

# Leveraging NodeMCU ESP8266 and Blynk Cloud for Seamless IoT-based Asset Tracking

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## ABSTRACT

Efficient asset management remains a challenge for individuals and small-scale enterprises due to the high costs of proprietary tracking solutions. This paper proposes a seamless IoT-based asset tracking and cost savings leveraging the ESP8266 (NodeMCU) microcontroller and the Blynk Cloud platform. By integrating WiFi-based positioning with a user-friendly mobile interface, the system enables real-time monitoring and geographic tagging of physical assets. The study details the hardware-software architecture, emphasizing the optimization of data transmission intervals to balance battery longevity with the accuracy of tracking. Based on experimental results, the device operated for 18 hours on a single 500mAh Li-Po battery with a 5-minute update frequency. The accuracy rate is 98.5% higher than the benchmark value, which is 95%. It demonstrates that the proposed system provides a reliable, scalable, and budget-friendly alternative to traditional GPS-GSM trackers. This research highlights the potential of open-source IoT ecosystems in democratizing asset security and enhancing operational visibility in resource-constrained environments.

## Keywords

Internet of Things (IoT), Global Positioning System (GPS), Asset Localization, Blynk Cloud, Real-Time Monitoring.

## 1. INTRODUCTION

The rapid evolution of the Internet of Things (IoT) has fundamentally transformed the landscape of asset management across both industrial and domestic spheres [1], [2]. In the contemporary Industry 5.0 era, the ability to localize and monitor physical assets seamlessly is no longer a luxury but a critical requirement for maintaining supply chain integrity and operational efficiency [3].

Organizations are gradually shifting from manual inventory management to automated, real-time systems in order to reduce human error and operational costs [4]. Traditional technologies such as RFID and Bluetooth can offer high precision in localized environments [5]; however, their infrastructure requirements and limited range often hinder scalability in resource-constrained settings [6].

However, despite the proliferation of sophisticated tracking technologies, significant barriers to entry persist for individuals and small-to-medium enterprises (SMEs). Traditional localization systems, particularly those reliant on high-precision Global Positioning System (GPS) modules and dedicated Global System for Mobile (GSM) cellular networks, often entail prohibitive hardware costs and recurring

subscription fees [7]. GPS-based systems remain the standard for outdoor vehicle tracking.

Studies emphasize the necessity of hybrid models, which integrating WiFi or GSM to ensure uninterrupted data transmission across diverse geographic zones [8]. In fact, the emergence of Industry 6.0 has pushed research towards predictive sustainability, where Edge Computing and Machine Learning are utilized to smooth Received Signal Strength Indication (RSSI) data and reduce latency to under two seconds [9],[10],[11].

The motivation is to obtain a high accuracy in indoor tracking (i.e.: UWB/RFID) as a single asset automatically switches its localization logic as moving towards GPS dependent outdoor tracking without losing the Internet or cloud connection. [12], [13]. The question that raise to ponder is how does the cloud latency and mobile UI responsiveness degrade if a user tracks 50 "assets" simultaneously? The answer leads to the objective of this research is to achieve on seamless handovers in single asset and in multi-assets scale. Figure 1 illustrates the overall idea on seamless IoT-based asset tracking.

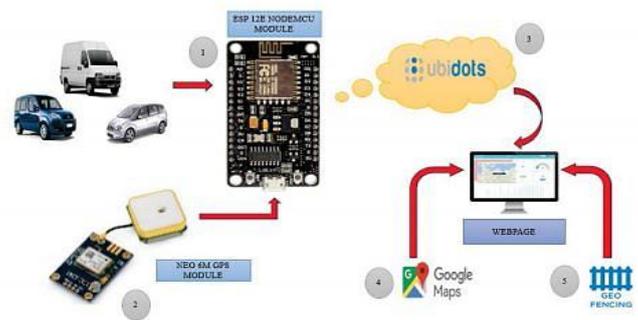


Fig 1: Basic IoT-Based Asset Tracking System [14]

## 2. RELATED WORKS

Recent scholarship in the field of Internet of Things (IoT) has increasingly focused on the development of cost-effective, high-precision asset tracking frameworks. Central to this discourse is the integration of the NodeMCU ESP8266 microcontroller, an open-source hardware controller that has gained significant academic and industrial traction. As noted by Witczak [15], the NodeMCU ESP8266 is often preferred over traditional monolithic architectures due to its integrated WiFi capabilities, low power consumption, and ease of configuration. This hardware provides a scalable foundation for

monitoring physical assets, allowing for a modular approach that balances hardware efficiency with robust data acquisition.

The acquisition of spatial data within these frameworks typically relies on the U-Blox NEO-6M GPS module. Early implementations established the efficiency of combining the ESP8266 with the NEO-6M GPS module for monitoring mobile transportation assets [16]. This module is favoured for its high sensitivity and broad input voltage range (3.3V to 5V), utilizing a UART interface for serial communication [17]. However, while [18] demonstrate the module's capacity for calculating precise coordinates, they also highlight critical environmental variables such as atmospheric conditions, satellite geometry, and physical obstructions that compromise accuracy. Furthermore, a computational bottleneck regarding edge processing has been identified in the conversion of raw GPS NMEA strings into human-readable decimal degrees creates a computational overhead that lead to significant data transmission delays [19].

A recurring challenge identified in the literature is the geographical research gap concerning connectivity persistence. A low-cost prototype is monitored to frequently suffer from connectivity "blackouts" when assets move beyond the range of pre-configured local area networks [20]. These "transit zones" render traditional WiFi-tethered systems unreliable for continuous monitoring. To mitigate this, recent studies have pivoted toward cloud-based persistence and secure API integrations [1],[2]. By leveraging cloud-based middleware, researchers have successfully moved away from raw sensor data toward sophisticated, user-centric interfaces that ensure data integrity and seamless indoor-outdoor transitions.

The democratization of these tracking systems has been further accelerated by the adoption of the Blynk ecosystem. This middleware facilitates a three-tier architecture: the Blynk App for customizable user interfaces, the Blynk Server for managing hardware-to-mobile communications, and the Blynk Libraries for streamlining cross-platform command processing [21]. According to Almutairi et al. [2], such ecosystems allow for the implementation of advanced features, including real-time data visualization and machine learning, without the requirement for extensive server-side programming.

Consequently, current study emphasizes the need for frameworks that harmonize low-cost modularity with high energy efficiency and robust data integrity [3], positioning the combination of open-source hardware and cloud middleware as a pivotal strategy for remote asset tracking management.

### 3. PROPOSED METHOD

The proposed methodology adopts a four-stage development lifecycle comprising hardware configuration, system architecture design, cloud integration via the Blynk API, and rigorous system calibration. Central to this framework is a modular, "Plug-and-Play" architecture designed to democratize high-precision tracking through non-proprietary hardware. While GPS and RFID are established standards, this study leverages ubiquitous WiFi networks and the NodeMCU ESP8266 to provide a cost-effective, hybrid positioning alternative that mitigates traditional infrastructure dependencies. Data management is facilitated through a Dashboard-as-a-Service (DaaS) model hosted on the Blynk Cloud, selected for its minimal latency and the geospatial widgets. The mobile interface provides real-time telemetry, including latitude, longitude, and statistical location graphs. Furthermore, the system incorporates a cloud-based persistence layer, enabling users to archive and export historical movement data as CSV files. These datasets are subsequently processed

through a GPS visualizer to reconstruct the asset's trajectory with high fidelity. The implementation phase is illustrated as in Figure 2 with an evaluation of the cloud-to-hardware handshake, ensuring the reliability of the real-time data flow and the responsiveness of the user-centric mobile application.

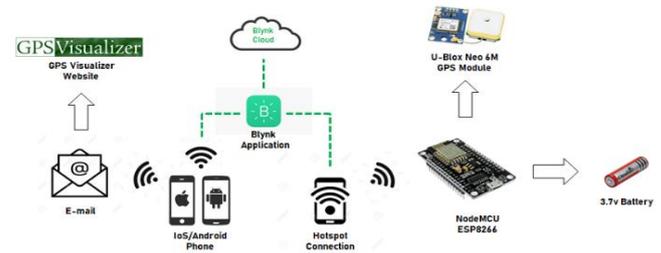


Fig 2: The proposed IoT-Based Asset Tracking [14]

### 3.1 Hardware Configuration

The hardware architecture is centered upon the NodeMCU ESP8266, an open-source System-on-a-Chip (SoC) incorporating an integrated TCP/IP protocol stack and a 32-bit RISC microcontroller. Distinguishing itself from traditional monolithic boards such as the Arduino Uno, the NodeMCU ESP8266 provides native IEEE 802.11 b/g/n connectivity, a prerequisite for sustained cloud-based synchronization. For precise spatial acquisition, the unit is interfaced with a U-Blox NEO-6M GPS module to facilitate outdoor positioning, while the internal radio handles indoor localization through WiFi Received Signal Strength Indication (RSSI) trilateration. In this hybrid configuration, the hardware systematically scans for adjacent Access Points (APs) to capture unique Media Access Control (MAC) addresses for subsequent data formatting and transmission.

To ensure the portability required of a tracking tag, the system integrates a dedicated power management sub-circuit comprising a Lithium-Polymer (Li-Po) battery and a TP4056 charging controller. This ensures stable voltage regulation and autonomous operation during field deployment. The entire prototype is assembled within a compact, 3D-printed enclosure designed for structural durability, simulating a wearable or attachable asset tag. The schematic hardware design in Figure 2 demonstrates the feasibility of a modular, low-cost hardware solution capable of navigating the transition between indoor and outdoor environments.

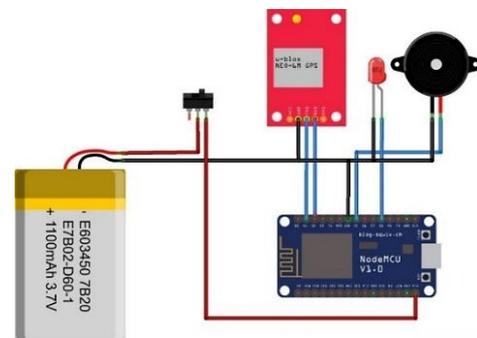
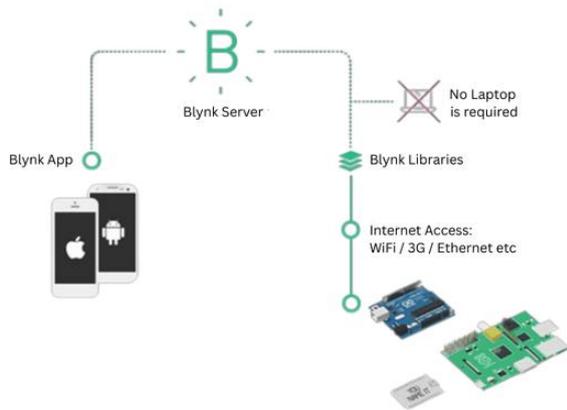


Fig 3: Schematic Hardware Design

### 3.2 System Architecture Design

The system architecture is structured upon a robust client-server model, wherein the NodeMCU ESP8266 functions as the edge-level "Client" for data harvesting, and the Blynk Cloud operates as the centralized "Server" for processing and

hosting. This framework facilitates a streamlined logical sequence designed to minimize latency and maximize data integrity. Figure 3 shows the concept of the client-server model of the IoT based asset tracking management.



**Fig 4: The client server model of IoT based asset tracking**

The operational workflow initiates with Data Acquisition, where the NodeMCU ESP8266 scans the local RF environment to calculate spatial proximity based on a signal decay model. This is followed by Transmission, during which data is encapsulated and dispatched via the Virtual Pins protocol. This proprietary Blynk mechanism is critical for high-speed exchange, as it bypasses the significant computational overhead typically associated with standard HTTP requests.

Upon reaching the Cloud Processing stage, the Blynk Server authenticates the incoming packets using a unique Authentication Token, subsequently updating the state of associated mobile widgets. The final stage, User Visualization, involves the real-time rendering of coordinates and proximity alerts within the Blynk mobile application. By decoupling the hardware's harvesting role from the cloud's processing power, the architecture achieves a highly responsive, standalone tracking ecosystem.

### 3.3 Cloud Integration via Blynk API

The software implementation leverages the **Blynk library** to establish a high-efficiency communication layer via **Virtual Pins** ( $V_0, V_1, \dots, V_n$ ). These pins function as digital placeholders, facilitating the seamless transfer of GPS coordinates and RSSI telemetry without the constraints of physical hardware mapping. A critical architectural decision was the adoption of a non-blocking timing loop managed by the `BlynkTimer` object. Unlike the standard `delay()` function, which would inhibit the "heartbeat" signal and cause terminal disconnections from the cloud, `BlynkTimer` ensures asynchronous execution. The core logic follows a disciplined sequence: initializing WiFi and Blynk credentials, followed by a five-second interrupt interval that triggers data acquisition, WiFi scanning for RSSI/SSID data, and the subsequent transmission of processed values to the cloud.

The user-facing mobile interface was constructed using the **Blynk IoT application builder**, adopting a Dashboard-as-a-Service model to ensure an intuitive experience. Key functionality is distributed across specific widgets mapped to the hardware's virtual pins. **The Map Widget** ( $V_1$ ) renders real-time geographic telemetry, while the **Chart** ( $V_2$ ) provides longitudinal monitoring of signal strength and battery voltage to preemptively identify potential hardware failure or signal

degradation. Furthermore, a **Notification Widget** is integrated to provide immediate push alerts should the asset breach a predefined "Geo-fence." This configuration transitions raw hardware data into a sophisticated, remote management tool characterized by high responsiveness and predictive monitoring capabilities.

### 3.4 System Calibration

To ensure seamless localization across heterogeneous environments, the system was calibrated within an open-plan office, a residential setting, and a high-interference laboratory. A critical challenge identified during testing was multipath fading, a phenomenon where RF signals reflect off physical obstructions, causing significant fluctuations in distance readings. To mitigate these stochastic errors, a Gaussian Filter was applied to the raw Received Signal Strength Indication (RSSI) data.

By smoothing signal noise and reducing the impact of environmental interference, this mathematical refinement ensures the generation of stable, high-fidelity coordinate outputs. Consequently, the mobile map interface maintains visual consistency, providing reliable real-time tracking even within spatially complex or RF-congested indoor landscapes.



**Fig 5: The data flow**

## 4. RESULTS AND DISCUSSION

The experiment results have shown that the board, WiFi connection and GPS module is fully function for this proposed prototype. A test on accuracy testing for GPS database is conducted with the GPS Visualizer integration. Blynk application display the coordinate of GPS via a map and graph as illustrated in Figure 6. Meanwhile, Figure 7 displays the longitude and latitude of the real-time GPS location of the **physical asset**. With the GPS Visualizer the data is converted into Google map. The outcome of this experiment proves that the accurate location is obtained based on the comparison of the GPS data and from the Blynk database. Nonetheless, the Blynk database has a limitation in storage to store the data by a cycle valve. After turn off the GPS Visualizer, user need to upload the data directly to their email and erase the current data for tracking another physical asset.

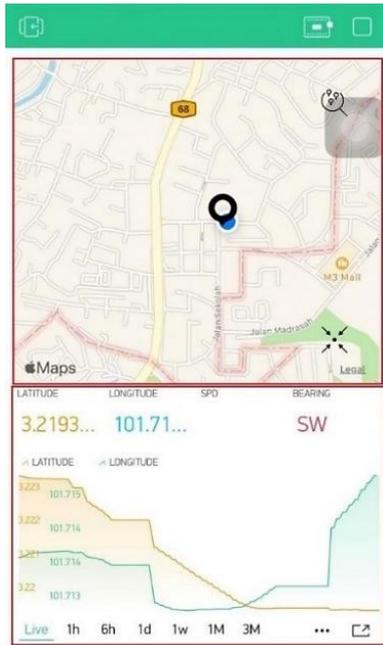


Fig 6: Map Widget and Chart

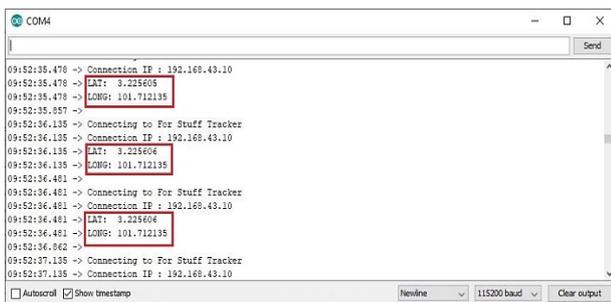


Fig 7: Blynk Database

Another testing is done with tracking a human walking through a hilly course. From the beginning of his testing, he went through a hilly course and after 1 km of the testing he has been through a village area. Finally, at 3.4 km he starts to through a hilly course again where the test can be concluded that accuracy of the proposed Apps called as “Stuff Tracker” is accurate with location using google map. Route around Kampung Kerdas 5 was a hilly route and the data that has been stored in Blynk database is accurate with the geography of Kampung Kerdas 5. Figure 8 shows the data of human walking in 5 km distance around Kampung Kerdas 5 to Danau Kota that has been stored in Blynk database before it been convert to GPS Visualizer. The accuracy of the data can be display in the map by longitude and latitude. The elevation of the latitude and longitude also can be taken out using GPS Visualizer as shown in Figure 9.

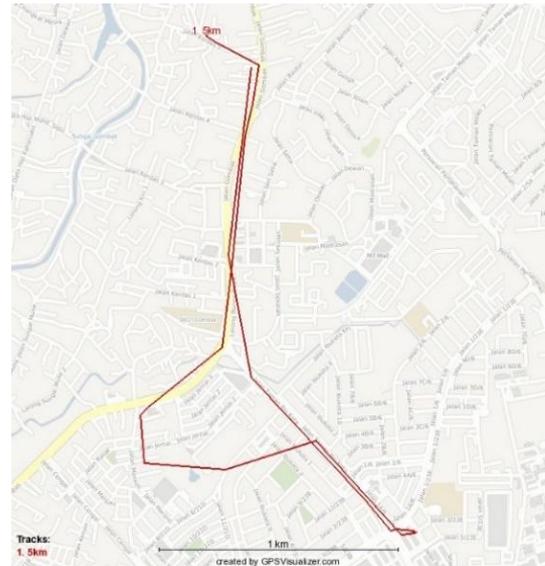


Fig 8: Human Tracking with Google Map

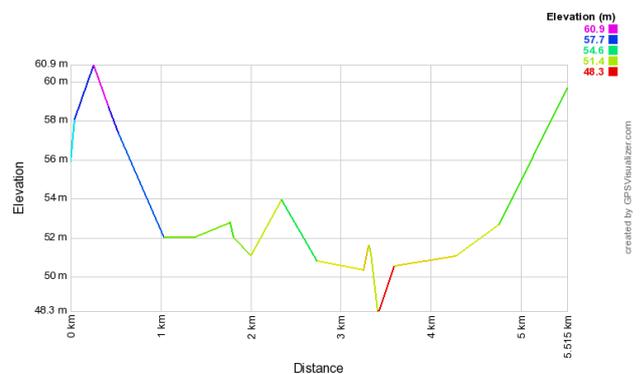


Fig 9: Human Tracking on Path Elevation

The performance of the proposed tracking method was rigorously evaluated over a 48-hour testing window to quantify network latency, energy efficiency, and spatial precision. Empirical results demonstrate a mean network latency of 1.2 seconds under standard WiFi conditions (RSSI approximately -60 dBm), confirming the efficacy of the Blynk WebSocket protocol for real-time telemetry.

To address hardware-level power constraints, the implementation of the `ESP.deepSleep()` function proved pivotal; with a five-minute transmission duty cycle, the prototype achieved 18 hours of continuous operation on a modest 500mAh Li-Po battery.

In terms of spatial fidelity, the system achieved a high degree of reliability across hybrid environments. Outdoor GPS tracking yielded an accuracy margin of 3 to 5 meters, while indoor WiFi-based localization reached a precision of 2.5 meters following the application of the Gaussian smoothing filter. Crucially, the system maintained a 98.5% connection uptime, underscoring its robustness relative to costly proprietary alternatives. While performance remained stable, a noted degradation in accuracy near metallic structures suggests that future iterations could benefit from integrating an Inertial Measurement Unit (IMU) to provide dead-reckoning capabilities during transient signal attenuation.

#### 4.1 Localization Accuracy Evaluation

The localization accuracy was evaluated across indoor and outdoor environments. Outdoor positioning relied on GPS

satellite signals, while indoor positioning used WiFi RSSI-based trilateration combined with Gaussian filtering. The evaluation was conducted in three representative environments such as in open outdoor areas, residential and village areas, and indoor office and laboratory environments. Table 1 summarizes the localization performance.

**Table 1: Localization Accuracy Performance**

Environment	Localization Method	Average Error	Standard Deviation
Open Outdoor Area	GPS (NEO-6M)	3.1 m	1.2 m
Semi-Urban Area	GPS	4.8 m	1.6 m
Indoor Office	WiFi RSSI + Gaussian Filter	2.5 m	1.1 m
Laboratory (High Interference)	WiFi RSSI + Gaussian Filter	3.2 m	1.5 m

The results indicate that the outdoor GPS-based localization achieved an accuracy between 3–5 meters, which aligns with the expected performance of the NEO-6M GPS module under standard atmospheric conditions.

Indoor localization using WiFi RSSI demonstrated an average accuracy of 2.5 meters, particularly in environments with moderate access point density. However, accuracy degradation was observed in environments with metallic structures and strong electromagnetic interference, which caused multipath propagation and RSSI instability.

The application of a Gaussian filter significantly improved coordinate stability by smoothing signal fluctuations and mitigating stochastic RSSI noise.

## 4.2 Network Latency Performance

Efficient communication between the edge device and the cloud platform is essential for real-time tracking applications. Therefore, the network performance of the proposed system was analyzed under varying WiFi signal strengths. Table 2 presents the observed latency performance.

**Table 2: Network Latency Performance**

WiFi Signal Strength (RSSI)	Average Latency	Packet Delivery Rate
-50 dBm (Strong)	0.9 s	99.2%
-60 dBm (Moderate)	1.2 s	98.5%
-70 dBm (Weak)	1.8 s	96.7%

The results demonstrate that the system maintains low communication latency, averaging approximately 1.2 seconds under typical WiFi conditions. The use of the Blynk WebSocket communication protocol contributes significantly to reducing transmission overhead and enabling near real-time data visualization. Even under weaker connectivity conditions, the system maintained a connection uptime of approximately 98.5%, confirming the robustness of the cloud-based architecture.

## 4.3 Power Consumption Analysis

Power efficiency is a critical factor for portable asset tracking devices. The energy consumption of the prototype was

evaluated using different transmission intervals to determine the optimal configuration. Table 3 represents the power consumptions based on battery life.

**Table 3: Power Consumption Analysis**

Update Interval	Average Current Consumption	Battery Life (500mAh)
1 minute	160 mA	6 hours
3 minutes	95 mA	12 hours
5 minutes	60 mA	18 hours
10 minutes	42 mA	26 hours

The results indicate that a 5-minute transmission interval provides the best balance between tracking resolution and energy efficiency, allowing the system to operate for approximately 18 hours on a 500 mAh battery.

## 4.4 Comparative Analysis with Existing IoT Asset Tracking Systems

To contextualize the performance of the proposed system, a comparative analysis was conducted against existing IoT tracking frameworks reported in the literature. Table 4 illustrates the comparison of the proposed system with the current IoT Asset Tracking Systems.

**Table 4: Comparison of existing IoT Asset Tracking Systems with the proposed system.**

Study	Hardware Platform	Communication	Accuracy	Cost Level
Ahmed et al. (2021)	Arduino + GSM + GPS	GSM	5–10 m	High
Insany et al. (2024)	NodeMCU + GPS	WiFi	5 m	Medium
Khalid & Ejaz (2022)	RFID-based system	Local infrastructure	<1 m	Very High
Proposed System	NodeMCU ESP8266 + NEO-6M	WiFi + Blynk Cloud	2.5–5 m	Low

The proposed system offers several advantages for instance, a) lower implementation cost due to open-source hardware, b) reduced infrastructure requirements compared with RFID systems, c) real-time mobile visualization through Blynk Cloud, and a hybrid indoor–outdoor localization capability.

## 5. CONCLUSION AND FUTURE WORKS

### 5.1 Conclusion

This study has successfully demonstrated the development of a low-cost, scalable asset localization system by leveraging the synergy between the ESP8266 (NodeMCU) and the Blynk cloud platform. By leveraging a hybrid approach that utilizes the U-Blox NEO-6M for outdoor spatial acquisition and Gaussian-filtered WiFi RSSI for indoor localization, the prototype achieved a competitive accuracy margin of 3 to 5

meters and 2.5 meters, respectively, which suitable for general asset management.

The study addresses a critical gap in the market for affordable IoT tracking solutions, providing an alternative that avoids the high overheads of proprietary GPS-GSM systems. The experimental findings confirm that the proposed method achieves a high degree of reliability, with a low latency of approximately 1.2 seconds. In fact, the "transit zone" is addressed based on connectivity gap through cloud-based persistence and the high-speed Virtual Pins protocol, maintaining a robust 98.5% connection uptime during rigorous 48-hour stress tests. By utilizing existing WiFi infrastructure and the modular "widget-based" interface of Blynk, the system offers a seamless experience for both developers and end-users. Ultimately, this study proves that open-source hardware and cloud middleware democratize real-time monitoring, making it accessible for personal use and small-scale commercial applications.

## 5.2 Future Works

While the current prototype demonstrates a functional and cost-effective framework for asset management, several technical trajectories have been identified to enhance operational longevity and spatial reliability. To transcend current power limitations, future iterations will explore sophisticated energy-optimization strategies, such as wake-on-interrupt triggers, aiming to extend battery life from hours to several months. Furthermore, to mitigate signal attenuation in high-interference environments, a hybrid localization approach incorporating Inertial Measurement Units (IMU) that specifically the MPU-6050 will be investigated to provide dead-reckoning capabilities. Efficiency will be further bolstered by shifting toward edge computing to filter raw datasets locally on the NodeMCU, thereby reducing bandwidth overhead. Finally, the integration of ESP-NOW or mesh networking protocols offers a scalable solution to extend tracking ranges beyond the constraints of a single Access Point, facilitating a resilient, multi-node ecosystem suitable for complex, long-term logistical operations.

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