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University –Ain Temouchent- Belhadj Bouchaib  
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**SafeFind: A Bluetooth Low Energy (BLE)-Based Smart tag for Preventing the Loss of Personal Belongings**

**Presented By:**

MEBREK Samir Oussama M2 Department of Electronics and Telecommunications

**Before the jury composed of:**

Dr. MERADI Abdelhafid  
Dr. HACHEMI Belkacem  
Dr. HAMLILI Heyem  
Dr. HANDAOUI Mahfoud  
Dr. BENYANI Mourad  
Ms. BENROUAK Wafaa

U.Ain Témouchent President  
U.Ain Témouchent Examiner  
U.Ain Témouchent Supervisor  
U.Ain Témouchent Co-Supervisor  
U.Ain Témouchent Incubator Representative  
Social and economic partner

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## **Abstract**

The loss of personal items such as keys, wallets, and important documents is a widespread issue, often resulting in stress, wasted time, and potential security risks. While existing tracking solutions offer post-loss recovery features, they tend to be expensive, depend on internet connectivity, and are frequently limited by proprietary ecosystems. All of these limitations ultimately make them less practical for global use, especially in countries like Algeria.

This research presents “**SafeFind**”, a preventative tracking system utilizing Bluetooth Low Energy (BLE) technology to effectively reduce the chances of losing belongings occurring before it happens. The SafeFind tag continuously checks the distance between the user’s phone and an item with the use of a machine learning component, a Random Forest classifier trained on real world data of BLE signal features like RSSI (Received Signal Strength Indicator). And detects patterns that signify a potential item lost situation.

The system uses light sleep and deep sleep modes to maximize the battery lifetime of the tag. SafeFind additionally allows for the manual activation of an alarm, safe zone creation and the ability to support multiple devices through a cross-platform mobile app developed with Flutter.

**Key words:** Bluetooth Low Energy (BLE), RSSI, Proximity Detection, Random Forest Classifier, Machine Learning, Preventive Tracking, IoT Security,

## المخلص

يعد فقدان الأغراض الشخصية مثل المفاتيح والمحافظ والوثائق المهمة مشكلة واسعة الانتشار، وغالبًا ما تؤدي إلى الإجهاد وإضاعة الوقت بالإضافة إلى مخاطر الأمنية المحتملة. وعلى الرغم من أن الحلول الحالية توفر ميزات الاسترداد بعد الفقدان، إلا أنها تميل إلى أن تكون باهظة الثمن، وتعتمد على الاتصال بالإنترنت، وغالبًا ما تكون مقيدة الانظمة مغلقة و خاصة. كل هذه القيود تجعلها في النهاية أقل قابلية للاستخدام على نطاق عالمي، خاصة في دول مثل الجزائر.

تقدم هذه الدراسة نظام "SafeFind"، وهو نظام تتبع وقائي يعتمد على تقنية البلوتوث منخفض الطاقة (BLE)، ويهدف إلى تقليل احتمالية فقدان الأغراض الشخصية قبل حدوث ذلك. تقوم علامة SafeFind بالتحقق باستمرار من المسافة بين هاتف المستخدم وأغراضه باستخدام مكون ذكاء اصطناعي، وهو مصنف الغابة العشوائية تم تدريبه على بيانات حقيقية من مميزات إشارة BLE مثل RSSI (مؤشر قوة الإشارة المستقبلية). ليكتشف الأنماط التي تشير إلى حالة فقدان غرض شخصي محتملة.

يستخدم النظام وضعي النوم الخفيف والنوم العميق لزيادة عمر بطارية الجهاز إلى أقصى حد. بالإضافة إلى ذلك، يسمح SafeFind بالتفعيل اليدوي للإنذار، وتعريف مناطق أمنة و تفعيل وتعطيل الانذارات اوتوماتيكيا، والقدرة على دعم أجهزة متعددة من خلال تطبيق جوال متعدد المنصات تم تطويره باستخدام Flutter.

**الكلمات المفتاحية:** البلوتوث منخفض الطاقة (BLE)، مؤشر قوة الإشارة (RSSI)، كشف القرب، مصنف الغابة العشوائية، التعلم الآلي، التتبع الوقائي، أمن إنترنت الأشياء.

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## Résumé

La perte d'objets personnels tels que les clés, les portefeuilles et les documents importants est un problème très répandu, qui entraîne souvent du stress, une perte de temps et des risques potentiels pour la sécurité. Bien que les solutions de suivi existantes offrent des fonctions de récupération après la perte, elles ont tendance à être coûteuses, dépendent de la connectivité Internet et sont souvent limitées par des écosystèmes propriétaires. Toutes ces limitations les rendent finalement moins utilisables pour une distribution mondiale, en particulier dans des régions telles que l'Algérie.

Cette recherche présente “**SafeFind**”, un système de suivi préventif utilisant la technologie Bluetooth Low Energy (BLE) pour réduire efficacement les risques de perte d'objets avant qu'ils ne se produisent. L'étiquette SafeFind vérifie en permanence la distance entre le téléphone de l'utilisateur et les objets à l'aide d'un composant d'apprentissage automatique. Il s'agit d'un classificateur Random Forest formé sur des données réelles de caractéristiques de signaux BLE telles que RSSI (Received Signal Strength Indicator). Le système détecte les modèles qui signifient une situation potentielle de perte d'objet.

Le système utilise des modes de sommeil léger et de sommeil profond pour maximiser la durée de vie de la batterie de l'étiquette. SafeFind permet en outre l'activation manuelle d'une alarme, la création d'une zone de sécurité et la possibilité de prendre en charge plusieurs appareils grâce à une application mobile multiplateforme développée avec Flutter.

**Mots clés :** Bluetooth Low Energy (BLE), RSSI, Détection de proximité, Random Forest Classifier, Machine Learning, Suivi préventif, Sécurité IoT,

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## *Dedication*

**To** my father and mother, whose unwavering love, guidance, and sacrifice have shaped who I am today. Your strength, wisdom, and support have carried me through the toughest of times, and I am forever grateful for the foundation you've given me.

**To** my two sisters, 'Asma' and 'Rofaida', especially the one whose simple idea sparked the beginning of this project.

**To** my niece and nephews, 'Ines' 'Mohammed' and 'Khalil', your presence in my life reminds me why it's worth contributing to the building of a safer future.

**To** my cousin 'Oussama' serving in the military, Your courage inspire me more than you think.

**To** my friends, thank you for standing by me.

**To** every student who dares to dream beyond what their circumstances afford them. And to those who work in silence, with no applause, no shortcuts, and no guarantees, yet persist anyway.

**And finally,** to the unseen guidance that stood by me, you helped me find clarity when I felt lost.

*May this humble contribution reflect my gratitude to each of you.*

---

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I would like to thank the members of **the jury** for evaluating this work. I appreciate their contribution to the academic process.

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## *List of Acronyms*

**AI** : Artificial Intelligence  
**AoA** : Angle of Arrival  
**BLE** : Bluetooth Low Energy  
**CNN** : Convolutional Neural Network  
**DZD** : Algerian Dinars  
**GPS** : Global Positioning System  
**IoT** : Internet of Things  
**iOS** : Apple's mobile operating system  
**LSTM** : Long Short-Term Memory  
**PBS** : Proximity-Based Service  
**PER** : Packet Error Rate  
**RFID** : Radio-Frequency Identification  
**RN** : Receiving Node  
**RSSI** : Received Signal Strength Indicator  
**RTT** : Round-Trip Time  
**SDAS** : The Social Distancing Alert System  
**SNR** : Signal-to-Noise Ratio  
**SVM** : Support Vector Machines  
**T<sub>a</sub>** : Advertising Interval  
**T<sub>s</sub>** : Scanning Interval  
**T<sub>x</sub> Power** : Transmit Power  
**UWB** : Ultra-Wideband  
**Wi-Fi** : Wireless Fidelity  
**RFID** : Radio-Frequency Identification

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## *General Introduction*

Losing personal items such as keys, wallets, and cell phones is a frustrating problem many people deal with all across the world. This issue is compounded in Algeria due to economic constraints and the lack of affordable tech-based options to help prevent such losses. Existing solutions, such as electronic trackers focused on recovery, do not tackle the root of the problem and fail to help people prevent losing their belongings in the first place.

This thesis explores an innovative approach to solving this problem through the development of SafeFind, a personal security device designed to alert users when their belongings are at risk of being lost or left behind. The project was carried out as part of Ministerial Instruction No. 1275, which encourages students to not only engage in academic research but to transform their ideas into viable entrepreneurial projects with real-world applications. This directive aligns with the increasing focus on fostering innovation and creating practical solutions that can have a significant impact on communities.

The primary objective of this project was to create an affordable, efficient, and accessible solution for preventing the loss of personal belongings in a practical and sustainable manner. To achieve this, I developed a Bluetooth Low Energy (BLE)-based device capable of detecting proximity and alerting users when an item is in danger of being misplaced or left behind. The SafeFind system was designed with a focus on simplicity and low power consumption, making it a solution for everyday Algerian users, regardless of their technological background.

By combining BLE technology with a mobile application and incorporating machine learning techniques for accuracy, this work aims to offer a preventive alternative to traditional tracking devices. Through this project, I aim to contribute to the broader movement of making technology more accessible and relevant to local challenges, ultimately helping individuals safeguard their belongings and reduce the emotional and financial costs associated with lost items.

In the following sections, this thesis will outline the problem of lost personal items, the development of the SafeFind system, and the technical methods used to create this solution.

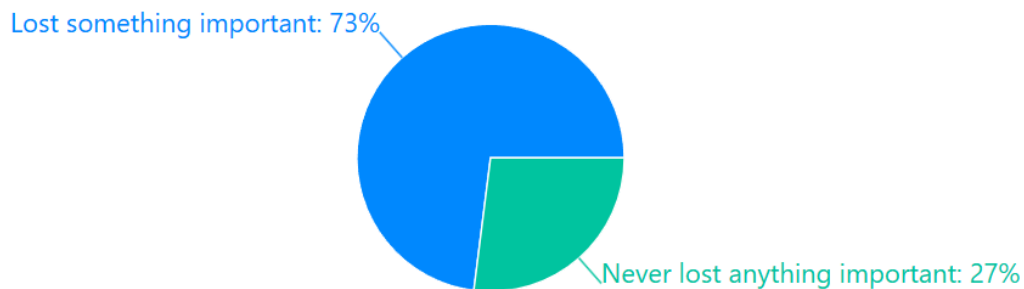
***Chapter I: Understanding the Problem of Lost  
Personal Belongings***

## I.1 Introduction

The loss of personal belongings such as keys and wallets, as well as valuable documents, is a recurring problem in modern life, disrupting routines and leading to emotional and financial costs. The problem, fueled by theft and forgetfulness, runs through the society, especially in Algeria, where economic and infrastructural constraints affect access to solutions. Current methods, such as electronic trackers, are largely insufficient, leaning towards recovery rather than prevention and relying on resources that many people do not have access to. In this chapter, we examine the prevalence and impact of the problem using data from our conducted survey with 100 Algerians, identifying affected groups, assessing current solutions, and proposing potential interventions. Using a systematic analysis, we discuss the dimensions of the problem, examine current vulnerabilities, and set the stage for a practical and preventive strategy for the protection of personal assets.

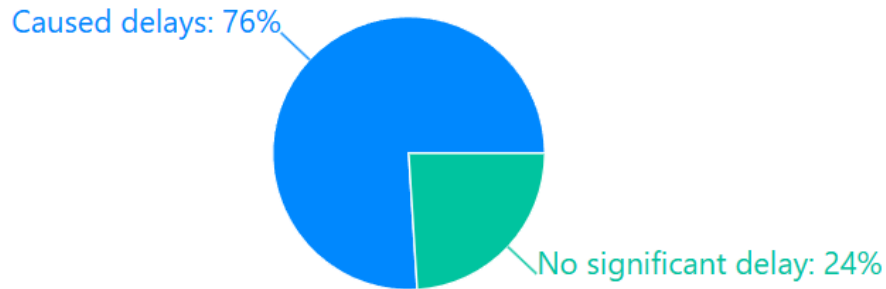
## I.2 Description of the Lost Items Challenge

Within today's world, the loss of essential personal items, comes as a common problem that has a significant emotional, temporal, and financial cost on individuals. This issue disrupts daily routines and generates unnecessary anxiety in a world where security and time are the most valuable commodities. As can be seen in Figure I.1, our survey showed that 73% of respondents had lost an important item on at least one occasion.



**Figure I. 1: Lost Important Items Experience.**

For instance, misplacing keys in the house before one departs for school or work leads to desperate searches and delays, as 76% of our respondents have witnessed delays as a consequence of searching for an item, as seen in Figure I.2.



**Figure I. 2: Delays**

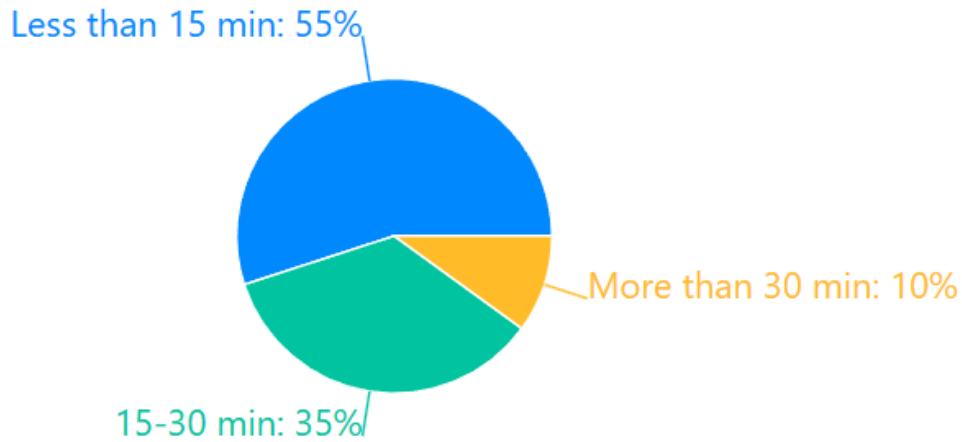
### **I.3 Dimensions of Item Loss**

#### **I.3.1 Misplacement Across Indoor and Outdoor Environments**

The loss of personal belongings happens differently in private versus public, each with distinct effects. Indoors, misplacements often occur in familiar spaces like homes or offices, typically under time-sensitive pressures. As Figure 3 demonstrates, 88% of respondents have lost items at home while rushing, with 76% experiencing delays as a result previously shown in Figure I.2 while Figure I.4 shows Search Time for a lost item at Home.

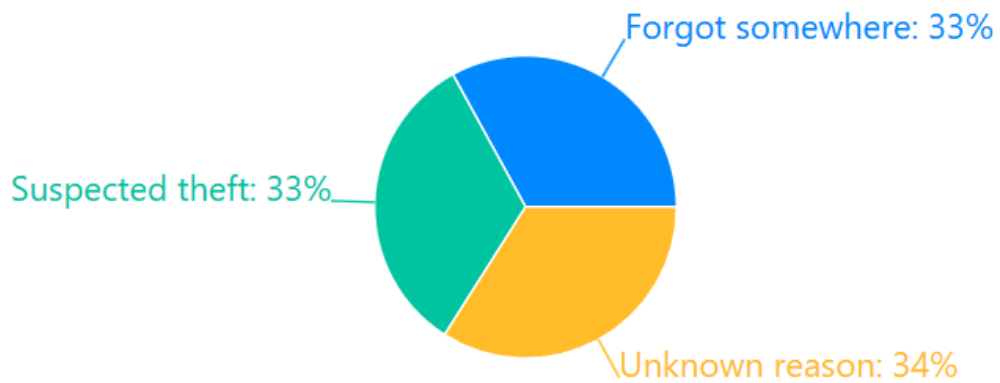


**Figure I. 3: Lost Items at Home**

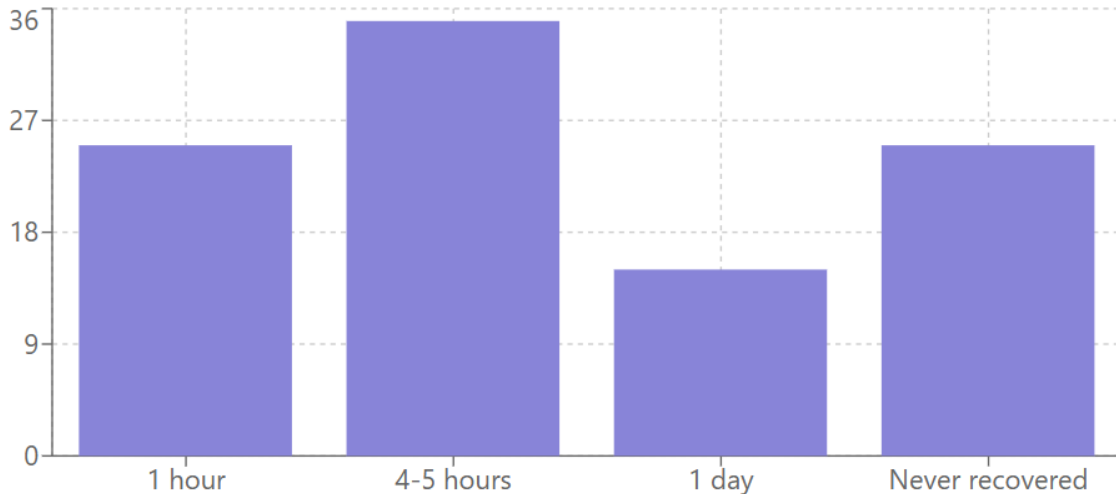


**Figure I. 4: Search Time at Home**

Outdoors, the issue grows more complex in unpredictable public spaces such as markets, buses, or airports. 69% of respondents lost an item outdoors, with reasons evenly split between forgetting items somewhere, suspecting theft, and not knowing exactly what happened as illustrated in Figure I. 5. Recovery is harder outdoors: as shown in Figure I.6, 25% retrieved their item within an hour, 35% took 4-5 hours, 15% needed a full day, and 25% never recovered their belongings.



**Figure I. 5: Reasons for Losing Items Outdoors**



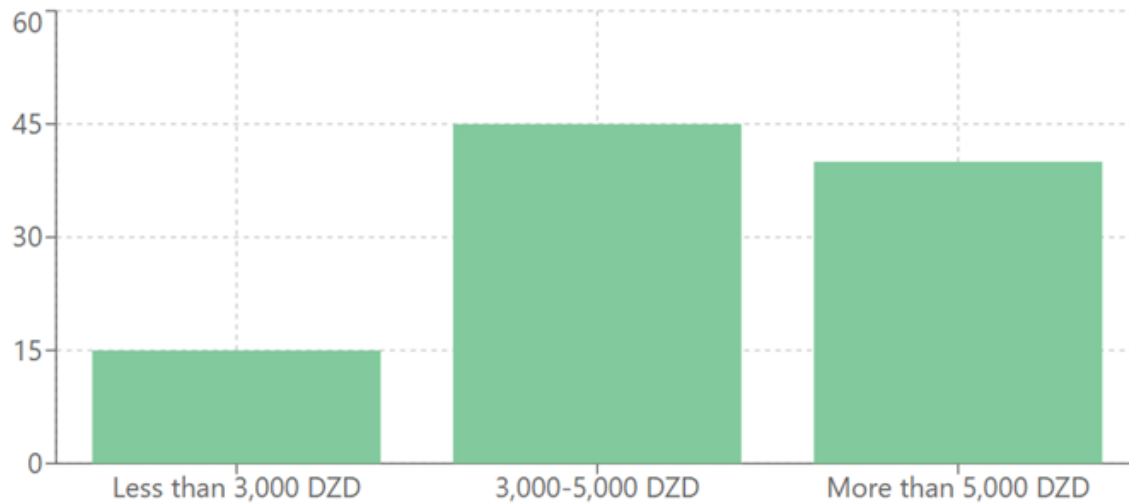
**Figure I. 6: Outdoor Item Recovery Time**

The contrast lies in detection and retrieval: indoor losses cause short-term chaos but are usually resolved, while outdoor losses incur greater logistical challenges and financial consequences, reinforcing the need for a solution adaptable to both contexts.

### **I.3.2 Theft as an Aggravating Factor**

Theft significantly exacerbates the lost-items problem, particularly outdoors, by introducing an external threat beyond personal control. Unlike misplacement, which stems from forgetfulness, theft transforms loss into a deliberate act, prevalent in public settings. As previously illustrated in Figure I.5, our survey results show that approximately 33% of outdoor losses were suspected to be theft, heightening the stakes for affected individuals.

The financial impact is severe, with stolen items like wallets or bags contributing to the substantial costs faced by respondents. Figure I.7 reveals that 45% of respondents face costs between 3,000-5,000 DZD and 40% exceeding 5,000 DZD. This financial burden represents a significant hardship in the Algerian context, where these amounts may constitute a substantial portion of monthly income for many citizens.



**Figure I. 7: Financial Impact**

### **I.3.3 Populations Impacted by Item Loss**

The loss of personal items reverberates across diverse segments of society, with specific populations bearing pronounced consequences due to their unique circumstances.

#### **a. Travelers**

According to the Algerian Ministry of the Interior, there were over 240 million recorded land transport trips, including 35.7 million train journeys, and more than 4 million air travel movements in 2019 [1]. These travelers are typically aged between 18 and 60. navigating local commutes or international journeys, encounter elevated risks in dynamic settings. Figure I.8 demonstrates that 65% of respondents lost something important while traveling, with Figure I.9 showing that 40% experienced loss in another city within Algeria, 35% at transportation hubs (airports, train/bus stations), and 25% in foreign countries. The impact on travel plans was significant, with Figure I.10 revealing that 45% reported major disruptions that affected the trip severely, 40% moderate impact, and only 15% minimal consequences.

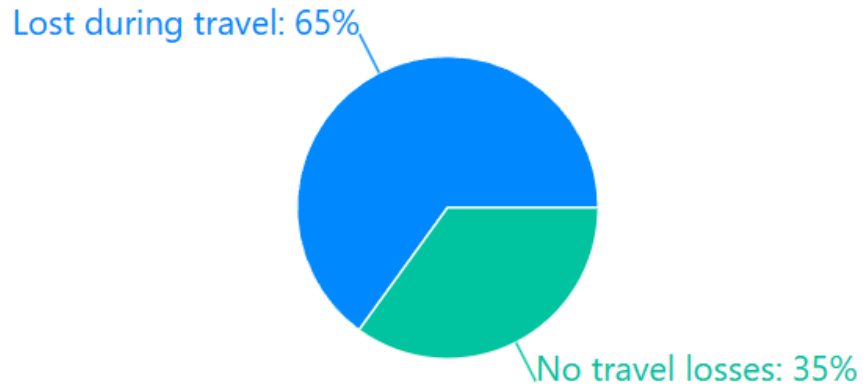


Figure I. 8: Lost Items during Travel

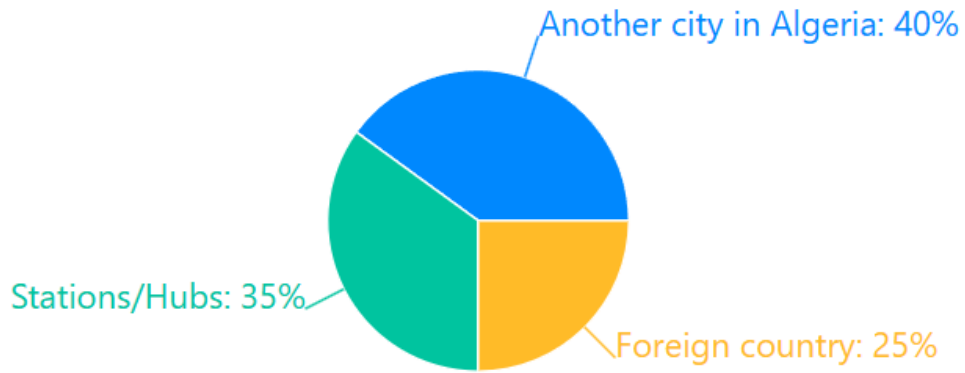


Figure I. 9: Location of Travel Losses

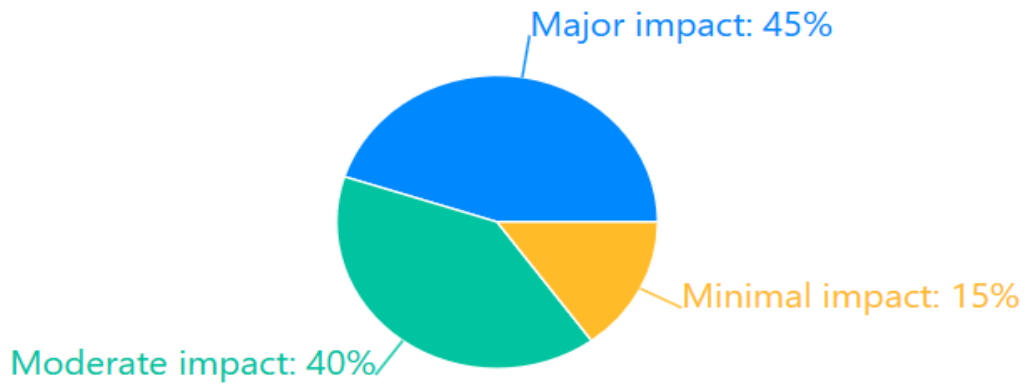


Figure I. 10: Impact on Travel

**b. Students**

Students numbering approximately 1.8 million for the 2024/2025 academic year [2], bound by rigorous schedules and limited resources, face significant disruptions from losing items such as keys, backpacks, or wallets. Half of our survey participants were students, and they reported similar rates of item loss as the general population. For students, misplacing a dormitory key before a lecture can delay attendance, risking missed content or academic penalties, and heightening stress in an already demanding environment where timely access to resources is critical.

**c. Workers**

Workers in time-sensitive roles experience notable setbacks when personal items go missing. In our sample of non-student participants, workers represented a significant portion, and their experiences highlight how lost items directly affect professional responsibilities and reliability. The survey indicates these groups share the universal challenges of wasted time, financial loss, and increased stress when personal belongings go missing.

### **I.4 Existing Strategies for Preventing Item Loss**

In Algeria, the theoretical possibility of using electronic trackers contrasts sharply with the practical reality revealed by our survey. Remarkably, 100% of survey participants reported not using any electronic tracking devices, relying instead solely on personal vigilance.

Electronic trackers, such as Apple AirTags and Tile, SmartTags, are devices that attach to items like keys, wallets, or bags, allowing users to track them through smartphone apps but they have some limitations [3] [4] [5] especially on the Algerian context.

- **Delayed Tracking Response**

Trackers like AirTag, Tile, or SmartTag only show the item's location in a map after the user realizes it's lost, which can cause permanent loss.

- **Dependence on Crowd-Sourced Networks**

Many trackers rely on nearby users with the same app and an internet connection. If no such users are around, location updates fail, especially in rural or low-signal areas.

- **Paid Subscriptions for Full Features**

Some ecosystems require ongoing payments (1,000 to 3,000 DZD/month) to access essential features like smart alerts, extended history, or customer service.

- **Battery Maintenance Costs**

Competitors often use disposable coin batteries, which need to be replaced regularly, adding recurring costs and inconvenience.

- **Limited Device Compatibility**

Trackers like AirTag only work with iOS, and SmartTag only with Samsung Galaxy, making them unusable for many users.

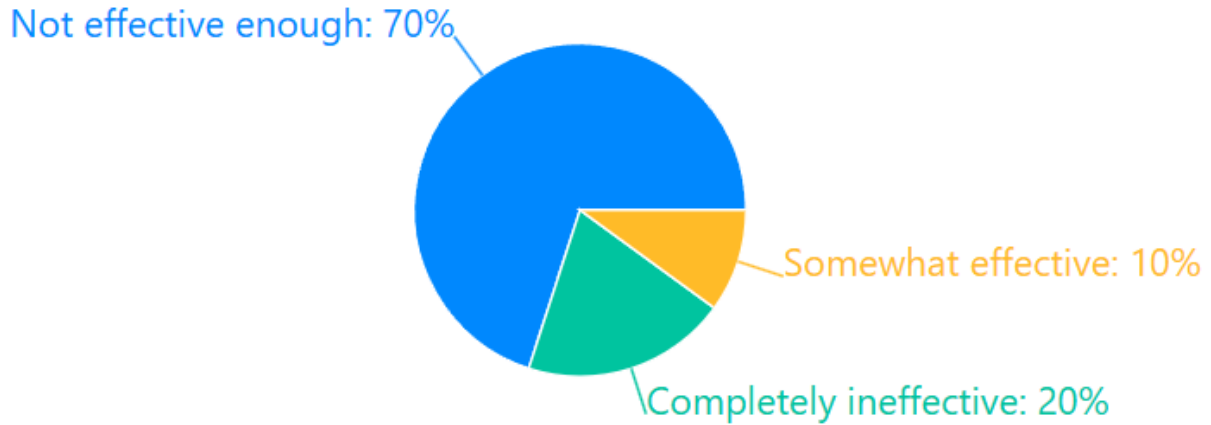
- **High Price and Poor Market Reach in Algeria**

Most imported trackers cost 9,000–12,000 DZD, making them too expensive for many Algerians. They're mostly sold in high-end urban stores, making them inaccessible to rural and small-town consumers.

When asked why they don't use electronic trackers, respondents cited several barriers:

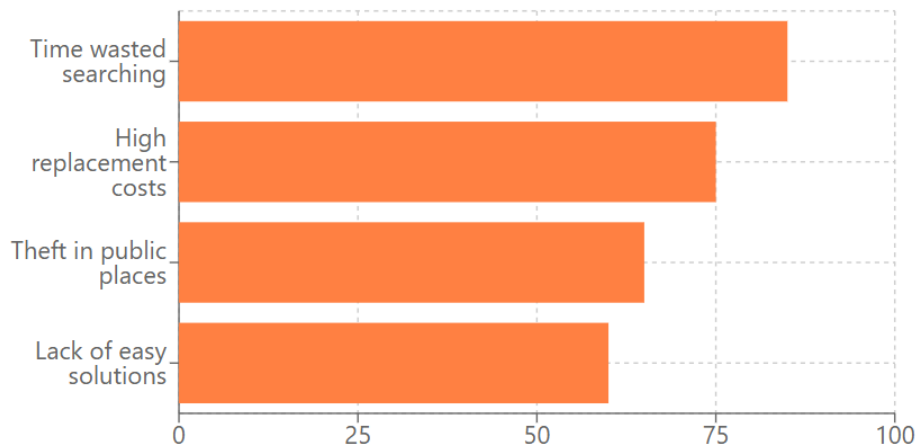
- High cost (approximately 8,000-12,000 DZD)
- Limited availability in the Algerian market
- Technical barriers such as dependence on internet connectivity
- Lack of trust in their effectiveness

As for the existing solutions effectiveness, Figure I.11 illustrates that 70% of respondents believe current methods are not effective enough, 20% consider them completely ineffective, and only 10% find them somewhat effective.



**Figure I. 11: Current Solutions Effectiveness**

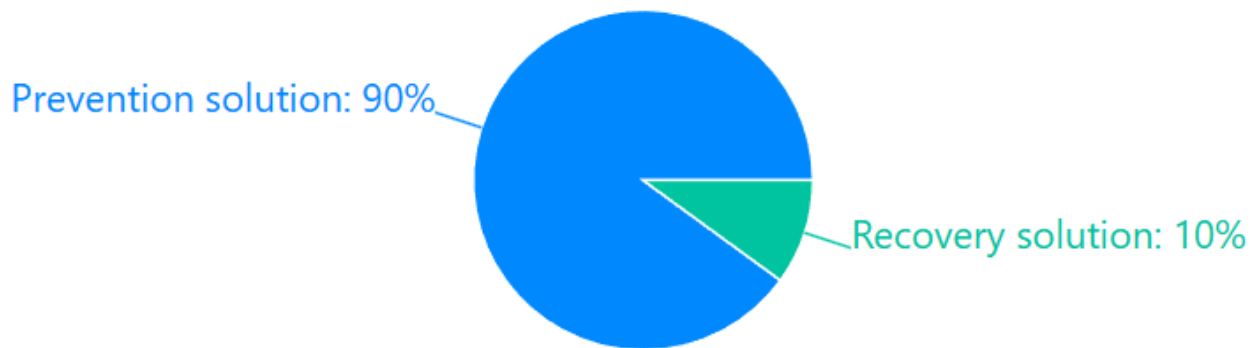
The most commonly cited problems were time wasted searching, high replacement costs, theft in public places, and lack of immediate solutions as Figure I.12 shows.



**Figure I. 12: Common Problems (Multiple Selection)**

### I.5 Conclusion

Our survey confirms that lost personal items represent a significant challenge across diverse Algerian demographics. The problem manifests differently in various contexts—home, public spaces, and during travel—with each setting presenting unique obstacles. Over 90% of respondents expressed a preference for preventive solutions rather than recovery-based approaches, as clearly shown in Figure I.13, highlighting a critical gap in current offerings. Additionally, 100% of participants indicated that they rely solely on carefulness rather than any form of technological aid, revealing a clear opportunity for affordable, contextually appropriate interventions to address this everyday challenge.



**Figure I. 13: Preferred Solution Type**

This overwhelming reliance on vigilance over technology, combined with widespread dissatisfaction with current solutions, creates an opportunity for a new approach. In the next chapter, we explore how Bluetooth Low Energy (BLE) technology known for its low power consumption, affordability, and compatibility can form the backbone of a simple, preventive system that addresses these everyday challenges in the Algerian context.

***Chapter II: The Technology Behind SafeFind: BLE  
Proximity Detection***

## II.1 Introduction

Proximity detection technologies have rapidly evolved to meet the growing demands of personal security, asset tracking, and location-based services. Among these technologies, Bluetooth Low Energy (BLE) stands out for its energy efficiency, affordability, and wide compatibility with modern devices. This chapter thoroughly examined how BLE proximity detection works, covering basic methods like RSSI thresholding and propagation models, as well as more advanced techniques using Artificial Intelligence (AI). By understanding the strengths, limitations, and practical applications of these techniques, we establish a strong technical foundation for building intelligent, reliable proximity-based systems.

### II.1.1 Definition

Proximity detection refers to the process of identifying the presence, relative distance, or location of objects, items, or individuals within a defined range using wireless communication technologies. It exploits signal characteristics, such as received signal strength (RSSI) [6] or timing, to estimate spatial relationships without requiring exact geolocation. Bluetooth Low Energy (BLE), an energy-efficient version of Bluetooth, is a dominant technology for proximity detection due to its low power consumption, cost-effectiveness, and widespread adoption in smartphones and IoT devices, enabling applications like proximity-based services (PBS) [6] and real-time locating systems [8].

### II.1.2 Advantages of BLE for Proximity Detection

The technical, practical, and economic advantages of Bluetooth Low Energy (BLE) make it the most suitable wireless technology for proximity sensing, distinguishing it from alternatives like Wi-Fi, Ultra-Wideband (UWB), or RFID. These benefits enable BLE to scale from small consumer use cases to large enterprise deployments [8].

- **Low Power Usage:** BLE is designed for ultra-low power consumption, suitable for battery-powered devices. It allows devices to operate for years with coin cell batteries by staying in sleep mode most of the time and waking up briefly to transmit or receive data [8].

- **Cross-platform Compatibility:** BLE is universally supported by smartphones, allowing direct communication between smartphones and BLE devices without requiring extra hardware [8].
- **Cost-effective:** BLE is cost effective for large scale IoT deployments, as its hardware is affordable, supporting extensive beacon networks [8].
- **Small Form Factor:** BLE devices are small, with chipsets and antennas compact enough to fit wearable devices, labels, or even stickers or adhesives.
- **Reliability:** BLE operates in the 2.4GHz ISM band and uses adaptive frequency hopping to minimize interference from other wireless technologies like Wi-Fi, Zigbee, microwave ovens [8]. It is effective in:
  - Congested environments where BLE maintains reliable communication in environments with high device density.
  - Noisy RF conditions where adaptive frequency hopping reduces the impact of co-located wireless technologies [8].
  - Indoor environments where satellite-based GPS is unreliable, making BLE suitable for proximity detection [6, 8].
- **Privacy and Security:** BLE ensures privacy through encrypted user IDs in presence messages, preventing tracking or identification, and uses lightweight advertising packets with minimal data like UUIDs, Major/Minor values [8].
- **Low Latency for Real-Time Applications:** BLE achieves low transaction latency (a few milliseconds), enabling real-time applications like interactive locating systems [8].

These advantages position BLE as the preferred technology for proximity detection, offering superior energy efficiency and simpler infrastructure compared to Wi-Fi, which consumes more power and requires complex setups [8].

### II.13 Applications of Proximity Detection

- **Healthcare:**
  - **Contact Tracing:** BLE enables social distancing by detecting proximity between users' smartphones. The Social Distancing Alert System (SDAS) uses RSSI and TxPower to estimate distance and issue alerts (Green: Safe, Yellow: Caution,

Orange: Warning, Red: Danger) to prevent COVID-19 spread, storing data locally for privacy [6].

- **Retail:**

- Personalized Marketing: BLE beacons deliver proximity-based services (PBS) by sending signals to smartphones with a pre-installed app, triggering personalized promotions based on the user's location (example: department or product) and customer profile data [6].
- Customer Analytics: Beacons collect data on shopper foot traffic and engagement, enabling retailers to optimize store layouts, reduce checkout wait times, and enhance customer segmentation for retargeting campaigns [6].

- **Smart Homes:**

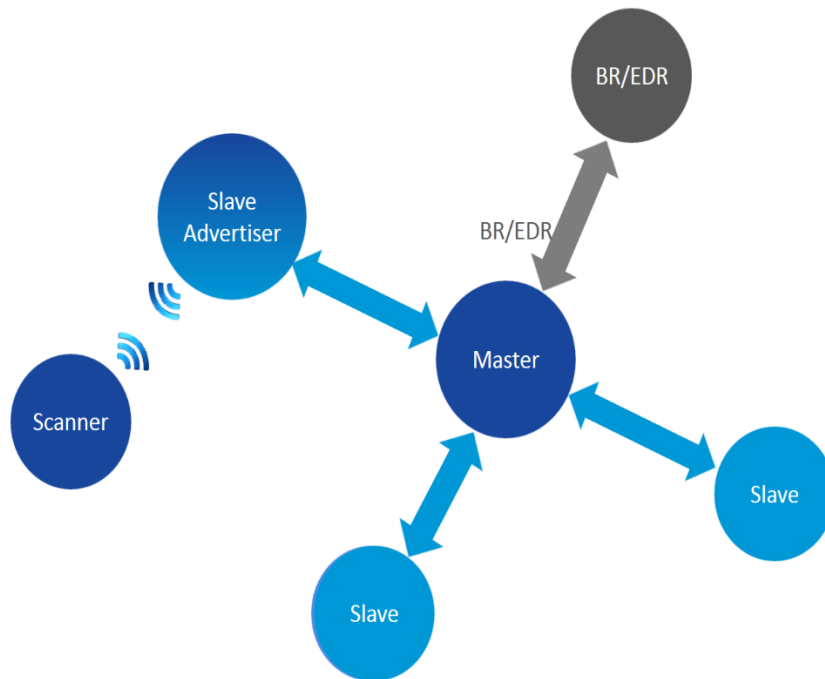
- Automation: BLE triggers actions like turning on lights or adjusting thermostats when a user's smartphone is detected nearby, supporting IoT-based home automation [8].
- Energy Efficiency: Proximity-based automation activates devices only when needed, reducing energy waste [8].

- **Security:**

- Access Control: BLE enables keyless entry systems, where smartphones authenticate users based on proximity to doors or gates, enhancing security in IoT applications [8].

## **II.2 Principles of BLE for Proximity Detection**

BLE is a short-range technology operating in the unlicensed 2.4-GHz ISM band, where a central device can initiate a connection and exchange data with a peripheral device [9]. A master device, such as a smartphone, initiates and controls communication with one or more slave devices, like beacons, as illustrated in Figure 1. The advertisement and scanning processes are the primary mechanisms for BLE-based proximity detection [9]. A PBS (Proximity-Based Service) system uses BLE beacons to communicate with the RN (Receiving Node) before providing the service through regular advertising signals [10].

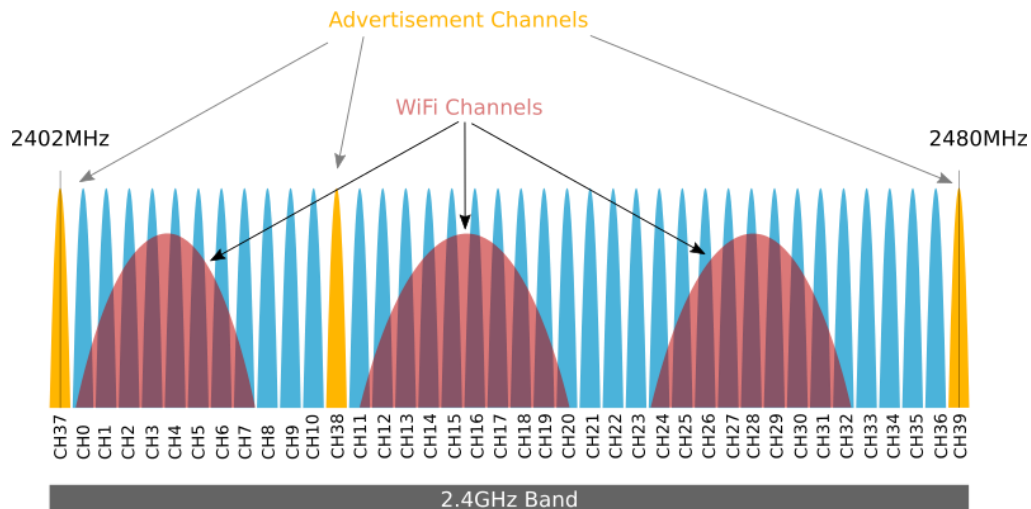


**Figure II. 1: Slave/master relations**

**a) Advertising**

BLE beacons periodically transmit advertisement packets that include useful information, such as UUID and RSSI calibration value [9]. A BLE beacon advertises its signals periodically according to a pre-configured advertising interval ( $T_a$ ), which defines the frequency of the beacon signals being transmitted [10]. The advertisement process utilizes three channels (37, 38, and 39) as illustrated in Figure 2 to minimize interference with other technologies operating in the 2.4-GHz band [9]. The advertising packets contain various data, including:

- UUID to identify the beacon [9].
- RSSI calibration value at 1 m [9].
- Environmental data from sensors (example: temperature, motion) in IoT applications [4].



**Figure II. 2: BLE Advertising channels <sup>1</sup>**

In Bluetooth 4.0 and 4.1, advertising packets are limited to 31 bytes. Bluetooth 5 introduces Extended Advertising, increasing the payload to 255 bytes. The advertising interval can be configured from 20 ms to 10.24 s, affecting power consumption and detection latency [9]. For example:

- An interval of 100 MS is used in applications that are latency-sensitive like smart access control systems that require immediate device recognition [9].
- A 1000 ms interval is common in power-constrained devices, like beacons, prioritizing battery life over detection speed [9].

#### **b) Scanning**

Before an RN can measure any incoming signals, it must first initiate scanning [10]. Scanners, such as smartphones or IoT gateways, monitor the three advertising channels to capture packets. Scanning operates in two modes:

---

<sup>1</sup> <https://argenox.com/library/bluetooth-low-energy/ble-advertising-primer/>

- **Passive Scanning:** The scanner listens without responding, conserving energy. This technique is used in applications like retail marketing, where a smartphone receives beacon packets to display notifications.
- **Active Scanning:** The scanner sends a scan request to the advertising device and awaits a scan response for additional data, such as device capabilities or telemetry.

Scanning parameters, such as scan windows (duration of active listening) and scan intervals (frequency of scanning cycles), balance detection speed and power consumption:

- **Continuous Scanning:** Used in latency-sensitive applications, like access control, where the scanner listens constantly, consuming more power.
- **Duty-Cycled Scanning:** Common in battery-powered devices, where the scanner listens intermittently (e.g., 10 ms every 1000 ms), reducing energy use but introducing detection delays.

In general, the scanning interval ( $T_s$ ) must be at least two times greater than the advertising interval ( $T_a$ ) to ensure a high signal acquisition rate [10].

### c) Connections

Connections establish a bidirectional communication link between two BLE devices using 37 data channels (0-36) in the 2.4 GHz band, employing adaptive frequency hopping to avoid interference. A master device, such as a smartphone, initiates a connection with a slave device, like a sensor, forming a point-to-point link. Data exchange occurs at connection intervals (7.5 ms to 4 s), with shorter intervals enabling faster data transfer but increasing power consumption.

Non-connected modes are preferred for proximity detection to save power and avoid the overhead of establishing and maintaining connections [9]. A PBS system leverages the BLE beacons without requiring a connection [9]. This technique enables scalable systems where one broadcaster can be detected by multiple scanners simultaneously, ideal for applications like retail beacons or contact tracing. Connections are used in rare cases requiring precise ranging or secure data exchange, such as BLE-based access control systems verifying user credentials after detecting proximity via advertising.

The advertisement and scanning processes are the primary mechanisms for BLE-based proximity detection [9]. The fundamental infrastructure of a beacon-based PBS system is the deployed BLE beacons [10]. By configuring advertising intervals, scanning parameters, and packet contents, developers can tailor BLE's behavior to applications ranging from real-time access control to long-term asset tracking.

### II.2.1 Key Metrics

Three key metrics—Received Signal Strength Indicator (RSSI), Tx Power, and Path Loss—form the foundation for traditional and advanced proximity detection methods. Below, these metrics are discussed, along with their roles.

#### a) RSSI (Received Signal Strength Indicator)

RSSI is the received signal strength indicator, measured in dBm, used to estimate the distance between devices [9]. RSSI describes the log-ratio of the received power (in mW) to the referenced power of 1 mW. It is defined [10] as:

$$RSSI = 10 \log_{10}(Pr(mW)) \quad (II.1)$$

Where:

- RSSI (dBm): The received signal power expressed in decibels relative to 1 milliwatt (dBm).
- Pr, (Wat) : The received signal power in milliwatts.

RSSI values are negative and decrease with distance, but environmental noise can affect accuracy [9].

#### b) Tx Power (Transmit Power)

Tx power is configurable and included in the advertisement packet as the RSSI calibration value [9]. It is included in advertising packets as "measured power," representing the expected RSSI at 1 meter [9]. For example, a beacon with a Tx Power of  $-59$  dBm implies that, under ideal conditions, the RSSI at 1 meter should be approximately  $-59$  dBm.

$$Tx Power = 10 \log_{10}(P_{tx} (mW)) \quad (II.2)$$

Where:

- Tx Power(dBm): Transmit power in dBm (decibels relative to 1 mW)
- P<sub>tx</sub>(mW): Transmit power in milliwatts (mW)

### c) Path Loss

Path loss is the attenuation of the BLE signal strength as it propagates [9]. These attenuations are caused by distance, obstacles, and environmental factors, it is calculated as:

$$Path Loss (dB) = Tx Power (dBm) - RSSI (dBm) \quad (II.3)$$

### d) Additional Metrics

Beyond RSSI, Tx Power, and Path Loss, other metrics influence BLE proximity detection:

- Signal-to-Noise Ratio (SNR): The ratio of signal power to background noise affects RSSI reliability. Low SNR in noisy environments reduces detection accuracy.[9]

$$SNR (dB) = 10 \times \log_{10} \left( \frac{P_r}{P_{noise}} \right) \quad (II.4)$$

Where:

- SNR (dB): Signal-to-Noise Ratio expressed in decibels
  - P<sub>r</sub>: Power of the received signal in milliwatts
  - P<sub>noise</sub>: Power of the background noise in milliwatts
- Packet Loss Rate: In dense or interfered environments, packet loss reduces RSSI measurement frequency, impacting proximity estimation. it is calculated as:

$$Packet Loss Rate (\%) = \frac{\text{Number of Lost Packets}}{\text{Total Number of Transmitted Packets}} \times 100 \quad (II.5)$$

- Packet Error Rate (PER): The ratio of incorrectly received packets to total received packets, indicating transmission quality degradation due to interference, distance, or obstacles, which affects the reliability of BLE-based proximity estimations. It is calculated as:

$$\text{PER} = \frac{\text{Number of Incorrectly Received Packets}}{\text{Total Number of Received Packets}} \quad (\text{II.6})$$

### II.3 Traditional Proximity Detection Methods

Traditional proximity detection methods use BLE signal attributes to estimate the proximity of devices. These methods vary in terms of accuracy, complexity, and environmental dependencies. Below is an explanation of the RSSI thresholding, Radio Propagation Models (Friis and Log-Distance Path Loss), Round-Trip Time (RTT), and Angle of Arrival (AoA) methods.

#### II.3.1 RSSI Thresholding

Instead of calculating exact distances, many applications define proximity zones based on RSSI thresholds:

- Immediate:  $\text{RSSI} > -70 \text{ dBm}$
- Near:  $-70 \text{ dBm} \geq \text{RSSI} > -85 \text{ dBm}$
- Far:  $\text{RSSI} \leq -85 \text{ dBm}$

These thresholds are not standardized and should be calibrated for specific environments and devices.

#### ❖ Advantages:

- takes minimal computational power, so it can be used on resource-limited devices such as beacons or low-end smartphones.
- Offers near-instantaneous proximity classification, suitable for real-time applications.
- Adequate for applications where exact distance is not significant.

#### ❖ Limitations:

- Reflections off walls or objects cause RSSI jumps for example  $\pm 10 \text{ dBm}$  within seconds.

- 2.4 GHz noise from Wi-Fi or other BLE devices distorts RSSI readings.
- Differences in antenna design and orientation across devices.
- Thresholding provides simple categories like near/far rather than continuous distance estimates. [11]
- Thresholds must be calibrated for each environment, as a -65 dBm threshold in an open space and cluttered room can give different distances.

### II.3.2 Radio Propagation Models

Radio propagation models like the Friis Transmission Equation and Log-Distance Path Loss Model are fundamental tools in BLE proximity detection. While originally developed to predict signal attenuation over distance, they are commonly rearranged to estimate the distance between devices based on measured signal strength (RSSI).

#### a) Friis Transmission Equation:

The Friis Transmission Equation models the signal strength in free-space, assuming line-of-sight conditions between the transmitter and receiver.

- Formula:

$$P_r = P_t + G_t + G_r - 20 \cdot \log_{10}(d) - 20 \cdot \log_{10}(f) - 32.44 \quad (\text{II.7})$$

- $P_r$ : received power (RSSI, in dBm)
- $P_t$ : Transmitted power (Tx Power, in dBm)
- $G_t, G_r$ : Antenna gains (in dB)
- $d$ : Distance (meters)
- $f$ : Frequency (2.4 GHz for BLE)
- 32.44 is a constant that converts units and adjusts for the free-space conditions at 1 km and 1 MHz.

To make the Friis model practical for BLE proximity detection, the model is simplified by considering fixed parameters and removing unnecessary complexity.

- For BLE, the frequency  $f$  is fixed at **2.4 GHz** (2400 MHz),

$$20\log_{10}(f) = 20\log_{10}(2400) \approx 67.6 \quad (\text{II.8})$$

- BLE devices typically use simple antennas, and  $G_t$  and  $G_r$  are either negligible or already incorporated into the transmitted power  $P_t$ . Therefore:

$$G_t + G_r \approx 0 \quad (\text{II.9})$$

- combine all constants into a calibration factor  $C$ . The equation becomes:

$$C = -20\log_{10}(f) - 32.44 + G_t + G_r \approx -67.6 - 32.44 + 0 = -100.04 \quad (\text{II.10})$$

The simplified version of the Friis model for BLE proximity detection, assuming  $P_t$  is already calibrated, becomes:

$$RSSI = Tx\ Power - 20 \cdot \log_{10}(d) + C \quad (\text{II.12})$$

- Where  $C$  is a constant that includes factors like antenna gains and frequency.
- Using the simplified version of the Friis model, we can estimate the distance based on RSSI by rearranging the formula:

$$d = 10^{\frac{(Tx\ Power - RSSI + C)}{20}} \quad (\text{II.13})$$

❖ Advantages:

- takes minimal computational power
- Works well in free-space environments.

❖ Limitations:

- Not accurate in indoor environments due to obstacles.
- Overestimates distance in obstructed areas.
- Device variations can affect accuracy. [12]

### b) Log-Distance Path Loss Model

The Log-Distance Path Loss Model accounts for environmental factors, such as walls and furniture, which cause signal attenuation. Unlike the Friis model, this model provides more accurate results in indoor environments. The model assumes the signal strength decays

logarithmically with distance, and the path loss exponent  $n$  helps adjust the model based on the environment ( $n=2$  for free space,  $n=3-4$  for indoor environments).

- Formula:

$$\text{Path Loss} = PL_0 + 10n * \log_{10} \left( \frac{d}{d_0} \right) \quad (\text{II.14})$$

- $PL_0$  is the path loss at the reference (usually 1 meter)
  - $n$  is the path loss exponent
  - $d$  is the distance between the devices
  - $d_0$  is the reference distance
- The RSSI value can be expressed as:

$$\text{RSSI} = \text{Tx Power} - PL_0 - 10n \log_{10} \left( \frac{d}{d_0} \right) \quad (\text{II.15})$$

- Distance Calculation:

$$d = d_0 \cdot 10^{\frac{(\text{Tx Power} - \text{RSSI} - PL_0)}{10n}} \quad (\text{II.16})$$

- Where:
  - $PL_0$  is the path loss at the reference distance (usually 1 meter)
  - $n$  is the path loss exponent (2 for free space, 3–4 for indoors)
  - $d$  is the estimated distance
  - $d_0$  is the reference distance
- a beacon would advertise its Tx Power or reference RSSI.
- The receiver measures RSSI and applies the model with the calibrated parameters  $n$  and  $PL_0$
- The model estimates the distance based on RSSI.

❖ **Advantages**

- Adjusts for obstacles like walls and furniture.
- Provides precise distance rather than simple zones.
- Better at handling multipath and interference compared to the Friis model.

❖ **Limitations**

- Needs to be calibrated for each environment.
- Changes in the environment (like rearranging furniture) affect the model's accuracy.
- Differences in devices can affect RSSI. [13]

**II.3.3 Round-Trip Time (RTT) and Angle of Arrival (AoA)****a) Round-Trip Time (RTT)**

To overcome the limitations of RSSI in proximity detection, Round-Trip Time (RTT) can be used as a ranging method in Bluetooth Low Energy (BLE) systems. The approach measures the time it takes for a SCAN request packet to travel from a scanner to a BLE advertiser and for the advertiser to respond with a SCAN response packet. The scanner uses its CPU clock to measure the total RTT in clock cycles as presented in Figure II.3. [14]

- The RTT includes both the signal propagation time ( $2t$ ) and internal processing delays:

$$RTT = 2t + \mathit{delay} \quad (\text{II.17})$$

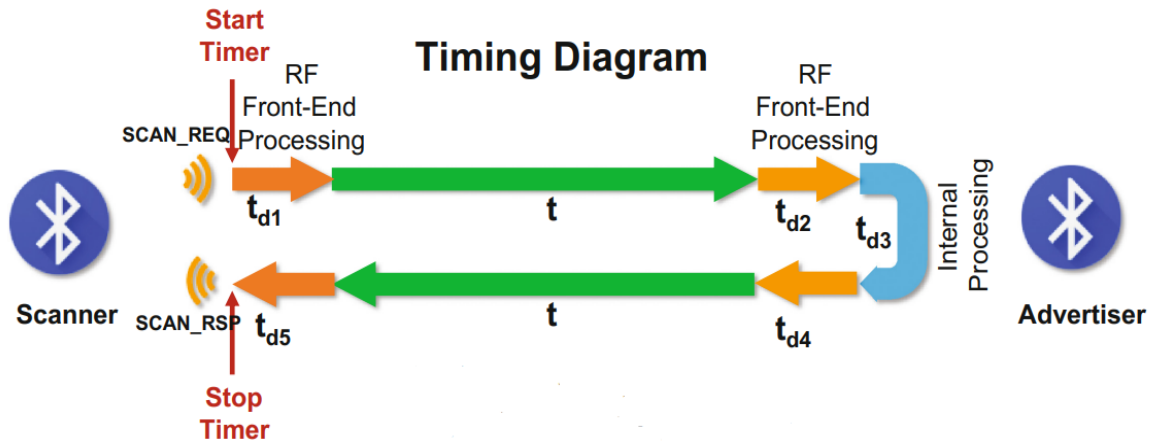
$$\mathit{delay} = \mathit{td1} + \mathit{td2} + \mathit{td3} + \mathit{td4} + \mathit{td5} \quad (\text{II.18})$$

- Where  $\mathit{tdi}$  are various internal delays in the scanner and advertiser.

To estimate distance using RTT in BLE systems, the theoretical formula is:

$$\mathit{distance} = \frac{c \cdot (RTT - \mathit{delay})}{2} \quad (\text{II.19})$$

where  $c$  is the speed of light ( $\sim 3 \times 10^8$ )m/s,  $RTT$  is the round-trip time, and  $delay$  accounts for internal processing time in both the scanner and advertiser devices.



**Figure II.3: Timing diagram of RTT determination by sending SCAN\_REQ and receiving SCAN\_RSP packet.**

#### ❖ Advantages

- Less affected by environmental factors than signal strength methods.
- No need for precise time synchronization between devices.
- More accurate than RSSI-based methods in most environments.
- Better resistance to radio interference from other devices.[14]

#### ❖ Limitations

- Heavily dependent on hardware timing capabilities.
- Internal processing delays can exceed actual flight time at short distances.
- Multipath signal reflections cause measurement errors.
- Requires calibration for hardware-specific delays and environmental changes.[14]

#### **b) Angle of Arrival (AoA)**

Angle of Arrival (AoA), introduced in Bluetooth 5.1, estimates the direction of a BLE signal by analyzing phase differences across multiple antennas in an array. Combined with RSSI or RTT, AoA enables 2D or 3D positioning with high accuracy.[16]

- The transmitter sends a packet with a constant tone extension (CTE), a sequence of unmodulated carrier waves.
- The receiver's antenna array measures the phase of the signal at each antenna.
- Phase differences are used to calculate the angle of incidence using:

$$\theta = \arcsin\left(\frac{(\Delta\phi \cdot \lambda)}{(2\pi \cdot d)}\right) \quad (\text{II.20})$$

Where:

- **$\theta$** : Angle of arrival
- **$\Delta\phi$** : Phase difference
- **$\lambda$** : Wavelength 12.5 cm at 2.4 GHz
- **$d$** : Antenna spacing
- Multiple angles from different receivers enable triangulation for precise positioning. [15]

#### ❖ Applications

- Tracks devices in retail or hospitals with sub-meter accuracy.
- Locates equipment in 2D/3D space for inventory management.
- Guides users in complex venues like museums or campuses.
- Monitors machinery or workers with directional context.

#### ❖ Advantages

- Provides angular resolution of 1–5 degrees, enabling sub-meter positioning when combined with ranging.
- Phase-based measurements are less affected by reflections than RSSI.
- Supports height estimation, unlike RSSI-based methods.
- Multiple receivers improve accuracy via triangulation.

#### ❖ Limitations

- Requires antenna arrays 4–16 antennas, increasing cost and size compared to single antenna BLE devices.
- Phase processing and triangulation demand significant resources, challenging for low power devices.
- Severe obstructions degrade accuracy, though less than RSSI methods.

- AoA is new introduced in Bluetooth 5.1, 2019, with fewer compatible devices as of 2025.
- Antenna spacing and orientation must be precisely calibrated. [15]

**c) Combined RTT and AoA**

When both RTT and AoA are used together, the distance can be calculated with high accuracy. By using the AoA to determine the angle and the RTT to determine the distance, you can triangulate the exact position of the device.

the device's position can be determined in a 2D or 3D space by combining these two measurements.

**d) Comparative Analysis:**

Method	Accuracy	Complexity	Calibration	Environment	Use Cases
RSSI Thresholding	Low (3–10 m)	Low	Moderate	All	Retail, smart homes
Friis Equation	Low (5–20 m)	Low	Low	Outdoor	Prototyping, open spaces
Log-Distance Model	Moderate (1–5 m)	Moderate	High	Indoor, outdoor	Navigation, asset tracking
RF Fingerprinting	High (1–2 m)	High	Very High	Indoor, static	Positioning, analytics
RTT	Very High (0.1–0.5 m)	High	Moderate	All,	Tracking, robotics
AoA	High (0.5–1 m)	Very High	High	Indoor	Positioning, navigation

**Table 1: comparison between traditional proximity detection methods**

These traditional methods provide a robust foundation for BLE proximity detection, with each suited to specific scenarios. Their limitations, particularly in dynamic or noisy environments, have driven the adoption of advanced AI-based approaches for greater accuracy and adaptability.

**II.4 Advanced Approaches with AI**

Traditional BLE proximity detection methods, such as RSSI thresholding and propagation models, suffer from limitations like environmental noise sensitivity, device variability, and calibration challenges. Artificial Intelligence (AI) offers advanced techniques to overcome these issues by leveraging machine learning to model complex signal patterns, adapt to dynamic

environments, and improve accuracy. AI-based approaches are categorized into Supervised Learning, Unsupervised Learning, and Deep Learning, each providing unique capabilities for proximity detection.

#### **II.4.1 Supervised Learning for BLE Proximity Detection**

Supervised learning involves training a model on labeled datasets, where the relationship between inputs and outputs is known. In the context of BLE proximity detection, algorithms such as Support Vector Machines (SVM) and Random Forests can be used to analyze features extracted from Received Signal Strength Indicator (RSSI) measurements, including signal mean, variance, and fluctuation patterns. These algorithms can classify proximity into different levels, such as "near," "medium," and "far," based on thousands of real-world signal measurements, which take into account environmental factors like multipath propagation and interference.[17]

##### **❖ Implementation Example:**

In indoor environments, Random Forest classifiers have been applied to BLE-based proximity detection, achieving an accuracy rate of up to 95%. This performance improvement over traditional threshold-based methods demonstrates the effectiveness of supervised learning models. By training on varied environmental conditions, these systems adapt to real-time signal fluctuations caused by obstacles, interference, and multipath propagation.[17]

#### **II.4.2 Unsupervised Learning for BLE Proximity Detection**

Unsupervised learning is used when labeled training data is unavailable. Clustering algorithms like K-means or DBSCAN sort similar BLE signal patterns into groups, making it easier to find areas that are close together without needing set categories. This capability is particularly useful for BLE systems in dynamic environments with fluctuating signal behaviors. Unsupervised learning allows for the dynamic adjustment of proximity zones based on observed RSSI distributions, overcoming the limitations of fixed thresholds, which might not work well in different situations. [18]

**❖ Implementation Example:**

In A study published in the Journal of Electronics, K-means clustering was applied to BLE RSSI measurements to automatically identify proximity zones. The K-means algorithm grouped similar signal patterns, enabling the system to adapt to different devices and environmental conditions. The clustering method offered a flexible solution, capable of handling dynamic and fluctuating signal behaviors caused by obstacles, interference, and environmental changes.[18]

**II.4.3 Deep Learning for BLE Proximity Detection**

Deep learning, particularly using neural network architectures like Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks, has shown great promise for Bluetooth Low Energy (BLE) proximity detection. By processing raw or minimally filtered RSSI sequences, these deep models can understand complicated patterns in signal behavior, effectively recognizing both time-related and location-related changes. For example, LSTM networks are adept at modeling the sequential nature of RSSI variations, which may be influenced by human motion or environmental factors. This improves the accuracy and reliability of proximity detection, surpassing the performance of shallow models. While deep learning approaches require large datasets and considerable computational resources, they offer highly adaptive and resilient solutions for BLE proximity systems.[19]

**❖ Implementation Example:** A study published in the Journal of Electronics (2022) demonstrated how CNN-LSTM architectures can be used for BLE proximity detection by leveraging continuous RSSI measurements. The model effectively estimated distances in dynamic indoor environments, reducing positioning error compared to traditional triangulation methods [19].

## II.5 Conclusion

In this chapter, we explored the core principles, traditional techniques, and AI-enhanced methods that enable accurate BLE-based proximity detection. We looked at how signal features like RSSI, Tx Power, and path loss are used, and we examined traditional methods like the Friis equation, Log-Distance Path Loss, and Round-Trip Time (RTT), along with newer machine learning models. This understanding is crucial for designing proximity systems that perform reliably in dynamic, real-world environments.

In the next chapter, we will apply these BLE proximity techniques to implement **SafeFind**, a personal security system designed to alert users when their belongings are at risk of being lost or left behind. By combining the theoretical foundations covered here with practical system design, we will create a more responsive solution for travelers and everyday users alike.

***Chapter III: Designing and Implementing  
SafeFind: A Preventive Personal Security Solution***

### III.1 Introduction

As discussed in the previous chapter, Bluetooth Low Energy offers a reliable, energy-efficient means for estimating proximity between devices, making it an ideal foundation for a personal security application.

Building upon this technology, the SafeFind system was developed to provide users with real-time alerts when their valuable belongings are at risk of being left behind or misplaced.

Unlike traditional electronic trackers, which focus primarily on item recovery after loss, SafeFind emphasizes preventing the loss of personal items in the first place.

This chapter outlines the design goals, system architecture, device features, and mobile application development, illustrating how BLE and machine learning techniques were integrated to ensure effective performance while maintaining low power consumption.

### III.2 System Description

This section outlines the goals and features of the system, highlighting its design and user-centric functionalities.

#### III.2.1 Goals of the System

The SafeFind system was developed with the following main objectives in mind:

- **Loss Prevention:** To prevent users from leaving behind or misplacing their valuable items by providing real-time alerts.
- **Theft Alert:** To detect potential theft or unauthorized movement of items and notify the user immediately.
- **Item Locating:** To help users locate misplaced items within a designated area using manual triggering mechanisms.
- **Phone Protection:** To help users remember their smartphones, reverse protection is enabled through the attached tag.
- **Energy Efficiency:** Maintaining low power consumption ensures an extended rechargeable battery life for the BLE tags.

- **User-Friendly Experience:** To provide an intuitive interface and seamless interaction, making the system accessible to users of all technical backgrounds.

### III.2.2 Features

#### a) AI-Powered Detection

- The system utilizes a machine learning-based Random Forest classifier trained on real-world RSSI data to distinguish between "Safe" and "Left Behind" states.
- This AI model ensures accurate detection of risk conditions, even in environments with signal interference or varying distances.
- The model evaluates RSSI readings every 200 milliseconds, enabling near real-time detection of potential item loss.

#### b) Manual and Automatic Alarm Triggering

- **Automatic Alarms:** When an item moves beyond the pre-defined range (2–3 meters in Outdoor Mode), the system triggers an audible alarm on the BLE tag and sends a notification to the smartphone.
- **Manual Alarms:** Users can manually activate the buzzer on the BLE tag via the mobile app to locate misplaced items within a safe area without triggering proximity alerts.

#### c) Safe Zone Automation

- Safe zones, such as homes or offices, can be defined using GPS coordinates.
- When the user enters a Safe Zone, the system automatically switches to Home Mode, disabling proximity alarms to prevent unnecessary notifications.
- Conversely, when the user leaves the Safe Zone, the system activates Outdoor Mode to enable full proximity monitoring.
- Users can also manually toggle between Home and Outdoor Modes as needed.

**d) Multiple Device Monitoring with One Smartphone**

- SafeFind app supports simultaneous connection and monitoring of multiple BLE tags, allowing users to protect several valuable items (like keys, wallet, bag...) with a single smartphone.
- Each device can be assigned a custom name for easy identification within the app interface.

**e) App Multilingual Support and Theme Customization**

- The SafeFind mobile application, offers multilingual support, enabling users to select their preferred language.
- Additionally, the app provides theme customization options, allowing users to switch between Light Mode and Dark Mode for enhanced usability in different lighting environments.

### **III.3 Hardware and Software Components Used**

The SafeFind system integrates a combination of hardware and software components to deliver its functionality. This section provides an overview of the key hardware components and the software tools used during development.

#### **III.3.1 Hardware Components**

**a) NRF52840 Microcontroller:**

- A powerful yet energy-efficient microcontroller from Nordic Semiconductor, chosen for its support of BLE 5.0 and low power consumption.
- Responsible for collecting RSSI data, running the AI model, and triggering alarms.

**b) Buzzer:**

- A 3V piezoelectric buzzer integrated into the device to produce loud, audible alarms when a "left behind" event is detected or when manually triggered by the user.

**c) Battery:**

- A 400mAh rechargeable battery for several days of continuous operation, and to avoid replaceable batteries.

**d) Plastic Casing:**

- A lightweight plastic enclosure to house all internal components, to ensure protection against external damage.

**III.3.2 Software used for development**

The development of the SafeFind system involved multiple software tools for different aspects of the project. Below is a breakdown of the tools and programming languages used:

**a) PyCharm:**

Used for developing, training, and exporting the machine learning model for deployment on the microcontroller.

- Key Python libraries utilized:
  - **NumPy:** For numerical computations.
  - **Pandas:** For data manipulation and organization.
  - **Scikit-learn:** For building and training the Random Forest classifier.
  - **Micromlgen:** For exporting and deploying the AI model for microcontroller deployment.
- **Programming Language:** Python.

**b) Flutter:**

A cross-platform framework was used to develop the mobile application, enabling simultaneous deployment on both Android and iOS devices.

- **Programming Language:** Dart.

**c) Arduino IDE:**

Used for coding the NRF52840 microcontroller and deploying the AI model onto the device.

- **Programming Language:** C.

**d) Fusion 360:**

A 3D design tool used to create the lightweight and ergonomic plastic enclosure for the BLE tag.

**III.4 Device Development****III.4.1 Alarm triggering logic****a) Initial Approaches**

Before implementing the AI-based solution, several traditional proximity detection methods were explored for alarm triggering. However, these approaches proved insufficient for real-world scenarios due to their sensitivity to environmental factors and hardware limitations.

**❖ RSSI Thresholding**

- The initial alarm logic relied on a RSSI (Received Signal Strength Indicator) thresholding method (triggered alarms when RSSI dropped below a predefined threshold of -70dBm, which corresponds to 2-3m). However, even with filtering techniques, environmental factors such as walls, interference, and line-of-sight variations introduced inconsistencies. For instance, the system struggled to distinguish between being 3 meter or 10 meters away in clear sight conditions. And that meant that system would not be able to alert users if their items are left behind.

**❖ Log-distance Path Loss Model**

- Later, the Log-Distance Path Loss Model was tested, which estimates distance based on RSSI and environmental factors (path loss exponent "n"). This method also proved problematic:
- "n" varies from place to place (open field vs. apartment), and could not be reliably predicted or adapted dynamically.

**❖ Round-Trip Time (RTT) approach**

In this method, the board was programmed to send a packet to the smartphone app, which would immediately respond with a packet back to the board. The round-trip time was measured to estimate the distance between the two devices. However, this technique faced major challenges:

- Slight delays between packet sending and receiving introduced errors, sometimes leading to distance miscalculations.
- This method became impractical due to hardware limitations, unsynchronized CPU clocks between the board and different smartphones, and the goal of keeping SafeFind affordable and compatible with all types of smartphones (Android or iOS).

Due to these limitations, the decision was made to adopt an AI-based approach that could learn patterns from real-world data instead of relying on fixed rules.

### **b) AI Model Development**

The development of the AI model was a critical step in enhancing the accuracy and reliability of the SafeFind system. This section outlines the key stages of data collection, model training, and deployment.

#### **1. Data Collection**

To create a robust machine learning model capable of detecting "left behind" events, a comprehensive data collection process was conducted:

##### **➤ RSSI Window Recording**

- The nRF52840 board was programmed to collect 20 RSSI readings per window, captured at 200 ms intervals, and stored in the board memory.
- These windows provided a snapshot of signal strength over time, enabling the model to analyze patterns rather than relying on individual readings.

##### **➤ Scenario Management Application**

As shown in Figure III.1. I developed a special mobile app to control the pre-coded scenarios on the board, to ensure organized data collection across different conditions:

- **Normal Cases:** The device remained close to the user in various environments (indoors, outdoors).

- **Risk Cases:** The user intentionally walked away from the device (2–3 meters) and stopped recording to simulate scenarios such as leaving the item behind, theft, or dropping.
- **Interference Cases:** Data was collected in environments with Wi-Fi, BLE noise, and other sources of signal interference (e.g., crowded areas, public transport).

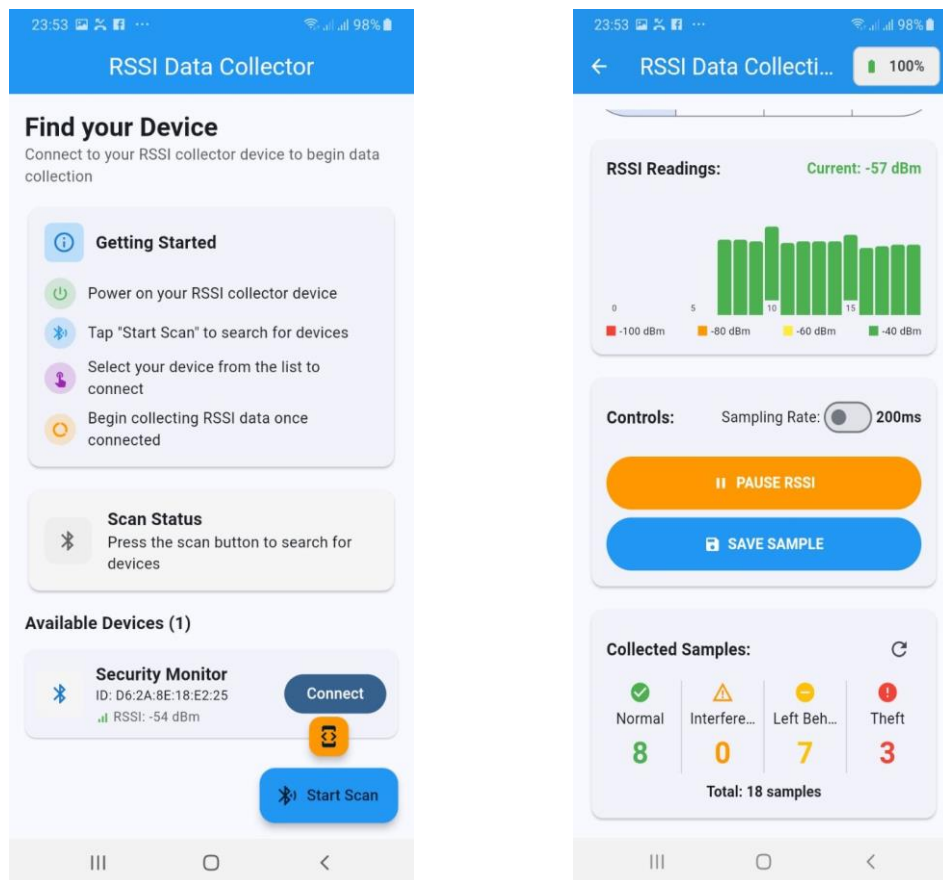


Figure III. 1: Scenario Management Application

➤ **Data Export and Organization:**

- After recording, the RSSI windows were exported from the board memory and organized into CSV files using a custom script.
- All risk scenarios (theft, left behind, interference) were merged under the "left behind" class for binary classification, simplifying the model's task of distinguishing between "normal" and "Left Behind" states as shown below (Figure III.2).

138	normal	-54	-52	-51	-47	-51	-56	-51	-49	-51	-57	-54	-49	-49	-49	-54	-51	-50	-49	-49	
139	normal	-50	-49	-55	-55	-56	-50	-47	-51	-47	-52	-55	-47	-52	-50	-56	-59	-61	-48	-47	-51
140	normal	-54	-55	-50	-46	-49	-47	-54	-50	-47	-53	-47	-56	-52	-52	-51	-48	-50	-51	-48	-52
141	normal	-49	-52	-49	-48	-57	-52	-46	-50	-50	-48	-50	-48	-48	-49	-47	-57	-51	-46	-50	-47
142	normal	-46	-47	-50	-51	-47	-46	-47	-45	-45	-51	-43	-45	-47	-46	-43	-45	-45	-44	-47	-45
143	normal	-48	-45	-47	-42	-45	-48	-47	-50	-47	-45	-45	-47	-45	-45	-46	-46	-50	-49	-50	-47
144	normal	-46	-50	-53	-47	-44	-47	-47	-46	-47	-45	-47	-48	-48	-47	-45	-50	-48	-47	-46	-47
145	normal	-45	-45	-45	-46	-44	-47	-46	-46	-46	-45	-46	-47	-46	-50	-45	-45	-47	-55	-50	-50
146	normal	-45	-45	-44	-45	-44	-45	-42	-46	-41	-45	-47	-40	-46	-41	-44	-39	-41	-42	-45	-44
147	normal	-42	-40	-42	-42	-42	-42	-35	-43	-42	-47	-40	-42	-39	-42	-45	-41	-42	-43	-43	-47
148	normal	-45	-42	-46	-53	-52	-54	-46	-45	-46	-41	-45	-42	-45	-47	-46	-52	-45	-46	-43	-44
149	normal	-42	-39	-37	-43	-40	-35	-47	-48	-43	-43	-44	-43	-43	-47	-43	-46	-42	-52	-43	-44
150	normal	-43	-42	-43	-48	-42	-45	-46	-42	-47	-46	-42	-42	-43	-47	-41	-42	-43	-47	-42	-43
151	left_behin	-57	-56	-51	-59	-56	-46	-47	-49	-46	-47	-52	-57	-55	-54	-62	-74	-75	-63	-61	-66
152	left_behin	-43	-45	-43	-47	-43	-49	-62	-54	-48	-56	-55	-52	-65	-64	-62	-65	-62	-61	-75	-60
153	left_behin	-45	-60	-47	-41	-47	-45	-43	-44	-46	-46	-54	-48	-63	-54	-64	-62	-63	-63	-73	-67
154	left_behin	-55	-53	-59	-56	-55	-56	-57	-55	-55	-61	-58	-55	-61	-60	-62	-75	-65	-63	-68	-60
155	left_behin	-46	-47	-50	-53	-53	-53	-59	-66	-61	-57	-67	-61	-65	-67	-63	-64	-68	-68	-61	-67
156	left_behin	-49	-50	-55	-54	-57	-54	-54	-52	-51	-64	-67	-56	-62	-67	-61	-63	-69	-79	-62	-66
157	left_behin	-46	-47	-47	-45	-43	-49	-50	-51	-57	-53	-57	-61	-61	-58	-60	-64	-69	-67	-58	-65
158	left_behin	-43	-42	-44	-44	-39	-42	-40	-41	-43	-45	-47	-47	-49	-53	-49	-54	-69	-57	-52	-51
159	left_behin	-40	-40	-41	-40	-35	-40	-42	-40	-46	-49	-57	-57	-63	-56	-57	-58	-73	-56	-67	-63
160	left_behin	-45	-43	-43	-52	-40	-42	-40	-57	-57	-51	-52	-60	-62	-64	-63	-62	-62	-61	-60	-64
161	left_behin	-46	-52	-47	-52	-56	-85	-59	-51	-59	-64	-56	-66	-68	-59	-78	-64	-63	-55	-62	-67

Figure III. 2: RSSI data CSV file

## 2. Model Training

The collected data was used to train a Random Forest classifier, which demonstrated strong performance in handling real-world variability:

- **Preprocessing and Training:**
  - Python libraries such as NumPy, Pandas, and scikit-learn were used to preprocess the data, train the model, and validate its performance.
  - The model achieved a classification accuracy of 93% on validation sets as seen in figure 3, with high precision and recall for both "Safe" and "Left Behind" classes.

```
Accuracy: 93.44%

Classification Report:
              precision    recall  f1-score

   normal      0.95      0.95      0.95
 left_behind   0.91      0.91      0.91

 accuracy              0.93
 macro avg      0.93      0.93      0.93
 weighted avg   0.93      0.93      0.93
```

**Figure III. 3: Ai model validation set**

- **Exporting the Model:**

- Once trained, the Random Forest model was exported into C language using specialized tools, making it compatible with the nRF52840 microcontroller for embedded integration.

### 3. Model Deployment

The final step involved deploying the AI model onto the microcontroller for real-time inference:

- **Embedding on Microcontroller:**

- The exported C code was integrated into the nRF52840 microcontroller, enabling it to perform real-time RSSI inference.

- **The microcontroller was programmed to:**

- Measure RSSI every 200 Ms.
- Maintain a sliding window of the last 20 RSSI readings in memory.
- Update the window with each new reading and input it into the model for classification.

- **Continuous Evaluation Logic:**

- The model evaluates the situation every 200 ms, ensuring near real-time detection of potential "left behind" events.
- If a "left behind" event is detected, the buzzer is triggered immediately, and a BLE notification is sent to the smartphone.

### III.4.2 Battery Optimization

#### a) Deep Sleep When Outdoor Mode Is Not Activated

➤ **Connection Maintenance:**

When Outdoor Mode is deactivated (e.g., in Home Mode or Safe Zones), the device enters deep sleep mode to conserve energy.

In this state, the device suspends continuous RSSI monitoring and AI model evaluations. However, it maintains a minimal BLE connection to allow manual alarm activation if needed. This ensures users can still trigger the buzzer via the mobile app to locate misplaced items without fully waking the device.

➤ **Battery Life in Deep Sleep:**

In deep sleep mode, the SafeFind tag can reach an impressive battery life of 10 months to a year on a single charge, making it highly energy-efficient for long-term use in low-risk environments.

#### b) Power Consumption in Outdoor Mode

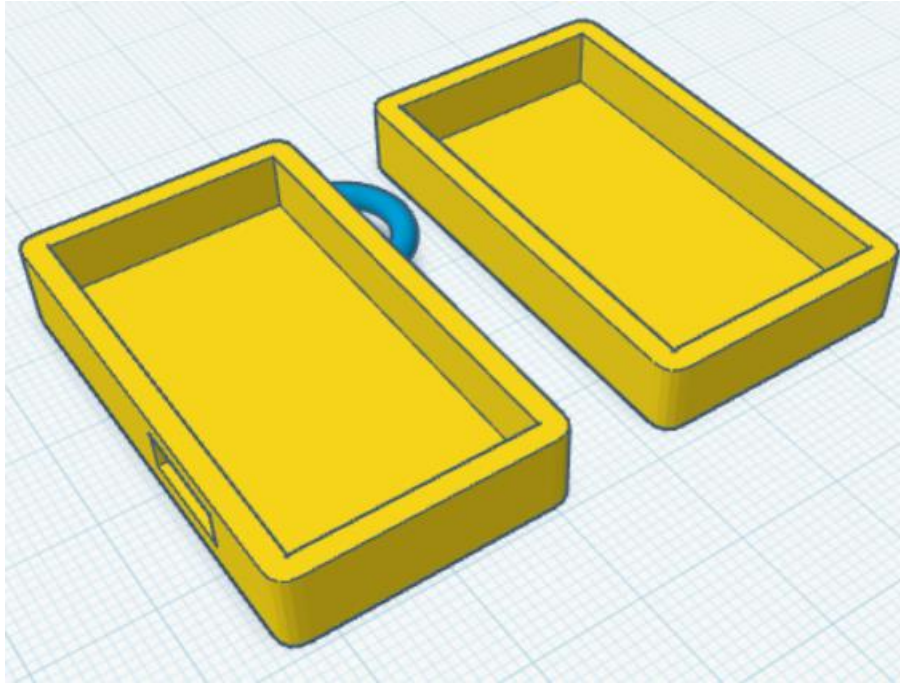
➤ **Light Sleep Between Measurements:**

In Outdoor Mode, the device performs continuous RSSI scanning and AI evaluation to monitor proximity. To optimize power consumption, the device employs light sleep between the 200ms RSSI measurement intervals.

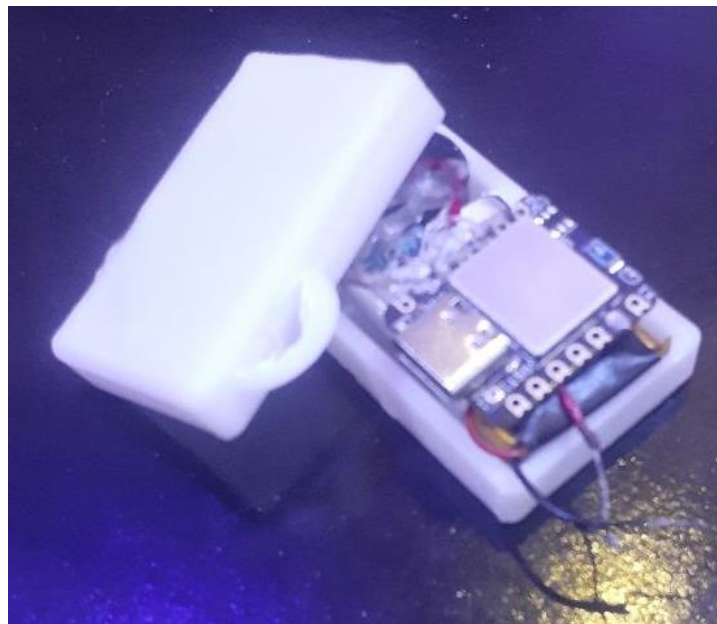
This approach balances performance and energy efficiency, allowing the device to achieve 15 to 20 days of operation under continuous RSSI scanning and AI evaluation.

### III.4.3 Device Enclosure

The device enclosure was designed using Fusion 360 to house the electronic components of the system. It was modeled to accommodate the layout of the circuit, allow access to necessary ports and connectors, and include a hook for attaching it to keys. As seen in Figure III.4 and Figure III.5,



**Figure III. 4: 3D Enclosure Design**



**Figure III. 5: Device enclosure with mounted components**

### III.4.4 Device work flow:

Figure III.6 shows how the device operates, starting from advertising and waiting for a connection, going through signal monitoring, and ending with an alarm if certain conditions are met.

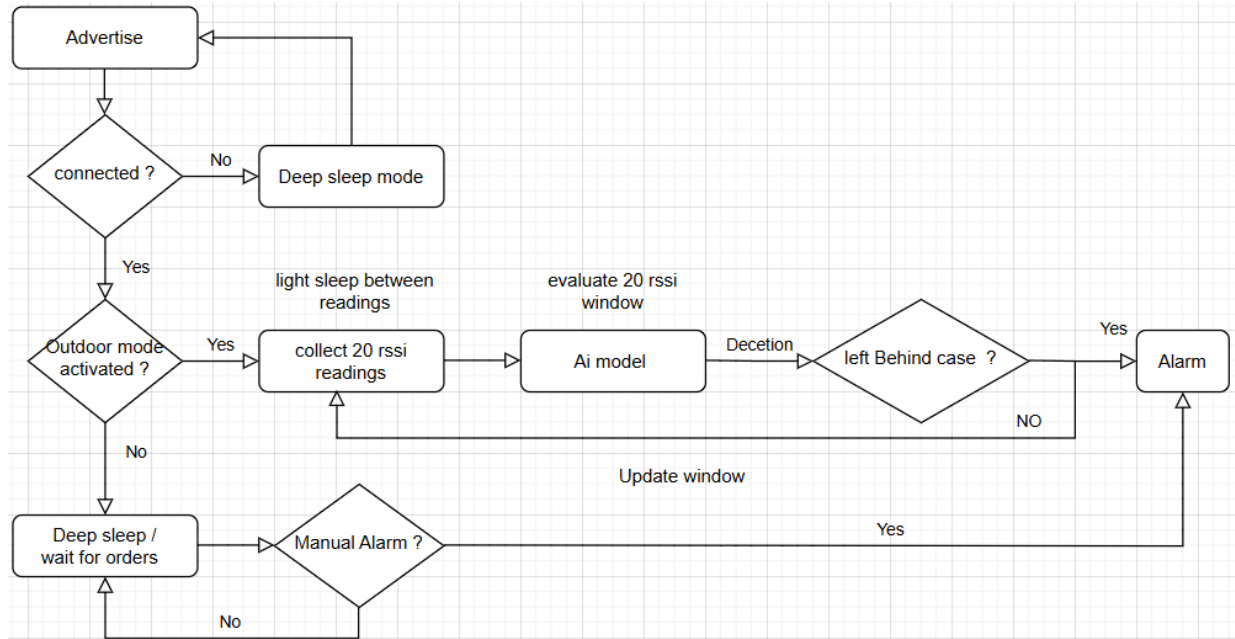


Figure III. 6: Device work flow diagram

## III.5 Mobile Application Development

The SafeFind mobile application serves as the central interface for managing and interacting with the SafeFind system. It was designed with a focus on usability, and cross-platform compatibility.

- ❖ **Development Framework:** The app was built using Flutter, a modern, open-source framework developed by Google. Flutter enables the creation of visually appealing and high-performance applications with a single codebase.
- ❖ **Cross-Platform Support:** The use of Flutter ensures that the SafeFind app is fully compatible with both Android and iOS devices, allowing users to access the system's features regardless of their smartphone platform.

### III.5.1 Mobile Application Features

The SafeFind mobile application serves as the central interface for managing the system's features, offering intuitive controls and personalization options. Below is a breakdown of its key functionalities:

#### a) Device Scanning and Naming screens

As seen in figure III.7 the scanning screen allows users to:

- ❖ **Filter Device Display:** The app ensures that only SafeFind devices are displayed during the scanning process, avoiding confusion with other BLE peripherals.
- ❖ **Custom Naming:** After pairing, users can assign a custom name to each device (for example: "Keys," "Bag," "Wallet") for easy identification within the app interface, especially when multiple devices are connected to a single smartphone.

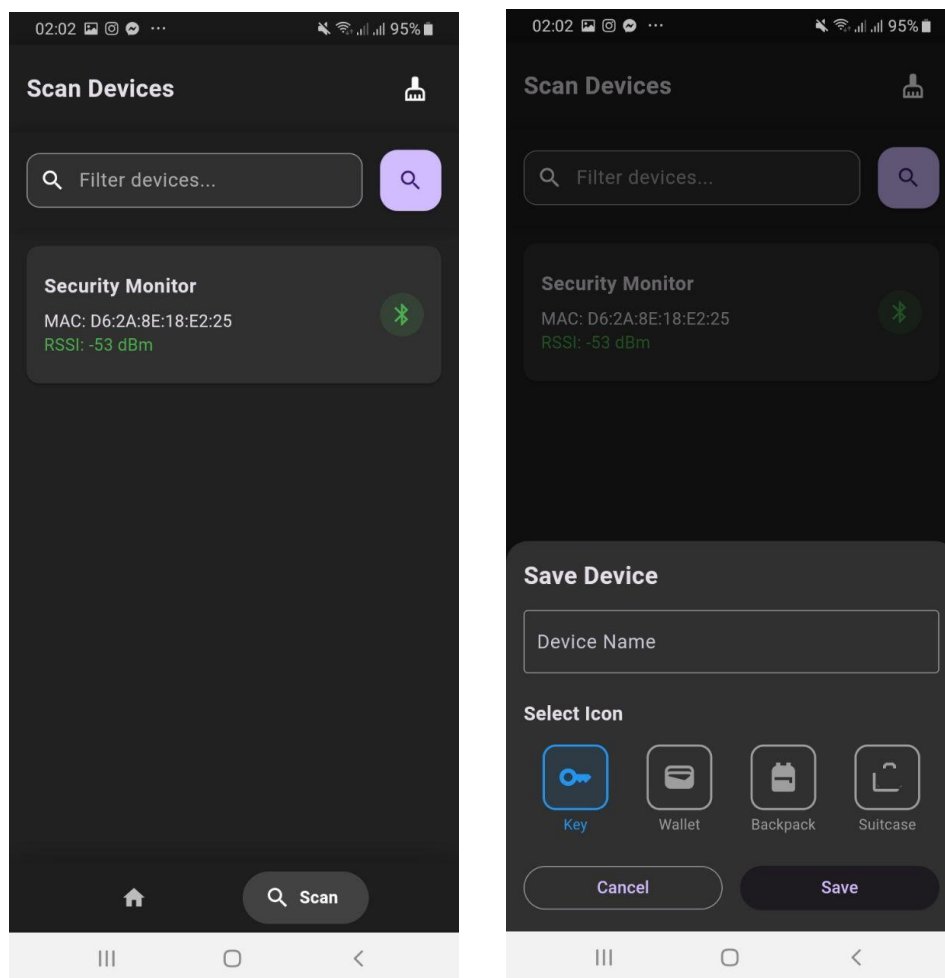


Figure III. 7: Device Scanning and Naming screens

**b) Home Screen****❖ Battery and Connection Monitoring:**

The home screen as shown in Figure III.8 provides real-time information about the connected devices, including:

- **Battery percentage:** Displays the remaining charge of the BLE tag.
- **Connection status:** Indicates whether the device is "Connected," "Disconnected," or "Connecting."

**❖ Device Management:**

- Users can rename, remove, or disconnect devices from the list as needed.

**❖ Outdoor Mode Activation**

When Outdoor Mode is enabled via a toggle switch on the home screen, the device begins:

- Continuously measuring RSSI values every 200 Ms.
- Passing these readings to the onboard AI model for evaluation.
- If a "left behind" event is detected, the device triggers an audible alarm and sends a notification to the smartphone.

**❖ Manual Alarm Activation**

Users can manually activate the buzzer on the BLE tag via a command sent through the app. This feature is particularly useful for locating misplaced items within a safe area where proximity alarms are not required.

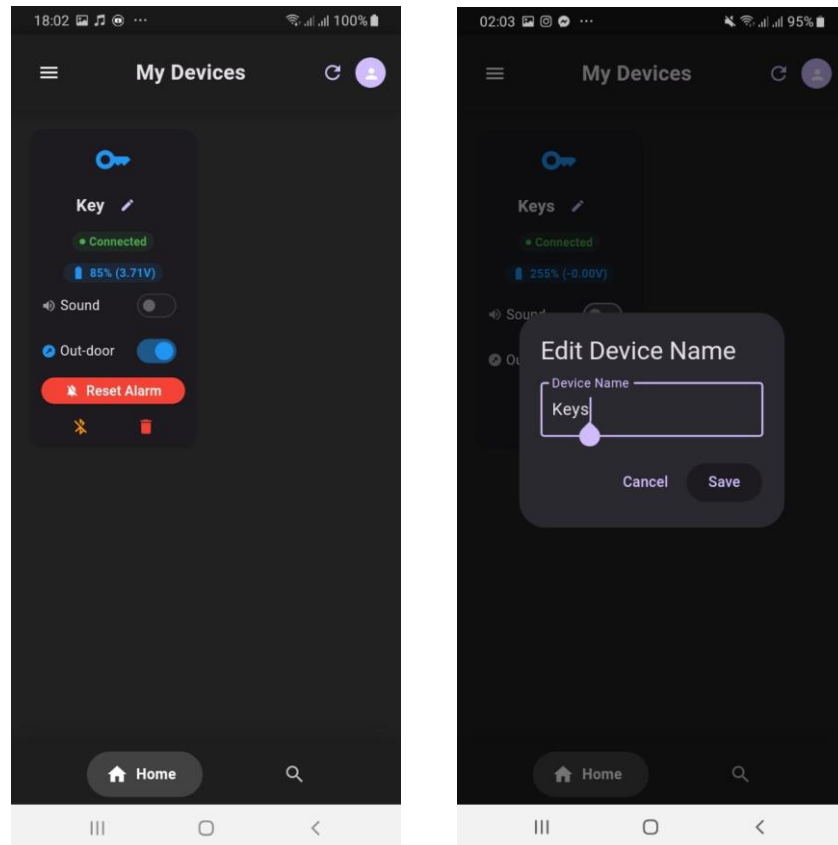


Figure III. 8: Home screen

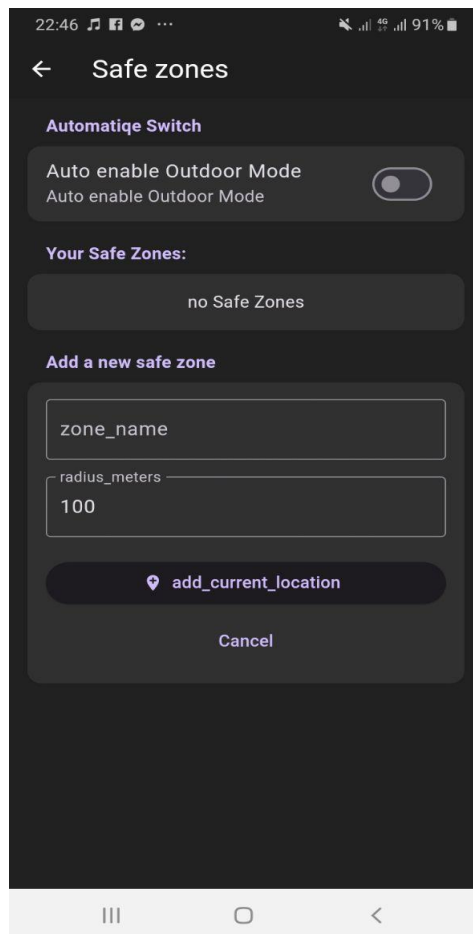
### c) Safe Zone Screen

#### ❖ GPS-Based Automation:

- As shown in figure III. 9 Users can define a Safe Zone by saving their current GPS coordinates (e.g., home or office).
- When the user moves more than 100 meters away from the defined Safe Zone, the app automatically activates Outdoor Mode to enable full proximity monitoring.
- Upon returning to the Safe Zone, the app deactivates Outdoor Mode to prevent unnecessary alarms.

#### ❖ Manual Override:

- Users retain the ability to manually switch between Home Mode and Outdoor Mode at any time, ensuring flexibility based on their immediate needs.



**Figure III. 9: Safe zone Screen**

d) Settings screen

❖ **Background Service:**

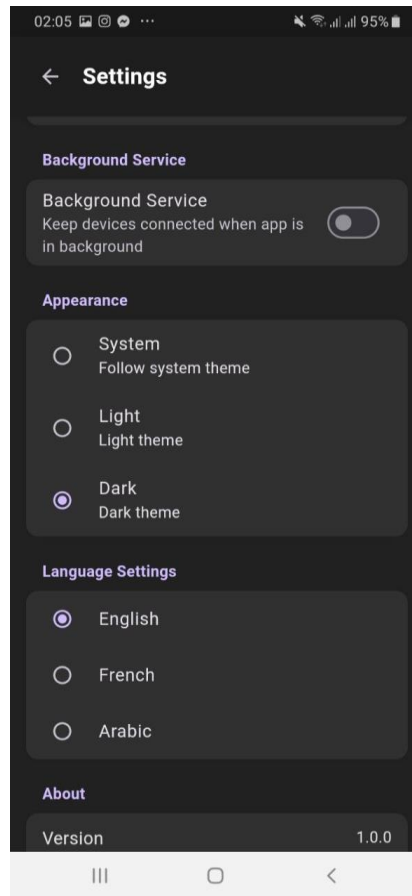
- Enabling this option allows users to keep the trackers connected and running in the background, even when the app is closed or not actively in use. This ensures continuous tracking without needing to keep the app open.

❖ **Language Customization:**

- Users can change the application language to suit their preferences,

❖ **Theme Customization:**

- As seen in figure III.8 The app supports both Light Mode and Dark Mode, allowing users to adjust the interface based on lighting conditions or personal preference.



**Figure III. 10: Settings screen**

## III.6 Testing and Results

To ensure the SafeFind system met its design goals and performed reliably in real-world scenarios, a comprehensive testing process was conducted. This section outlines the key tests performed and their results.

### III.6.1 Functional Tests

#### ❖ App and Device Features:

- Various features of the mobile application and BLE tag were tested to ensure seamless integration and functionality.

- Key functionalities such as pairing, device naming, battery monitoring, and connection status updates were validated across multiple devices and operating systems (Android and iOS).
- ❖ **Alarm Activation:**
  - Both manual and automatic alarm activation were rigorously tested:
    - **Manual Alarm:** Verified that users could trigger the buzzer on the BLE tag via the app without errors.
    - **Automatic Alarm:** Ensured that alarms were triggered correctly when the device exceeded the pre-defined range (2–3 meters) in Outdoor Mode.
- ❖ **Environment Testing:**
  - The model was tested in diverse environments, including homes, public places, streets, and crowded areas with Wi-Fi or BLE interference.
  - Results demonstrated robust performance across varying conditions, confirming the AI model's adaptability to real-world scenarios.

### **III.6.2 Battery Life Tests**

- ❖ **Power Consumption Analysis:**
  - Battery consumption was measured under different usage scenarios:
    - **Without Optimizations:** Continuous RSSI scanning and AI evaluation resulted in higher power usage, limiting battery life.
    - **With Optimizations:** Implementing light sleep between measurements and deep sleep during idle periods significantly improved energy efficiency.
- ❖ **Deep Sleep Impact:**
  - In deep sleep mode, the device achieved an impressive battery life of 10 months to a year on a single charge.
  - In Outdoor Mode, with continuous RSSI scanning and AI evaluation, the device maintained a battery life of 15 to 20 days, thanks to light sleep optimizations.

### III.6.3 Range Tests

#### ❖ **Maximum Communication Distance:**

- The maximum reliable Bluetooth communication distance was tested under various conditions:
  - **Clear Line-of-Sight:** Achieved up to 50 meters of stable communication.
  - **Obstructed Environments:** Signal stability decreased with obstacles like walls, but remained functional up to 20–25 meters indoors.

### III.7 Conclusion

In this chapter, we successfully transformed theoretical knowledge into a practical and functional system by developing SafeFind, a smart device based on BLE proximity detection. The design focused on real-time alerts, low power consumption, and ease of use, all while considering local constraints and user needs. The integration of a custom mobile application and machine learning techniques improved system accuracy and adaptability in real-world scenarios.

Testing confirmed the device's effectiveness in preventing loss by alerting users before items are left behind, a key feature that differentiates SafeFind from recovery-focused trackers. These results validate the project's core objective offering a preventive, affordable, and locally relevant solution to everyday security challenges.

### *General Conclusion*

SafeFind provides a practical solution to the ongoing problem of losing personal belongings. By using Bluetooth Low Energy (BLE) and integrating machine learning, this system allows users to receive alerts before their items are lost, rather than just recovering them afterward. The focus is on prevention, making it a more effective and proactive solution than current methods.

The project successfully created an affordable and efficient system, particularly suited for environments with limited access to advanced technologies. SafeFind's real-time alerts and ability to work across various devices and environments make it a valuable tool for everyday users.

Looking forward, there are several potential improvements. SafeFind could be developed to work on a mesh network or crowdsourced system, allowing users to track items in real-time through a wider network of devices. This would expand the utility of the system significantly. Additionally, the technology could be adapted to protect vehicles, motorcycles, and other valuable assets, increasing its range of use.

Future improvements could include adding more advanced AI-driven features for better detection accuracy and creating more robust user interfaces. The hardware could also be improved for better performance in challenging environments.

In conclusion, SafeFind demonstrates how technology can solve a common problem with a simple, cost-effective solution. With the potential for further development, it could become a versatile tool for personal security, asset tracking, and more.

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***Annex***

1- SafeFind – Business Model Canvas



الجمهورية الجزائرية الديمقراطية الشعبية  
وزارة التعليم العالي والبحث العلمي  
جامعة عين تموشنت بلحاج بوشعيب  
حاضنة الأعمال عين تموشنت



# ملحق نموذج العمل التجاري

**Project data sheet**

**البطاقة التقنية للمشروع**

<b>First and last Name</b> الاسم و اللقب	Mebrek Samir Oussama
<b>The commercial name of the project</b> الاسم التجاري للمشروع	SafeFind
<b>Phone number</b> رقم الهاتف	0782812680
<b>Email address</b> البريد الالكتروني	Safefind46@gmail.com
<b>City or municipality of activity</b> مقر مزاولة النشاط	Ain Temouchent

**The nature of the product**

**طبيعة المشروع**

**The product is hybrid in nature, combining a hardware component and a service component**

**Problem Statement**

The loss of personal belongings is a widespread problem that disrupts people's daily lives and creates significant costs. This issue becomes particularly serious during travel, where unfamiliar places, time pressure, and stress greatly increase the chances of losing important items like passports, wallets, phones, and bags.

Travel settings create specific risks for losing items. Busy airports, crowded markets, and new cities create situations where brief moments of inattention, such as leaving items at a coffee shop table, dropping things while rushing through stations, or forgetting devices in taxis, can lead to major problems. These incidents may cause missed flights, emergency document procedures, and high costs for replacements and recovery efforts.

The effects of losing items go beyond immediate problems. These situations create financial costs through replacements, lost time during recovery efforts, and stress from uncertainty and disrupted plans.

Our survey data shows that 65% of frequent travelers have lost valuable items during trips, with many losses happening in high-risk areas like transportation centers and busy markets.

This problem is not limited to travel situations. It also appears frequently in homes and workplaces. People often lose everyday items, especially during stressful or rushed times, such as getting ready for work or school in the morning. While these incidents may seem small individually, their combined effect is significant.

Our conducted survey findings show the following patterns:

- 88% of people surveyed said they frequently spend less than 15 to 30 minutes looking for lost items, and 76% reported being late as a result. This issue was especially common among students.
- 69% of people surveyed have lost items in public places like coffee shops, gyms, or public transportation.
- Recovery and replacement expenses typically range from 3,000 to 5,000 DZD, with some cases costing more.

The high number of incidents, substantial financial impact, and widespread dissatisfaction with current solutions create a clear need for better approaches. Our survey reveals two critical findings that highlight this opportunity:

- Over 90% of respondents favor preventive approaches over recovery-based solutions.
- 100% of participants rely exclusively on vigilance rather than technological assistance.

This complete dependence on personal attention, combined with the strong preference for preventive measures, shows a significant gap in available technology solutions designed for local needs and economic conditions.

This analysis identifies an opportunity for practical solutions that address the everyday challenges of keeping track of personal items. The SafeFind system was developed to provide users with real-time alerts when their valuable belongings are at risk of being left behind or misplaced. Unlike traditional electronic trackers, which focus primarily on item recovery after loss, SafeFind emphasizes preventing the loss of personal items in the first place.

### 1- Value



### 1- القيمة المقترحة proposition:

The value SafeFind offers to users is a personal object tracking and anti-loss system that is based on Bluetooth low energy technology to prevent loss or theft of important belongings. Designed to operate without requiring an internet connection.

SafeFind delivers significant benefits to users by providing:

- **Real-time loss prevention:** When a user moves away from an item tagged with SafeFind, the tag immediately issues alerts through a sound. This early warning allows the user to promptly return and recover the item before it is left behind.
- **Theft detection and anti-pickpocket alerts:** Should another individual attempt to remove a tagged item, the system triggers the same alerts, notifying the user in real time and enabling rapid intervention.

- **Efficient location of misplaced items:** Users can activate a sound signal on the tag via the smartphone app, facilitating the quick recovery of items misplaced within the home or workplace, even if hidden beneath other objects.
- **Management of multiple items through a single interface:** SafeFind supports multiple tags linked to one user smartphone, allowing centralized control and monitoring of various personal belongings such as keys, bags and wallets.
- **Operation without internet dependency:** The device functions exclusively through Bluetooth communication, eliminating the need for Wi-Fi or mobile data. This ensures usability in remote locations or indoor environments lacking network coverage.
- **Rechargeable and long-lasting battery:** Each tag incorporates a built-in rechargeable battery charged via USB, providing up to 15 days of continuous use per charge. This feature eliminates the frequent replacement of disposable coin-cell batteries.
- **Customizable alert modes:** The accompanying application includes different operational modes that fits into context, such as ‘home mode’ which mutes unnecessary notifications in safe environments, and ‘outdoor mode’ which maintains active alerts to prevent loss in public spaces.
- **Privacy-centred design:** Without reliance on cloud storage or external servers, user data remains securely on the device. The system does not record location history, share user data, or store personal information externally.
- **User-friendly and practical:** SafeFind is compact, lightweight, and easily attachable to various objects. It requires no technical expertise for setup or operation.
- **Affordable and can be locally adapted:** The device is manufactured with cost efficiency in mind, making it accessible to a broader demographic without dependence on costly imports or international pricing structures.
- **Environmental sustainability:** The casing of SafeFind can be constructed from recycled plastic, contributing to the reduction of plastic waste. Additionally, the rechargeable battery system minimizes electronic waste compared to devices powered by disposable batteries, reducing the environmental impact associated with frequent battery replacement.

### ❖ Analysis of Competing Products

There are some existing solutions on the market, but they suffer from ecosystem dependencies, network requirements, and high costs that limit their effectiveness and accessibility including:

#### ❖ Apple AirTag

Apple AirTag is a widely used Bluetooth tracking device designed to help users locate lost personal belongings through Apple's Find My network. It connects seamlessly with iOS devices and leverages a large network of Apple users to crowd source location updates.

#### ➤ **Limitations:**

- **Reactive Tracking:** AirTag mainly assists in recovering lost items by showing their last known location on a map after the user realizes the item is missing. This reactive approach may lead to missed opportunities to prevent theft or forgetfulness before the item disappears.
- **Dependence on Apple Ecosystem:** AirTag requires an iOS device to function, limiting accessibility for Android users.
- **Network Dependency:** The device relies on nearby Apple users with internet access to update location data. In rural or low-coverage areas, this can limit its effectiveness. In Algeria, where Android devices are more common, the Apple Find My network may not function properly.
- **Battery Waste:** Uses replaceable coin-cell batteries, which generate additional costs ongoing waste and inconvenience.
- **No Immediate Alerts:** AirTag does not provide instant proximity alerts when an item moves away from the user, reducing its effectiveness for real-time theft prevention.
- **High Cost:** With a retail price typically between 9,000 and 12,000 DZD, AirTag is expensive for most Algerian consumers.

### ❖ Samsung SmartTag

Samsung SmartTag operates similarly, providing Bluetooth-based tracking integrated into Samsung's SmartThings Find network. It is designed primarily for Samsung Galaxy users.

#### ➤ **Limitations:**

- **Post-Loss Location Tracking:** Like AirTag, SmartTag focuses on locating lost items via a map only after the user discovers the loss. It lacks real-time preventive notifications to stop loss or theft before it happens.
- **Samsung Device Restriction:** SmartTag functions exclusively with Samsung Galaxy phones, excluding users of other Android brands or iOS.
- **Crowdsourced Location Dependency:** It requires other Samsung users nearby with internet access to relay the location, making it less reliable in areas with sparse network coverage.
- **Subscription Costs:** Some features may require paid subscriptions, adding recurring costs.
- **Disposable Batteries:** SmartTag uses replaceable coin batteries, which contributes to electronic waste and user inconvenience.
- **Cost-Prohibitive:** Priced similarly high (9,000 to 12,000 DZD), it remains out of reach for many users in Algeria.

#### ➤ **Comparison with SafeFind**

As shown in Table 01, SafeFind stands out by focusing on real-time loss prevention rather than delayed recovery after loss. It works with any smartphone and eliminates ongoing subscription costs. Additionally, SafeFind offers a more affordable and environmentally friendly option for Algerian users.

## Annex

Feature	SafeFind	Apple AirTag	Samsung SmartTag
<b>Primary Focus</b>	<b>Prevention</b> (real-time alerts)	Recovery (map-based)	Recovery (map-based)
<b>Alert Method</b>	Device beep	App notification only	App notification only
<b>Functionality</b>	✓ no internet needed	✗ Requires internet & Apple network	✗ Requires internet & Samsung network
<b>Internet/Crowd Dependency</b>	Not required	<b>Required</b> (Find My network)	<b>Required</b> (SmartThings Find)
<b>Rechargeable</b>	✓ Yes (15-day battery life)	✗ No (replaceable battery)	✗ No (replaceable battery)
<b>Battery Replacement</b>	✗ No	Yes	Yes
<b>Cross-Platform Compatibility</b>	✓ iOS & Android	✗ iOS only	✗ Samsung Galaxy only
<b>Subscription Required</b>	✗ No	✗ No (but limited features)	✗ No (but limited features)
<b>Price (DZD)</b>	Proposed price : 2,500 DZD	12,000 DZD	9,000 DZD
<b>Availability in Algeria</b>	proposed solution	✗ Limited to high-end stores in major cities	✗ Limited to high-end stores in major cities
<b>Safe Zone Switching</b>	✓ Automatic with setup	✗ Not supported	✗ Not supported
<b>Multiple Object Tracking</b>	✓ Yes	✓ Yes	✓ Yes
<b>Use Case Example</b>	<b>Prevents</b> loss or theft <b>instantly</b>	Helps locate lost items <b>later</b>	Helps locate lost items <b>later</b>

**Table 01: comparison between SafeFind and other available Trackers**

### 2- Customer segments:



2- شرائح العملاء

The following segments represent the primary consumer groups targeted by our product, identified through survey data and contextual analysis of prevalent challenges in Algeria.

#### a) **B2C**

While the potential user base for our solution includes the general public, since the risk of losing valuable items is universal, our survey results have revealed a distinct demographic that constitutes our primary target market.

##### ❖ **Travelers**

This segment focuses on our primary target audience: individuals traveling through unfamiliar environments, often carrying valuable items such as money, legal documents (example: passports), and personal belongings. According to the Algerian Ministry of the Interior, there were over 240 million recorded land transport trips, including 35.7 million train journeys, and more than 4 million air travel movements in 2019. These travelers are typically aged between 18 and 60. In our survey, 65% of respondents reported having lost a valuable item while traveling. The loss of critical items in public spaces like airports, bus stations, or marketplaces can result in serious logistical, financial, and sometimes even legal challenges.

##### ❖ **University Students**

The second most important target market is university students, numbering approximately 1.8 million for the 2024/2025 academic year. Typically aged 18 to 25, students manage academic schedules and limited financial resources. The loss of essential items like keys, wallets, phones, and ID cards is especially disruptive during time-sensitive commitments such as lectures and exams. Our survey data shows that a lot of students in Ain Témouchent spend 15-30 minutes searching for misplaced belongings, with many of them reporting tardiness as a result.

##### ❖ **Daily Workers**

Our third most targeted group includes daily workers, estimated at 11 million in 2018, with ages ranging from 20 to 50. These individuals, such as delivery personnel and market vendors, rely on punctuality to maintain their income stability. Losing personal items like phones, keys, or wallets in public spaces results in financial losses averaging 3,000 to 5,000 DZD. A lot of workers

surveyed report incidents of misplaced items outside and inside the home, making this segment a key secondary target.

### b) **B2B**

The following organizational segments represent potential commercial adopters of SafeFind, integrating the product into their operations and markets.

#### ❖ **Travel Agencies**

Agencies offering travel packages, including tours and transportation services, target leisure and business travelers. Client loss of personal belongings during travel disrupts itineraries and strains agency resources through complaint resolution, potentially affecting reputation and revenue. Agencies can integrate SafeFind as an add-on service or complimentary feature.

#### ❖ **Manufacturers of Bags and Wallets**

Producers of personal carry items (example: wallets, backpacks) operate in local or regional markets. These manufacturers seek differentiation in a saturated market, where traditional designs lack innovative features to justify premium pricing or attract discerning consumers. By embedding SafeFind into, manufacturers can offer integrated tracking capabilities, enabling them to market “smart” or “secure” items at a higher price point.

### **3- Customer Relationships :**



### **-3 العلاقات مع العملاء:**

The customer relationships strategy for SafeFind ensures spreading awareness, Value demonstration, accessible support, efficient after-sales service, and engagement incentives, customized for B2C and B2B segments.

#### ➤ **Awareness:**

- We will raise awareness about the risks of losing personal belongings and the importance of early detection, primarily through targeted digital marketing campaigns aimed at high-risk groups (example: Travelers, Students).

### ➤ Value Demonstration:

- We will emphasize the ease of use, portability, and the advantages of our system, using explanatory videos, customer testimonials, and personal cases that demonstrate the system's effectiveness.

### ➤ Continuous Customer Support

- Offers a 24/7 WhatsApp helpline for immediate assistance on inquiries and issues.
- Delivers on-site assistance to B2B clients during initial integration.
- Shares instructional videos on the SafeFind website and social media, demonstrating the setup process to boost user confidence despite its simplicity.

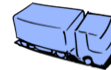
### ➤ After-Sales Service

- Replace defective units at no cost during the warranty period (example: six months), managed via mail-in options.

### ➤ Loyalty and Incentive Programs

- Grants B2C customers discounts on additional units, promoting multi-unit purchases for families or groups.
- Provides B2B partners with bulk-order discounts, fostering repeat business.
- Collects feedback and reviews via WhatsApp, the app, website, and social media, showcasing positive testimonials on these platforms to enhance trust and attract new customers.

## 4- Channels :



## 4- القنوات:

### ➤ Awareness Channels

- Engages influencers, especially vloggers, to showcase SafeFind's 30-second setup and efficiency in combating theft, and protecting personal belongings during travels (example: alarm the user dropping an item in the market), targeting B2C segments like travelers and students.

- Runs targeted social media ads (example: Facebook, Instagram) with funny videos like a train scenario where a thief triggers the alarm while stealing a wallet, leading to their catch.
- Participates in local university events and exhibitions with posters and tables, offering live demos and flyers to promote the product to students, workers, and businesses.
- Exhibits at international and local trade shows, such as “**Salon International du Tourisme et des Voyages (SITEV)**” and “**ALGERIA EXHIBITIONS SPA**” using booths to demonstrate marketing SafeFind as a security system during travels and attract global clients (e.g., travel agencies, hotels).
- Promotes via the SafeFind website and social media with instructional videos and testimonials, amplified by reviews collected across WhatsApp, the app, website, and social media.
- Partners with local radio stations for short, low-cost ads, reaching workers and travelers.

### ➤ **Purchase Channels**

- Enables direct B2C sales through the SafeFind website at 2,500 DZD, with app download links available on the site, Play Store, and Google Play for full functionality post-purchase, supporting payments like cash on delivery.
- Facilitates B2B bulk orders through direct negotiations and contracts.
- Offers limited-time bundles (example: SafeFind + keychain) to boost initial sales, including app download guidance.

### ➤ **Delivery Channels**

- Utilizes local courier services for B2C website orders to ensure delivery across Algeria (example: Yalidin, ZRexpress).
- Coordinates bulk shipments to B2B partners at their locations.

### 5- Key partners:



### 5- الشركات الرئيسية:

The key partners are essential to the development, production, distribution, and promotion, across B2C and B2B segments.

#### ➤ **Investors and Startup Incubators**

- Collaborates with the Ain Temouchent University Incubator for prototyping facilities and mentorships.
- Engages investors in tech and security specializing in personal safety solutions to finance the production.

#### ➤ **Suppliers and Production Partners**

- Collaborates with electronics retailers and companies for electronic components.
- Sources sustainable materials from recycled plastic factories (example: PLA filament suppliers) for eco-friendly 3D-printed casings.

#### ➤ **Distribution and Commercial partners**

- Collaborates with travel agencies to integrate SafeFind into travel packages.
- Collaborates with producers of personal carry items to integrate SafeFind in their products.
- Utilizes e-commerce platforms (example: Jumia, SafeFind website) for direct B2C sales and app downloads.
- Partners with local and international shipping companies to deliver SafeFind units to customers after online purchases.

### 6- Key activities:



### 6- الأنشطة الرئيسية:

The production of our system includes several key stages, from the acquisition of raw materials to the final product:

#### ➤ **Component Selection and Research**

- Identifies and selects optimal components (example: Bluetooth chip, buzzer) to balance cost and performance.
- Researches technical specifications (example: Bluetooth range, power efficiency) to align with user needs and prototype goals.
- Sources materials like 3D-printable PLA for casings.
- Evaluates component compatibility to guarantee integration in the prototype

#### ➤ **Device prototype design and application development**

- Designs the tracker's hardware layout, integrating selected components into a compact, clip-on form factor
- Assembles initial prototypes using 3D printing and manual electronics integration (example: soldering Bluetooth chip, buzzer)
- Program the Bluetooth chip for core features (example: 2- 3-meter alert triggers).
- Develops a smartphone app to control the tracker via Bluetooth.
- Integrates the app with the prototype's hardware.

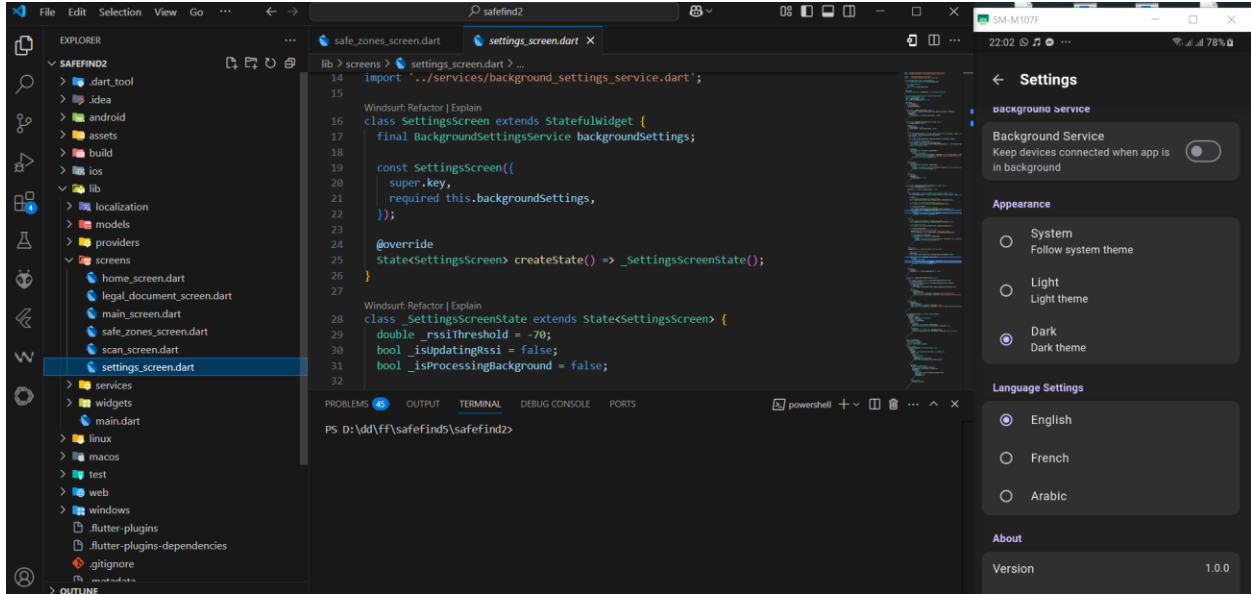


Figure 1: Application Development



Figure 2: Device Coding



**Figure 3: Device Assembly**

### ➤ **Prototype Testing and Validation**

- Conducts controlled tests to assess device performance (example: alert accuracy, battery life) and app reliability
- Validates the prototype against theft-prevention goals.
- Adjusts both hardware and software based on test results to prepare a finalized prototype for production scaling.

### ➤ **Production and Distribution**

- **Begin Scaled Production:** Initiate production of the finalized prototype, ensuring all components are sourced at scale and manufacturing processes are optimized for efficiency and cost-effectiveness.

## Annex

- **Quality Control:** Implement quality control procedures throughout the production process to ensure each device meets the required standards for performance.
- **Packaging:** Design and implement attractive and protective packaging for the final product, ensuring it is both functional and appealing to the consumer market. Packaging should protect the product during transport and storage while offering clear instructions for use.
- **Distribution:** Establish distribution channels, including partnerships with retailers, physical stores, and direct-to-consumer sales through the company's website.
- **Customer Support and Returns:** Set up dedicated customer support to address inquiries and handle returns or exchanges efficiently.
- **Post-Launch Marketing:** Implement a marketing campaign targeting the key customer segments identified earlier, using digital channels, social media, and influencer partnerships to boost product visibility and drive sales.

### 7- Key Resources



### 7- الموارد الرئيسية:

#### ❖ Physical Resources

Supplier المورد	Local or foreign source مصدر محلي أو أجنبي	Resources الموارد
Shanghai Xuanxin Technology Co., Ltd.	Foreign	Electronic Materials
Powertech	Local	Battery
Powertech	Local	Pla plastic
EMBAG	Local	Packaging

❖ Human Resources

Type of human resources صنف المورد البشري	Number العدد
Software developer	1
Marketing and communications Assistant	1

8- Cost Structure (yearly)



8- هيكل التكاليف:

Coûts d'investissement	Couts
Establishment fees تكاليف التعريف بالمنتج أو المؤسسة	Frais d'obtention du registre du commerce : 15,000 DA
Meter opening fees تكاليف الحصول على العدادات	Électricité : 6000 DA
Application fees رسوم إيداع الملفات	2,000 DA
Notary fees تكاليف الموثق	30,000 DA
<b>Total</b>	<b>53,000 DA</b>

## Annex

### ❖ Fixed costs

Couts fixes	Couts
Insurance التأمينات	46,000 DA
Telephone, internet, electricity الهاتف, الانترنت و الكهرباء	60,000 DA
Other subscriptions اشتراكات أخرى	Website Housing: 6000 DA
Workshop rental اجار الورشة	144,000 DA
Fixed salaries الرواتب الثابتة	480,000 DA
Transportation النقل	20,000 DA
Machinery الالات	120,000 DA
Miscellaneous supplies لوازم متنوعة	20,000 DA
<b>Total</b>	<b>896,000 DA</b>

### ❖ Variable costs

Couts Variable	Couts
Raw materials المواد الاولية	1,375,000 DA
Delivery costs تكاليف التوصيل	200,000 DA
Office supplie لوازم مكتبية	180,000
Marketing and advertising الاعلانات	300,000 DA
<b>Total</b>	<b>2,055,000 DA</b>

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### ❖ Total costs

Investment costs	53,000 DA
Fixed costs	896,000 DA
Variable Costs	2,055,000 DA
<b>Total</b>	<b>3,004,000 DA</b>

### 9- Revenue Streams



### 9- مصادر الإيرادات

Stream المصدر	Units Sold الوحدات	Selling Price (DZD/unit) سعر البيع	Revenue (DZD) رقم الاعمال	Cost (DZD/unit) التكلفة / وحدة	Profit margin هامش الربح	Profit (DZD/unit) الفائدة / الوحدة	Total Profit (DZD) الفائدة الاجمالية
B2C Direct Sales	2 000	2 500	5 000 000	1 201.6	100.8%	1 298.4	2 403 200
B2B Wholesale	500	2 000	1 000 000	1 201.6	66%	798.4	399 200
<b>Total</b>	<b>2 500</b>		<b>6 000 000</b>				<b>2 802 400</b>