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Research Article

Offline Device Tracking: A Novel Approach to Locating Lost Devices through Advanced Application Development

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Abstract— The ability to track a smart device Smart Phone even when offline increases the chances of recovering that lost device quickly. Maybe the thieves or people who find lost devices often fear to switch on that device(s) or turn them off to avoid detection. The features in Offline tracking can still provide the last updated or known location or update the device owner when the device comes online. Here, in this research article, we have developed an enhanced application-designed system that can track lost devices even when offline or does not connect with any network. Here, we utilized advanced location tracking technologies and robust security features so that the application ensures constant monitoring and protection of Android devices or shields of that device(s). There are various key functionalities used including real-time and historical location tracking, remote device locking, anti-theft measures, etc. Our implemented application can track the addresses of the device(s) in offline mode which was the critical challenge of locating devices without internet connectivity, providing the original users or the owner with comprehensive security and peace of mind. The development process, technical architecture, and user benefits are thoroughly examined here.

Keywords— Global Positioning System (GPS); Cell Tower Triangulation; Wi-Fi positioning system (WPS, WiPS or WFPS); SMS Response Time; Personally identifiable information (PII); Kalman Filter.

1. Introduction

Nowadays, in this digital age, our dependence on electronic devices such as smartphones, laptops, tablets, and wearables has become essential/important. These devices not only store massive volumes of personal and professional data; but also, assist as an important tool for communication, productivity, and entertainment. However, the compactness and continuous use of these devices also make them susceptible to being lost or stolen. When a device goes missing, the instant concern is to trace it as fast as possible. In the old, the traditional tracking methods relied heavily on the device being online, connected to the internet, or within the range of a GPS signal[1]. But the question arises in our mind what happens when the device is offline. This is where offline tracking technologies come into play. Offline tracking refers to the ability to locate, secure, and recover a device that is not currently connected to the internet or cellular networks. This can occur when the device is turned off, in airplane mode, or simply out of range of a network connection. Offline tracking is a critical advancement in ensuring the safety and recovery of lost devices, offering several significant benefits and enhancing the overall security of our digital lives.

2. Fundamentals Details

The development of an enhanced application for tracking lost devices in offline mode requires a comprehensive understanding of several key technologies and theoretical frameworks. This section outlines the theoretical basis and calculations underpinning the application's functionality.

2.1 Location Tracking Technologies

Here, we have discussed about Location Tracking Technologies:

GPS (Global Positioning System): GPS provides precise location data using satellite signals. However, its effectiveness is limited in indoor environments and areas with poor satellite visibility [1].

This method estimates the device's location by measuring the signal strength from multiple cell towers. It is useful in urban areas with dense cellular networks but less accurate than GPS.

(WPS): WPS leverages the proximity of known Wi-Fi hotspots to determine the device's location. This method is effective in indoor environments and urban areas with numerous Wi-Fi networks [2].

By combining these technologies, the application can provide accurate location data even when one of the methods is unavailable.

2.2 Data Storage and Synchronization

Offline tracking necessitates local data storage on the device, which can later be synchronized with cloud servers when an internet connection is re-established. The application uses a lightweight database to store location data, timestamps, and status updates.

2.3 Kalman Filters

Kalman Filters can be effectively used to estimate and predict the location of lost mobile devices even when they are offline. This involves leveraging data from nearby devices, sensors, and historical data to make informed predictions about the device's location [3].

2.3.1 Overview of the Approach: Kalman Filters

Data Collection from Nearby Devices: Even in offline mode, mobile devices can use Bluetooth or other short-range communication technologies to exchange data with nearby devices.

Kalman Filter Implementation: Use a Kalman Filter to predict the location of the lost device based on historical movement patterns and data collected from nearby devices.

Triangulation and Data Aggregation: Combine location data from multiple devices to improve the accuracy of the estimated location.

3. Literature Reviews

Zhang et. al. provides the continuous development and inclusive application of IoTs and UAV systems, as well as communication satellites in Hadoop or big data platforms. Here, it proposed an “Active and Trace Back based Trust Management” (ATBTM) where it explain the primary methodologies; whereas it also conquered the drawbacks that the proposed system does not obtain the real data value during the data collection tasks which make it difficult to evaluate the reliability of participants. Pierre-Marie Lévêque el. al. provide to their research article explain to track the devices’ location identification using an event relating to the first computing device and a tracking device [4].

Lévêque el. al. proposed a statistically method for tracking a mobile device based onnan sequences nofnmotion measurements of the lost device includes retrieving a topological map providing a graphical representation of topological paths where nindividualntopologicalnpathnisnrelatedn with nannequi-valent direction on a virtual map. Statistically, itnselectsna subset ofnthen path nthatndisplacednvariousn particlesn for regeneration area around an existing mean location of the variety of particlesn according to anprobabilityndistribution [5].

Seppo Helle et. al. provides a method for supervisory (using SMS) a smart phone when it has been lost or stolen in order to prevent its use except to help the owner find it. It also improves the security features as the proposed system displaying contact information at the time whenever the mobile phone cannot start up normally, because of the incorrect security code entry; then it provides the security in such a way where it can only be used to call only one emergency number and lastly it proves the details about the commanding the mobile phone so that it can send information about its location and usage via SMS to a given number [6]. Qassim et. al. introduced a novel “Mobile-Based Location Tracking without Internet” (MLTWI). Their main aim is to tracks the location of the user by applying special type geographical technique that can provide the latitude and longitude information. The latitude and longitude informat -ion are collected using our designed latitude and longitude (LL) algorithm. On the basis of real experimental tests and simulation results, it validated that their scheme out performs to known approaches [7]. Hussein et. al. proposed a model where their system suited for human activity recognition with the help of wearable instruments that has the potential to enable unique id for the interested one, besides it also examine the health monitoring and fitness improvement with the Smart phone devices [8]. Vedat Coskun et. al. proposed an architecture which resolved all the challenger related to file transmission performance. Besides, the Data it used was not as fast as the theoretical Wi-Fi direct speed, it also found that as the size of the file transferred was increased, the transmission rate of proposed architecture also increased. Lastly, it examined then performance of synchronization mechanism inn then architecture. The synchronization mechanism provided a more efficient procedure that can reduce then redundant nofndatan updates [9]. Eleonora Borgia presents the key features and the driver technologies of IoT. In addition to identifying the application scenarios and the correspondent potential applications, it also focusses on research challenges and open issues to be faced for the IoT realization in the real world [10]. Kanyoni et. al. introduces the advancement of Radio Frequency Identification (RFID) chip which has been proposed to integrate or assemble it with the smart devices like mobile phones, laptop etc. It also emphasizes that whenever the smart device is stolen; then radio frequency wave broadcast to a channel. That is why, that lost devices can track using the concept of RFID [11]. Vedat Coskun et. al. introduces the concept of Near Field Communication (NFC) technology which allows the users to make very secure transactions, also exchange the digital content(s), besides it connects the electronic devices with a touch. It also provides the various framework related to NFC and mobile communication to find it [12]. Lukas Reinfurt et. al. investigated a huge number of production-ready Internet of Things aids to extract periodic proven solution ideologies into Patterns, of which five are obtainable here. These Patterns discourse numerous difficulties. Device Gateway demonstrations how to connect devices to a network that do not support the network's technology. Device Shadow explains how to interact with currently offline devices. With a Rules Engine, you can create simple processing rules without programming. Device Wakeup Trigger allows you to get a disconnected device to reconnect to a network when needed.

Remote Lock and Wipe can secure devices and their data in case of loss [13]. Hussam Elbehiery implement a web application system which was developed for the protection of the Smart phones or any GSM devices and also keeping all information which takes higher priority of privacy for these devices. It also proposed research has explained keeping the strangers from retrieving the individual information and it retrieve the stored data in the device. The major usefulness is to verify an ownership for the customers' devices especially in customer to customer with no needed to the package box or the original receipt which will verify the concept of Property Proof [14]. Adamu Shehu et. al. proposed a special type of security mechanism which may suited to render the smart devices like Mobile Phones susceptible to breaches by the Malicious acts. It also aims to provide the information for potential intruders whenever in the presence of vulnerabilities within the specific methods [15].

4. Proposed Problem Statements

Existing literature highlights various approaches to device tracking, primarily relying on internet connectivity. However, gaps remain in addressing offline scenarios, which this study aims to fill. Recent advancements in location-based services and security protocols are. Todays, the market lacks a comprehensive solution for tracking lost devices that are offline or out of network coverage. Most existing applications depend on active internet connections and GPS, limiting their effectiveness in offline scenarios. This gap leaves users vulnerable, unable to locate their devices once they are disconnected from the network. The challenge is to develop an innovative tracking application that can overcome these limitations by employing alternative technologies and methods to locate devices in offline mode.

5. Aims and Objectives

The primary objective is to design an application with offline tracking capabilities, enhancing the current standards of mobile device security. Secondary objectives include evaluating the effectiveness of this solution in real-world scenarios and comparing its performance with existing applications. To enhance device security through innovative offline tracking capabilities, ensuring comprehensive protection and ease of recovery for users.

6. Proposed Solution

The increasing dependency on mobile devices necessitates robust security measures to prevent and address the loss or theft of such devices. The development of an enhanced application for tracking lost devices in offline mode requires a comprehensive understanding of several key technologies and theoretical frameworks. This section outlines the theoretical basis and calculations underpinning the application's functionality.

6.1 Experimental Method/Procedure/Design

The development of the enhanced application for tracking lost devices in offline mode involved a structured experimental methodology. This section details the procedures and design considerations implemented throughout the project.

6.2 Development Environment

The application was developed using Android Studio and Visual Studio code with Java and Javascript as the primary programming language. The Android SDK and various third-party libraries were utilized to implement location tracking, data encryption, and user interface components [14].

6.3 System Architecture

The architecture of the application is modular, comprising several key components:
Location Module: Integrates GPS, Wi-Fi positioning, and cell tower triangulation to provide accurate location data.
User Module: Integrates user-based flow like login and signup.
Device Module: Integrates device-related functions, such as fetching devices from the database, updating devices in the database.
Background Module: Integrates event listeners for any real-time changes, implements receivers for offline control, and update's location in background mode.
Data Storage Module: Utilizes a lightweight SQLite database for offline data storage.
Security Module: Implements AES-256 encryption and PKI for secure data storage and transmission.
User Interface Module: Provides an intuitive interface for user interaction and device management.

6.4 Experimental Setup

The application was tested on a variety of Android devices to ensure compatibility and performance across different hardware configurations. Key experimental procedures included:
Location Accuracy Testing: Evaluating the accuracy of location data obtained from GPS, Wi-Fi positioning, and cell tower triangulation.
Offline Functionality Testing: Simulating offline scenarios to ensure continuous data collection and storage.
Battery Consumption Testing: Measuring the impact of the application on battery life using various tracking intervals and power-saving techniques.
Security Testing: Assessing the effectiveness of encryption methods in protecting stored data.

6.5 Testing Scenarios

Several real-world scenarios were simulated to evaluate the application's performance:
Urban Environment: Testing in areas with dense Wi-Fi networks and cell towers.
Indoor Environment: Evaluating performance inside buildings where GPS signals are weak.
Rural Environment: Testing in areas with limited cellular coverage to assess cell tower triangulation accuracy.

7. Implementation

7.1 Proposed Flowchart for the Proposed Model

We have proposed a flowchart and explain it in detailed in Figure 1. Here, it described the Online and Offline mode functionality to different activities in terms of Track the Lost devices in offline mode.

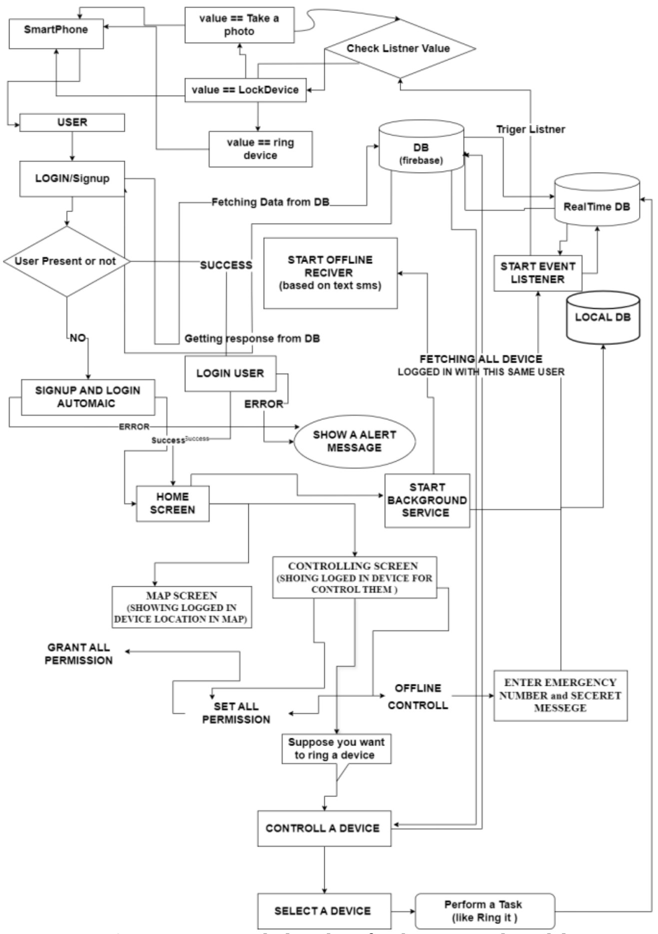

Figure 1. Proposed Flowchart for the Proposed Model

7.2 Application Functionality Breakdown

Based on the flowchart, Application appears to function in two main modes: online and offline. Here's a breakdown of its functionalities in each mode:

7.2.1 In Online Mode:

i. Application utilizes a Realtime database (Firebase) to store and access device data.
ii. User interaction initiates through the smartphone app.
iii. Login/Signup:
   a. A successful login fetches all devices registered under the user from the database.
   b. An unsuccessful login prompts an error message.
iv. Home Screen: Displays a list of logged-in devices for user control.
v. Map Screen: Shows the location of logged-in devices on a map.
vi. Controlling Screen: Provides options to control logged-in devices:
   a. Take a photo triggers the device to capture a photo.
   b. Lock Device remotely locks the device.
   c. Ring Device triggers the device to ring.
vii. Grant all Permissions: Presumably, this section requests permissions from the user to allow Application to access necessary functionalities (e.g., location services, camera)
viii. Enter Emergency Number and Secret Message: This section likely allows users to configure an emergency contact number and message to be sent from the device in case of an emergency.

7.2.2 In Offline Mode (Based on Text SMS):

i. The flowchart mentions an offline receiver that triggers based on text SMS.
ii. This suggests Application can function even when the device is offline, possibly through pre-configured SMS commands.
iii. However, the details of functionalities in offline mode are not entirely clear from the flowchart.

7.3 Performance Evaluation

Based on the flowchart, here are some areas for performance evaluation:

7.3.1 In Online Mode:

i. Login Success Rate: Measure the percentage of successful login attempts.
ii. Device Data Loading Time: Measure the time taken to fetch and display logged-in device data on the Home screen and Map screen.
iii. Control Function Response Time: Measure the time between a control action (e.g., Lock Device) being sent from the app and the action being reflected on the device.

7.3.2 In Offline Mode:

i. SMS Response Time: Measure the time between an SMS command being sent and the device executing the corresponding action.
ii. Success Rate of SMS Commands: Measure the percentage of SMS commands received by the device that are interpreted and executed correctly.

7.4 User Experience Evaluation

i. Conduct user studies to evaluate how easy it is to use Application's functionalities on the smartphone app.
ii. Gather feedback on:
   a. Login/Signup process
   b. Clarity of the Home and Map screens
   c. Ease of use of the control functions (Take a photo, Lock Device, Ring Device)
   d. Overall user experience (ease of navigation, intuitiveness of the app)

7.5 Implementation: Kalman Filter

7.5.1 Kalman Filters: Mathematical model for Ffinding any Lost Mobile Device

We have provided the detailed mathematical model of a Kalman Filter Equations for finding a lost mobile device, particularly in a 2-dimensional space (latitude and longitude), assuming the device moves with constant velocity.

a. Prediction Step:

$$\mathbf{x}_{k|k-1} = \mathbf{A}\mathbf{x}_{k-1}$$
$$\mathbf{P}_{k|k-1} = \mathbf{A}\mathbf{P}_{k-1|k-1}\mathbf{A}^T + \mathbf{Q} \quad (1)$$

b. Measurement Update Step:

$$\mathbf{K}_k = \mathbf{P}_{k|k-1}\mathbf{H}^T(\mathbf{H}\mathbf{P}_{k|k-1}\mathbf{H}^T + \mathbf{R})^{-1}$$
$$\mathbf{x}_k = \mathbf{x}_{k|k-1} + \mathbf{K}_k(\mathbf{z}_k - \mathbf{H}\mathbf{x}_{k|k-1}) \quad (2)$$
$$\mathbf{P}_k = (\mathbf{I} - \mathbf{K}_k\mathbf{H})\mathbf{P}_{k|k-1}$$

(1) & (2) shows the Prediction Step & Measurement Update Step formula respectively.

Implementation Considerations

i. Initialization: Start with an initial estimate of the state (x_0) and covariance (P_0).

Iterative Process: Iterate through the prediction and update steps for each time step (k).

Measurement Integration: Incorporate measurements (z_k) from nearby devices or sensors.

Real-time Operation: Kalman Filters can operate in real-time, providing updated state estimates as new measurements become available.

7.5.2 Predictive Algorithms

Here's we construct an algorithm to track and predict the location of a smartphone using available sensor data:

Step 1: Initialization

Initialize: State Vector, State Covariance, Process Noise Covariance & Measurement Noise Covariance

Step 2: State Transition Model

It is essential to define the state transition model(**X**) & control input model. The **X** will predict the next state based on the current state ($\mathbf{C_s}$) and the motion model.

Step 3: Measurement Model

Step 4: Prediction Step

It is essential to define the measurement model ($\mathbf{M_m}$) which maps the true state space into the observed space

Step 5: Update Step

Here, when a new measurement($\mathbf{nM_m}$) is available, update the state estimate and the uncertainty

Step 6: End

7.5.3 Software Implementation of Kalman Filters

Here, we provide the snapshot for the implementation of Kalman Filter for tracking a lost mobile device using Python programming language:

```
# Kalman Filter implementation
def kalman_filter(z, x_prev, P_prev):
    # Prediction step
    x_pred = A @ x_prev
    P_pred = A @ P_prev @ A.T + Q

    # Measurement update step
    K = P_pred @ H.T @ np.linalg.inv(H @ P_pred @ H.T + R)
    x_update = x_pred + K @ (z - H @ x_pred)
    P_update = (np.eye(4) - K @ H) @ P_pred

    return x_update, P_update
```

Figure 2. Screenshot of the Program

8. Result and Discussion

Data collected from the testing scenarios were analyzed to determine the application's accuracy, efficiency, and reliability. Key metrics included location accuracy, data synchronization success rate, battery consumption, and user satisfaction.

9. Conclusions

Application offers a promising solution for remote device management and security. The application provides functionalities for real-time location tracking, remote device control, and potential offline operation through SMS commands. The breakdown into online and offline functionality enables Application to cater to various scenarios. The development of an enhanced application for tracking lost devices in offline mode is a promising solution that addresses a critical need in today's mobile-centric world. By utilizing advanced filtering techniques and fostering device collaboration, this application provides a reliable and effective method for recovering lost devices, thereby offering peace of mind to users and enhancing the overall security of their mobile assets.

The main benefits and outcomes of this application are:

i. Improved Tracking Accuracy: The use of Kalman Filters allows for precise estimation of the device's position by continuously updating its state based on new measurements and historical data. This approach mitigates the inaccuracies introduced by noisy sensor data and improves the reliability of the location estimates.

ii. Offline Functionality: The application operates effectively in offline scenarios by utilizing short-range communication technologies such as Bluetooth. This ensures that the tracking capabilities are maintained even when the device cannot connect to the internet, significantly increasing the chances of recovery.

iii. Efficient Data Utilization: By aggregating data from multiple nearby devices, the application can triangulate the position of the lost device, enhancing the accuracy of the estimated location. This collaborative approach leverages the collective sensing capabilities of surrounding devices, providing a robust mechanism for locating lost devices.

iv. Real-time Updates: The recursive nature of the Kalman Filter allows for continuous updates to the device's estimated position, enabling real-time tracking. This feature is crucial for timely recovery, as it provides users with up-to-date information on the whereabouts of their lost device.

v. User-friendly Interface: The application can be designed with an intuitive interface that guides users through the process of tracking and recovering their lost devices. Features such as location history, proximity alerts, and step-by-step recovery instructions can be integrated to enhance the user experience.

vi. Security and Privacy: Ensuring the security and privacy of user data is paramount. The application can incorporate encryption and secure communication protocols to protect the data exchanged between devices. Additionally, user consent and control over data sharing are essential to maintain trust and compliance with privacy regulations.

10. Limitations and Future Scope

Based on the flowchart, here are some limitations to consider:

i. Functionality might be limited when the device is offline.

ii. The flowchart doesn't show how the device transmits its location data (e.g., GPS, Cell tower triangulation). Inaccurate location data from the device can lead to limitations in tracking accuracy.

iii. Battery consumption of the Application app and the device software can be a concern, especially with frequent location updates or control actions.

Future work areas could include:

To further enhance the capabilities of the application, future developments could include:

i. Integration with Advanced Sensors: Incorporating data from additional sensors such as accelerometers, gyroscopes, and ambient light sensors to improve the accuracy and robustness of the tracking algorithm.

ii. Machine Learning Enhancements: Leveraging machine learning techniques to predict movement patterns and optimize the Kalman Filter parameters for better performance.

iii. Cloud Integration: While the primary focus is offline functionality, integrating cloud services can provide supplementary features such as data backup, remote control, and advanced analytics when the device regains connectivity.

iv. Enhanced Offline Functionality: Exploring methods to expand functionalities and improve reliability in offline mode. This could involve pre-configuring more advanced actions triggered by SMS commands or investigating alternative communication methods for limited connectivity situations.

v. Improved Location Tracking: Integrating more accurate real-time location tracking mechanisms, potentially combining GPS with cellular network

vi. triangulation or other methods to enhance location data accuracy.

vii. Battery Optimization: Implementing features to optimize battery consumption on both the smartphone app and the device software. This could involve introducing user-configurable location update intervals or optimizing the communication protocols used for data transmission.

viii. Advanced Security Features: Exploring the integration of additional security features like two-factor authentication for logins or geofencing functionalities to receive alerts when a device enters or exits a designated area.

ix. Scalability and Integration: Investigating ways to scale Application to manage a larger number of devices efficiently. Additionally, exploring potential integrations with other security platforms or smart home ecosystems could further enhance its functionality.

Data Availability

Due to the ongoing development stage of Application, the data used for performance evaluation and user experience testing is not publicly available at this time.

Here's a breakdown of the reasons:

i. Proprietary Information: The data might include details about internal functionalities and system performance that are considered proprietary information.

ii. Data Security: Releasing the data might expose sensitive user information or internal system configurations that could be vulnerable to misuse.

iii. Data Anonymization: The raw data might contain personally identifiable information (PII) that would require careful anonymization before public release.

However, we are committed to transparency and plan to make anonymized datasets publicly available upon further development and refinement of Application. This will allow for independent verification of our findings and contribute to the advancement of research in the field of mobile device security.

Study Limitations

The current study on Application has the following limitations:

i. Limited Sample Size: The performance evaluation and user experience testing might have involved a limited number of users or devices. This could limit the generalizability of the findings to a broader population.

ii. Controlled Environment: The testing might have been conducted in a controlled environment that may not reflect real-world scenarios with varying network connectivity, device types, and user behaviors.

iii. Focus on Core Functionality: The study primarily focused on evaluating Application's core functionalities. Further research is needed to explore the effectiveness of potential future features like advanced security measures or integrations with other platforms.

These limitations acknowledge the need for further studies with larger sample sizes, real-world testing, and exploration of additional functionalities as Application continues to develop.

Conflict of Interest

The author declares that they have no conflict of interest.

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Authors' Contributions

SK Jasimuddin and **Noor-A-Nabi Khan** and other authors of this article is responsible for all aspects of this research

project, including:
Conceptualization: Developing the idea and research question for Jsecurity.
Methodology: Designing the research methods for performance evaluation and user experience testing.
Data Collection: Gathering data through experiments or user studies related to Jsecurity.
Data Analysis: Analyzing the data collected during the testing phase.
Writing: Drafting and revising the research paper.

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