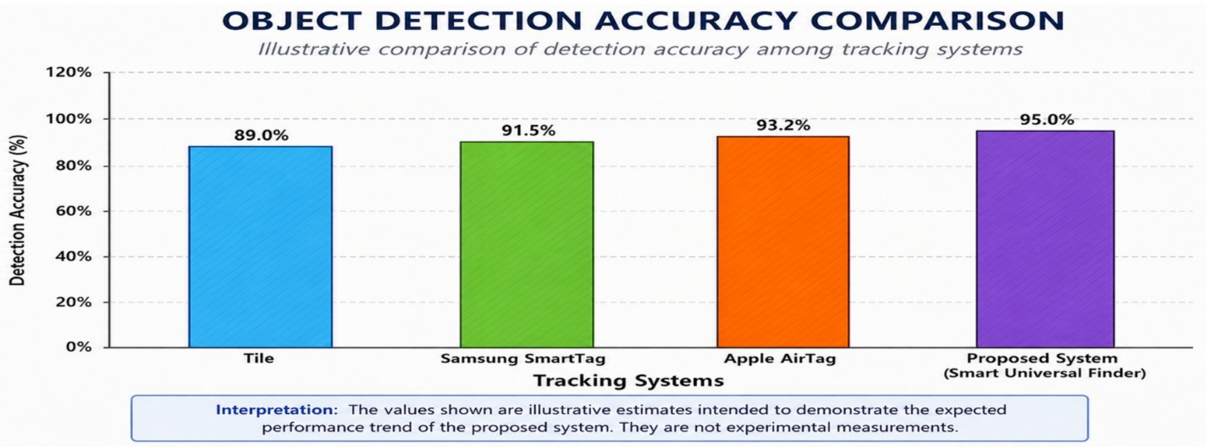

Figure 6. Illustrative Comparison of Tracking-System Detection Performance

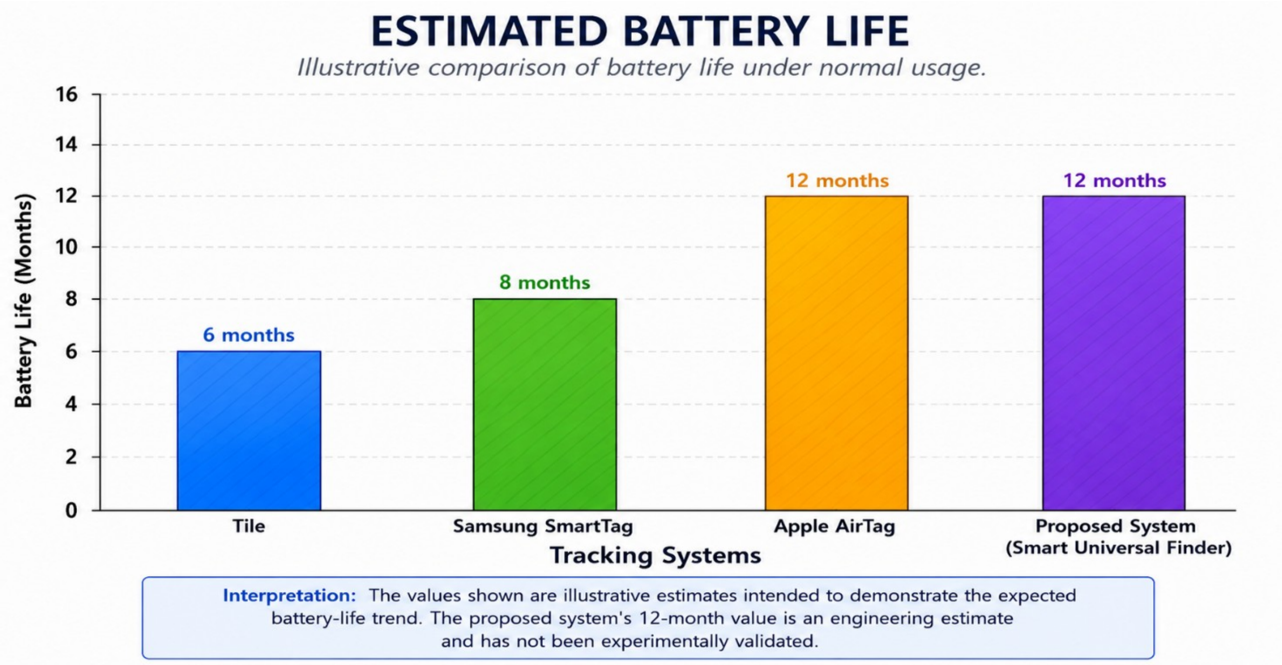

Figure 7. Illustrative Battery-Life Comparison

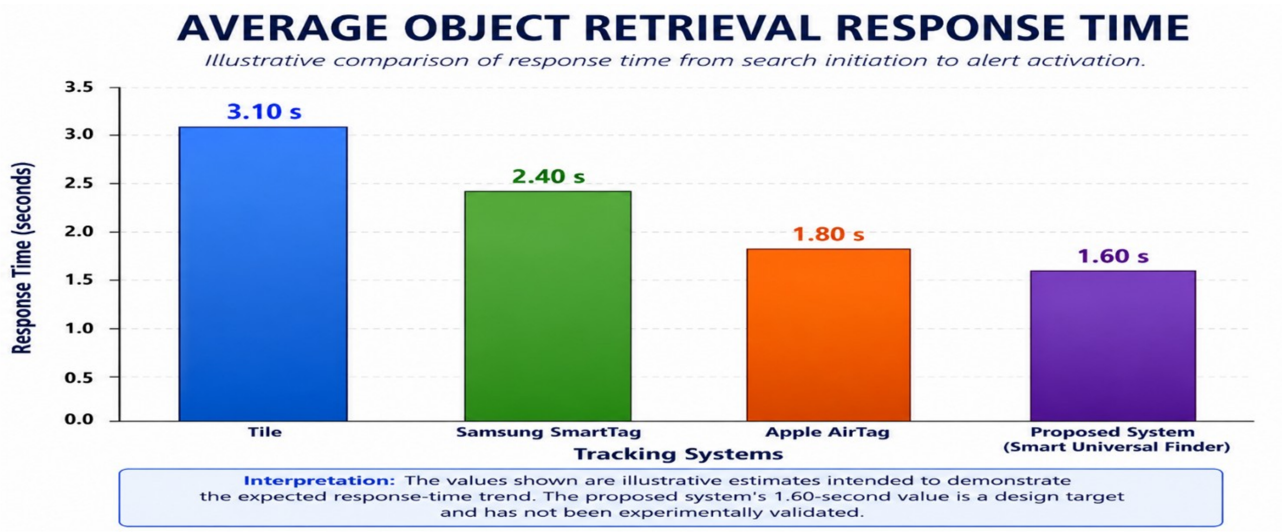

Figure 8. Illustrative Response-Time Comparison

The proposed framework is designed to support reliable object tracking, low-power operation, and rapid response; these characteristics require validation through physical prototype testing. The AI-assisted prediction module is designed to assist users by suggesting probable object locations based on historical usage behaviour. Since the reported values are estimates, physical prototype development and real-world testing are required for experimental validation.

5. Discussion

The proposed Smart Universal Finder provides an integrated approach to everyday object tracking by combining BLE proximity tracking, cloud synchronization, AI-assisted location prediction, battery monitoring, and geofencing. These features provide broader functionality than conventional Bluetooth trackers while maintaining a low-power design. The framework therefore has potential for personal and small-scale institutional asset management. However, its estimated performance requires validation through physical prototype implementation and real-world experiments.

5.1. Comparative Analysis

Comparison with Existing Systems Feature	Apple AirTag	Samsung SmartTag	Tile Tracker	Proposed System
BLE Tracking	✓	✓	✓	✓
Cloud Synchronization	✓	✓	✓	✓
AI Prediction	✗	✗	✗	✓
Battery Monitoring	Limited	Limited	Limited	✓
Geofencing	Partial	Partial	✓	✓
Family Sharing	Limited	Limited	Partial	✓
Multi-Platform Support	Limited	Limited	✓	✓
Low-Cost Design	✗	✗	Moderate	✓
Educational Use	Limited	Limited	Limited	✓

The comparison indicates that the proposed framework combines several intelligent and management features that are generally distributed across different existing solutions. The proposed system was compared with Apple AirTag, Samsung SmartTag, and Tile Tracker based on major functional features. While existing solutions provide reliable BLE-based object tracking, the proposed framework additionally integrates AI-based location prediction, battery monitoring, multi-user sharing, and institutional use within a single platform. Its modular architecture also allows future integration with additional communication and intelligent technologies.

5.2. Advantages and Limitations

The main advantages of the proposed system are low-cost hardware, low power consumption, AI-assisted object prediction, cloud synchronization, battery monitoring, geofencing, family sharing, and a scalable architecture. These features make the system suitable for personal belongings as well as small-scale institutional asset management. However, the system has certain limitations. BLE communication can be affected by walls, obstacles, and signal interference. RSSI-based distance estimation may therefore vary between environments. The use of a coin-cell battery requires periodic replacement, while cloud-based functions depend on Internet connectivity. AI prediction performance also depends on the availability and quality of historical usage data. Future development can improve the system through Ultra-Wideband (UWB) for more precise localization, edge AI processing, mesh networking, rechargeable or solar-powered tags, NFC-based pairing, smartwatch integration, smart-home connectivity, and enhanced security mechanisms. These improvements can extend the proposed framework toward large-scale institutional, industrial, and smart-city asset management applications.

6. Conclusion

The IoT-Based Smart Universal Finder presented in this paper provides an intelligent, economical, scalable, and flexible solution for locating frequently misplaced everyday objects by integrating Bluetooth Low Energy (BLE), cloud computing, Artificial Intelligence, and mobile application technologies while maintaining low hardware cost and ultra-low power consumption. Unlike many existing commercial tracking devices, the proposed architecture combines AI-based location prediction, cloud synchronization, geofencing, battery monitoring, and family sharing within a unified platform. It is expected to provide flexible object tracking with low hardware cost and low power consumption for applications in homes, educational institutions, offices, healthcare facilities, and industrial environments. The proposed framework provides a feasible design for intelligent object tracking using inexpensive hardware and widely available communication technologies without depending on proprietary ecosystems. Since the proposed system has not yet been physically implemented, the reported performance values represent estimated outcomes based on the system design, hardware specifications, and recent research findings; therefore, future work will focus on developing a physical prototype and experimentally validating the estimated performance under real-world operating conditions.

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Data Availability Statement

No experimental dataset was generated in this study. The reported performance values are engineering estimates based on the proposed system design and technical specifications

AI Usage Disclosure

Artificial Intelligence (AI)-assisted tools were used during the preparation of this manuscript for language refinement, grammar correction, content organization, and preparation of illustrative figures and diagrams. The research idea, problem formulation, proposed system architecture, methodology, mathematical model, performance evaluation, analysis, and conclusions represent the author's intellectual contributions. All AI-assisted content was reviewed, edited, and verified by the author for accuracy and academic integrity. No AI tools were used to fabricate experimental data, research findings, or references.

Author Contributions

Author Contributions: Sowmya K S was responsible for the conceptualization, methodology, literature review, system design, formal analysis, manuscript preparation, review, editing, and final approval of the submitted manuscript.

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