Offline BLE-Based Attendance System: A Scalable and Internet-Independent Attendance Solution Using Bluetooth Low Energy

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***Abstract*—Monitoring the attendance – whether in the classroom, training classes or any other environment – sounds straightforward. But usually, it's not. Paper logs get lost. Roll-calling takes time. And nearly all the digital systems require costly hardware or reliable internet connection that is not always provided. This work offers an attendance tracking mechanism based on BLE technology that is free of these drawbacks. It starts from the simplest premise possible – the teacher's device sends out BLE signal and phones of students automatically record it without using internet connection or adding any extra hardware. The main issue with this approach (having somebody mark your attendance instead) is addressed by using multiple verification mechanisms such as one-time session keys, threshold values for signal strength, continuous monitoring, and binding to user devices. Data storage occurs locally and uploaded to cloud service as soon as the connection becomes available. The prototype was tested in an actual class with 45 students during four-week period reaching accuracy 96.4% with 10-meter radius and consuming about 42% less energy compared to Wi-Fi based system.**

***Index Terms*—Bluetooth Low Energy, Attendance Management System, Offline Attendance, IoT, Mobile Computing, BLE Beacon, Smart Classroom, Proximity Detection**

I. INTRODUCTION

Walk into any lecture hall in any university and you will instantly recognise the following scenario: a lecturer going through the attendance list while students only half-heartedly pay attention or, alternatively, a sign-up list handed around and not really checked by anybody. Inefficient, prone to errors – and it has not changed much since the '70s. Organisations conducting training or other corporate activities are facing the same challenge, sans automation capabilities.

There have been some attempts at digital attendance solutions before. RFID, QR code scanning, GPS positioning, fingerprinting. They are all indeed improvements over the handwritten list, but each one has its limitations. RFID requires a reader device at every possible entrance point. Indoor use cases are problematic for GPS: besides its infamous unreliability inside buildings, it is rather resource-intensive and will drain student phones very quickly. The QR code system is easily spoofed: take a quick picture and send it to the WhatsApp group; one tap in the group chat, and a student half an hour away from campus is officially present for that day. As for the cloud-based solutions, all bets are off once there is no connection.

That is where BLE comes in. It has been included in smartphones since 2013, uses far less power than WiFi or GPS and operates reliably within distances typical of educational spaces. In our solution, BLE allows the teacher's device to broadcast the unique attendance session identifier. Students' phones would scan for that particular signal, check that their device is in range (hence they are physically present), store the data locally and sync it with cloud services whenever possible.

Proximity-based solutions are inherently vulnerable to proxy usage: having someone else register your attendance while you are chilling at home or in a café. We took that into account and designed several levels of protection against that type of fraud: unique session identifiers, proximity detection using BLE signal strength, active presence checks, and device binding.

This project's key contributions are:

- Fully offline BLE attendance framework that works without Internet connectivity.
- Proxy-resistant design involving several levels of security measures.
- Cross-platform Flutter mobile app for Android and iOS devices.
- Experimental results for BLE detection accuracy and energy consumption.
- Scalable by default solution for various sizes of teaching spaces.

II. RELATED WORK

There have been quite many different attempts at automated attendance through the years, and each of them has something valuable to offer – even those that have ultimately failed. RFID systems were perhaps one of the first large-scale solutions of their kind, and as such, they proved reliable and efficient in terms of both fast identification and high precision. Their main weakness, however, lies in hardware: card readers need to be installed throughout every entry point, and every participant needs a dedicated card. All in all, it's not particularly cheap to implement and maintain; losing your card means you have no attendance record.

As for GPS tracking, one might think that using every smartphone nowadays having a built-in receiver would solve the issue. The problem is that GPS itself wasn't made to track indoors. Its penetration through floors and ceilings is highly irregular, its positioning could shift by a number of meters, and finally, it has proven to be a real battery drain for a typical mobile device.

QR-code technology could have been a solution for some time because it's relatively easy and fast to integrate, requires almost zero additional hardware, and is very easy to explain to anyone. However, the system was too simple – participants could easily share QR codes between each other without the system being able to detect that.

Wi-Fi fingerprinting is a technique relying on network signals for precise location identification. It's a bit more complex than QR codes, although it still relies on the fact that students have a smartphone with them, and the signal maps need to be pre-installed and adjusted to changes in the surrounding networks. Also, like any other WiFi-based method, it requires functioning Wi-Fi infrastructure.

Biometric cloud systems represent one of the most advanced solutions available today. They are secure, accurate, require minimum user interaction, but still, they rely heavily on consistent internet connection.

The last few studies show that BLE signal strength could actually be used as a good measure of proximity in classroom-scale environments. However, what is lacking in those works is an approach which allows to utilize the system even when no internet access is possible.

III. SYSTEM DESIGN AND ARCHITECTURE

A. System Overview

The system has three distinct components, each with a clear role:

Component	Function	Platform
Teacher Module	BLE Beacon Broadcasting	Android / iOS / Raspberry Pi
Student Module	BLE Scanning and Attendance Detection	Android / iOS Smartphones
Admin and Sync Module	Data Management and Synchronization	REST API / Cloud Server

The broadcasting component in the system is the teacher's device; the authority of all sessions. Devices belonging to students listen out for the broadcasting signal, perform the relevant tests and store the results locally. Reporting and synchronization with the cloud falls to the admin component; however, no part of the attendance process depends on its availability.

B. BLE Communication Process

Once the teaching session begins, BLE advertisement packets will be sent by the teacher's device every 100 milliseconds. This period was selected carefully – frequently enough to pick up the packet at the receiver end almost immediately, but not too aggressively to negatively impact the battery of the teacher's phone in any way. These packets include the following pieces of information:

- Session UUID, allowing the system to uniquely identify each occurrence of the course.
- Course ID, informing the system about the corresponding subject of this attendance session.
- Timestamp, helping the system to identify fake or repeated packets.
- Unique one-time token.

At the receiver end (student's phone), BLE background scanning is performed by the application. Once it catches one such signal, it gathers the following data:

- Student's ID number.
- Received session identifier.
- Time of reception (timestamp).
- RSSI, allowing to estimate the distance between the devices.
- Status: present/absent/rejected.

The data is then saved directly in an SQLite database. No action from the student is required.

C. Anti-Proxy Mechanism

Detection accuracy is just part of the solution. Equally important is ensuring that the system is robust and cannot be spoofed. Here are four measures used to solve the issue:

- One-Time Session Token: Each session receives a unique one-time crypto-token. Intercepting and sending the BLE data packet from a previously concluded session will result in rejection of the token.
- RSSI Threshold: Power falls as distance increases. We have set the minimal threshold below which signal strength does not qualify for marking attendance – you need to be physically present in the classroom.
- Continuous Attendance Detection: Merely attending class within the first few minutes is not enough. Your device must detect the Bluetooth signal over a significant period of time.
- Device Binding: You register your device with your account and only the one device can mark your attendance. Using another person's phone or switching devices does not count.

No measure alone makes proxy attendance impossible but combining all these steps significantly increases its difficulty.

D. Offline Data Management

The entire system works offline in the sense that working in the online environment is the exception rather than the rule. Each instance of attendance will be recorded into a local SQLite database with the following columns:

- Student ID
- Course ID
- Session ID
- Date of detection
- The RSSI value at the moment of detection
- Attendance status
- A flag denoting if the record has already been uploaded to the cloud or not

This last one is very important since the syncing process is performed whenever the phone comes back to the internet and the sync module detects that there are records which need uploading. Thus, it uploads the records through RESTful APIs with JWT authentication. The server verifies the upload and updates the flag on the client side.

IV. SYSTEM IMPLEMENTATION

A. Software Technologies Used

Flutter seemed like an ideal choice for the app development process since having one code base working for both the Android and iOS platforms would have its own benefits in terms of maintenance. Full stack:

Technology	Purpose
Flutter	Cross-platform Mobile Application Development
Dart	Application Programming Language
flutter_blue_plus	BLE Communication Integration
SQLite	Local Offline Data Storage
Node.js & Express	Backend Server
MongoDB	Cloud Database
REST API	Data Synchronization

The application supports Android 8.0+ and iOS 13+ versions, meaning that most of the users' devices will fall into this category.

B. Teacher Module Features

All this was done keeping in mind just one idea: the session start process needed to take seconds, not minutes. It does not get in anyone's way. For the teacher, the app offers the following options:

- Course selection before session initiation.
- Session creation by simply tapping on an option button.
- Live view of attendance records as they come in.
- Functionality to start, pause, or end a session.
- Offline session data storage and synchronization.

C. Student Module Features

From the student's perspective, the module was designed to work automatically in the background with minimal user interaction:

- Auto-detects BLE signals from teacher's device.
- Works even when the app is in background or phone placed in one's pocket.
- Confirms session and takes attendance provided everything is OK.
- Saves attendance locally if there is no connection at the moment.
- Displays the history of sessions to check your records.

D. Admin Dashboard

The administrators receive a dashboard on their web-based portal that helps them manage data within the institution. The dashboard comprises the following:

- Analytics of attendance per course and student.
- Ability to export in CSV and PDF formats.
- Monitoring of attendance per individual student.
- Option for manual override when the automation needs adjustment.
- Management of cloud sync and its status.

V. EXPERIMENTAL RESULTS

A. Experimental Setup

The test was conducted in a real university classroom setting, not a laboratory one, with 45 students present in the classroom. During four weeks of experimentation, 20 sessions of taking attendance were performed. The classroom itself had the size of 10 by 8 meters, and had walls made from ordinary concrete. In order to avoid obtaining the results applicable only for a particular smartphone model, testing was performed using three different smartphone models, namely Samsung Galaxy S21, OnePlus 9, and iPhone 13.

B. Detection Accuracy Analysis

The signal level decreases with distance as one would expect, although the rate of decrease was less than expected. In a classroom setting, there is no problem with performance:

Distance Range	Detection Accuracy	False Positive Rate	Performance.
0–3 metres	99.2%	0.3%	Excellent
3–6 metres	98.1%	0.8%	Excellent
6–8 metres	96.4%	1.2%	Good
8–10 metres	91.7%	2.1%	Acceptable
Above 10 metres	62.3%	5.4%	Weak

The drop-off after 10 meters is definitely noticeable, but it is not a real issue for regular classroom use. This kind of space will normally be subdivided, or even the device itself can just be moved.

C. Battery Consumption Analysis

The energy savings benefit of BLE over Wi-Fi was evident from the data. In a one-hour period:

- Students' devices drained an average of only 4.2% of their battery, barely noticeable for a full school day's use.
- A similar system using Wi-Fi technology burned 7.3%, nearly twice as much.
- The teacher's device, in active use throughout, burned about 3.8%.

That 42% savings in battery usage versus Wi-Fi competitors is not just impressive math; it means the difference between students letting the app run in the background and turning it off to save battery life, defeating the purpose entirely.

D. Comparison with Existing Attendance Systems

Feature	Proposed BLE System	RFID	QR Code	GPS
Internet Dependency	No	No	Yes	Yes
Anti-Proxy Capability	High	Medium	Low	Medium
Infrastructure Cost	Low	High	Low	Low
Battery Consumption	Very Low	N/A	Low	High
Indoor Accuracy	High	Very High	High	Moderate
Scalability	High	Medium	High	High

While RFID truly stands out when it comes to indoor precision – specialized readers can't be beaten. But it fails miserably when it comes to cost-effectiveness and adaptability. QR codes are available but too easy to misuse. GPS is limited to outdoor uses. BLE finds a good compromise in all aspects.

VI. DISCUSSION

The empirical results obtained in the classroom context give us enough reason to believe that the approach will perform well under non-laboratory conditions. The accuracy of detecting attendance above 96% at the distances characteristic for classrooms is quite satisfactory for real-life use, and the battery consumption figures indicate that students are not forced to choose between conserving energy and taking part in the process.

It turns out that an offline-first approach was a key consideration for the success of the project. The obvious advantage of functioning even without internet access also means better tolerance to server-side issues the attendance will be registered regardless of the connection status and synced when things are back to normal. For educational establishments located in regions with unreliable internet access, this feature alone can ensure that the application performs its purpose.

Anecdotally, students participating in the tests agreed that the continuous presence check was indeed an effective means of preventing skipping classes arriving on time for the first five minutes and leaving did not work. You had to stay put.

There are some important limitations worth mentioning:

- The signal becomes weak after 8–10 meters, which may prove to be an issue in large lecture halls or auditoriums.
- RSSI is highly dependent on the surroundings — metal furniture, crowdedness, and the orientation of the device affect the measurements.
- Thick concrete walls caused inconsistencies during beacon detection requiring careful calibration.
- Some potential directions for further development of the application could be:
- Implementing machine learning-based approaches to filtering the signal and improving RSSI.
- Indoor localization for differentiating students physically present in the classroom from those standing at the doorway.
- Integration with the student information system and ERPs.
- Multi-classroom management and session comparison capabilities for large campuses.

VII. CONCLUSION

The idea of this project emerged due to a simple observation about the modern solutions for digital attendance tracking most of them are too costly, dependent on network availability, or easily cheatable. However, BLE-based solution solves all these issues and provides high accuracy and reliability, according to our test results.

During 20 classroom lessons with 45 participants, the system demonstrated an average accuracy of 96.4%, used significantly less battery capacity compared to Wi-Fi implementations and worked independently of internet connection. Thus, the offline-first approach combined with multi-layered anti-proxy mechanisms make it reliable and hard to cheat.

What is more, it does not require any additional hardware because such institutions as schools, universities, or other organizations where students and teachers use smartphones running Android or iOS operating systems are able to apply this technology right now. Besides, the low barrier to entry, offline support, and anti-proxy implementation make this solution very suitable for those organizations that have been using paper-based registers or cheatable QR-code systems for tracking attendance.

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