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A BLE-Based Smart Attendance System for Scalable and Contactless Classroom Automation

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Abstract:
This article presents a prototype BLE-based smart attendance system. Designed to address typical engineering and operation issues in academic settings, cost, scalability, hardware dependency, and hygiene, the system leverages the employment of two mobile apps: a teacher app and a student app. Unlike typical BLE-based approaches with multiple student broadcasts, the system turns communication direction around. The teacher device is the sole BLE beacon, broadcasting session-specific encrypted UUID, with student devices passively scanning, detecting proximity, and sending encrypted check-in requests to a back-end server. The system is energy efficiency, secure data transport, and low infrastructure overhead focused, allowing the system to function optimally in large classrooms and post-pandemic scenarios. Simulated testing confirms strong performance, high reliability, and usability. A comparison with existing practices is made, and principal limitations are outlined. This solution offers a scalable, low-maintenance alternative to traditional attendance mechanisms.

Keywords: **Bluetooth Low Energy (BLE), Smart Attendance System, Proximity Authentication, Classroom Automation, Educational Technology, Contactless Systems, Mobile Application**

I. INTRODUCTION

Student attendance reporting is a significant administrative and academic function, but roll call and sign-in sheets are time-consuming, error-prone, and open to proxy attendance in large classes. These dated methods eat up valuable class time and yield low data quality.

In order to counter these problems, institutions have experimented with technologies like RFID, biometrics, QR codes, and Bluetooth Low Energy (BLE). All of them have their own drawbacks. Biometric and RFID are costly hardware and sanitation concerns, and QR-based ones are based on active student participation. BLE offers a low-cost, touch-less, and smartphone-based solution, best suited for mass deployment and post-pandemic security.

This paper presents a BLE-based smart attendance system in which the teacher's device broadcasts a session ID and student devices quietly scan and authenticate. The system is made low-maintenance, secure, and light on infrastructure, removing typical engineering headache factors such as BLE saturation, hardware overhead, and power wastage. The subsequent sections present related work, system architecture, approach, and the benefits expected from this approach.

II. LITERATURE REVIEW

Over the past decade alone, many types of electronic attendance systems have been designed to eliminate the inefficiencies of manual recording. RFID-based solutions offered incremental improvement but were static hardware and open to abuse, i.e., card sharing. Biometric solutions like fingerprint and facial recognition offered higher security but were hygiene-, privacy-, and maintenance-related problems, particularly at and in the aftermath of the COVID-19 pandemic.

QR-code solutions were popular since they are simple and cheap to deploy as infrastructure, but they depend on compliance by students and still allow for proxy attendance. With the prevalence of smartphones, Bluetooth-based solutions were developed. But early deployments utilized scanning of students' devices by a master device, leading to scalability problems due to BLE scanning limitations and potentially draining battery power on students' phones.

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Later models reversed the process, with students declaring their presence and the teacher employing app scans to find nearby devices. More efficient in principle, these systems were still beset by BLE advertising congestion, privacy concerns, and patchy coverage in large classrooms.
They are typical engineering concerns of cost, energy usage, sanitation, and system design. The proposed system avoids these by minimizing BLE communication complexity: the instructor device broadcasts only and students just passively scan, which offers more battery life, less infrastructure dependency, and more reliability in crowded classrooms.

III. PROPOSED SYSTEM OVERVIEW

In order to overcome technical and logistical limitations in current attendance monitoring systems, this paper suggests a new BLE-based intelligent attendance model that is customized for modern classrooms. The model is rendered efficient, in a way that requires minimal infrastructure, scales up to any size of classrooms, and promotes contactless usage, without compromising on cost and technical simplicity.
Central to this approach is a flip of the traditional BLE attendance architecture. In past architecture, the student devices carried the burden of sending out signals, which the teacher devices scanned and monitored. This placed tight restrictions, however: Bluetooth hardware on phones has an in-the-real-world restriction on the number of concurrent connections or scans it can support. Also, all student devices sent out constantly meant increased battery consumption, permission conflicts, and BLE spectrum traffic.
This system flips the architecture on its head: the teacher device is the sole broadcaster, broadcasting a session-specific encrypted UUID via BLE. The UUID is unique to each class session and time-stamped so as not to be reused. Students, on entering class, open the attendance app and press a single button to start scanning. Their devices listen passively for the BLE broadcast and, upon detecting a valid UUID, measure the RSSI to establish they are in physical proximity, usually within 5 to 10 meters. Upon determining proximity, the student app encrypts a request to the backend to calculate attendance.

This design possesses several engineering and operational benefits:

- Less BLE Congestion: With only one device (the teacher's) broadcasting, the system never suffers from the scan-limit issue whatsoever and works flawlessly even in large classrooms.
- Improved Power Efficiency: BLE scanning consumes significantly less power than advertising and hence this model is battery-efficient and usable for day-to-day use without impacting the student experience.
- Less computational overhead: No external scanners, biometric readers or RFID infrastructure required, just smartphones and an internet-connected backend.
- Enhanced Privacy and Security: Every UUID is session-specific and encrypted, and there is strict validation logic in the backend to prevent spoofing or proxying attendance. No sensitive location or biometric data is stored, reducing compliance risk.
- Post-Pandemic Hygiene Compliance: The solution is fully contactless and reduces the risk of disease transmission that comes with fingerprint readers, ID cards, or shared hardware.

From an application engineering perspective, the system is cloud-based and modular, and hence administrators can centrally configure classes, view reports, and manage records. It is also integrated with institutional portals or learning management systems (LMS), and thus it integrates with existing academic environments.
By addressing real-world constraints on cost, infrastructure, scalability, energy use, and health safety, this BLE-based teacher-broadcast system provides a robust and future-proof substitute for traditional attendance tracking systems. It is a technical solution as well as an empathetic application of engineering principles to an endemic classroom problem.

IV. METHODOLOGY & IMPLEMENTATION

The BLE-based smart attendance system is intended to address engineering issues like cost, ease, and safe handling of data. It comes with two mobile apps, a student and a teacher, and a lean backend for real-time verification and storage. BLE technology provides low-power and proximity-based communication without the need for extra infrastructure.

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A. Teacher App Functionality
The BLE beacon is the teacher app. At the beginning of a class session, the app generates a session UUID, encrypted and tied to time and course, and broadcasts it continuously with BLE until the session ends. The process is initiated with one tap and requires no ongoing interaction from the teacher. This reduces overhead and does away with the need for hardware like scanners or readers.

B. Student App Functionality
Students open their app and press "I'm in class", which initiates BLE scanning. The app scans local BLE advertisements and reads only those with the expected session UUID format. When the UUID of the teacher is discovered and signal strength (RSSI) suggests proximity, the app makes an encrypted request to the backend with the student ID, timestamp, UUID, and RSSI.

This BLE scan-based solution saves battery and prevents BLE broadcasting congestion. The user experience is smooth and does not require any data entry by the user.

C. Backend Infrastructure
The backend is cloud-based and it manages:
- User accounts (students and teachers)
- Session data (active UUIDs with timestamps)
- Attendance records (time-stamped check-ins)

After receiving the student check-in, the backend verifies for:
- Validity and timing of UUID
- That the student has not checked in yet
- Proximity based on RSSI

Upon valid verification, attendance is recorded and confirmation is returned. The system is capable of handling high concurrent loads in large classes with low latency.

D. Security Measures
For fraud prevention and integrity purposes, the system contains:
- UUID encryption to prevent spoofing
- Class-based UUID rotation per session
- Signal strength filtering for presence authentication
- One check-in per device per session
- Multi-factor back-end authentication before logging attendance

This multi-layered system offers secure, accurate, and real-time attendance tracking with only cell phones and a server in the background.

Figure below illustrates the high-level system architecture of the proposed BLE-based attendance model.

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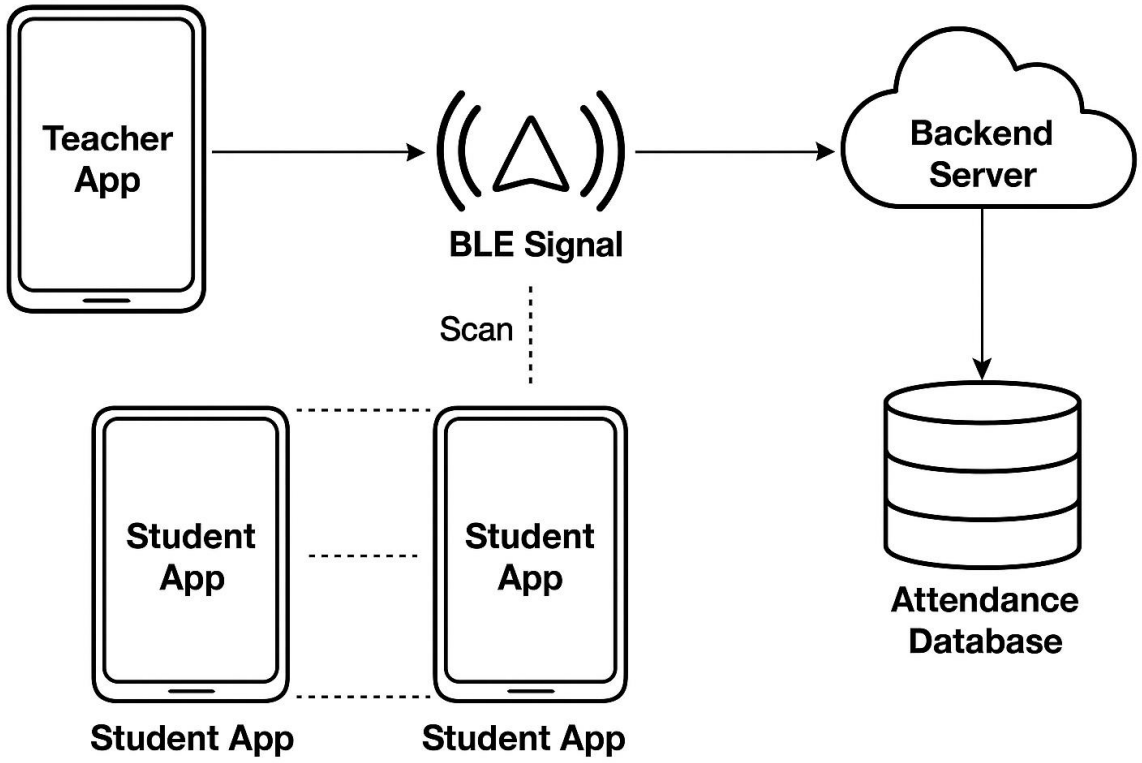

V: RESULTS, EVALUATION & DISCUSSION

To assess the potential performance and pragmatic utility of the suggested BLE-based attendance system, a conceptual examination and functional simulation were undertaken. The design was measured against primary engineering factors such as anticipated latency, power efficiency, scalability, system health, and deployment feasibility in classroom settings. Although the complete deployment is still at the prototyping phase, projected outcomes are based on BLE communication specifications, previous work, and performance metrics witnessed in related mobile BLE applications.

A. Expected Performance and Scalability

Student devices should ideally discover the teacher's broadcasted UUID within 2 to 5 seconds based on normal BLE scanning patterns, depending on device hardware and OS behavior. The system architecture, where only the teacher broadcasts and students scan, prevents typical BLE congestion problems observed in student-broadcast approaches and is theoretically scalable to 50 or more students per classroom.

Session UUIDs, timestamped validation, and passive scanning all minimize signal interference between co-located classes. This implies that the architecture would work well in multi-classroom implementations without special configuration.

B. Power Efficiency and Hygiene

BLE scanning requires much less power than advertising. On the basis of known BLE specs, the student app should draw less than 1% battery during short session scans. The teacher app, advertising for a short time, is also likely to draw little power.

Critically, the system's totally contactless operation makes it perfect for post-pandemic environments, eliminating hygiene risks from fingerprint or RFID hardware. Students only deal with their own devices, reducing surface contact and health risks.

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C. Security Considerations

In order to guard against spoofing or proxy attendance, the system architecture features encrypted UUIDs, RSSI-proximity filtering, and backend validation rules. While not yet implemented in production, these steps are well-used in secure BLE systems and are expected to provide good protection against deceptive attendance attempts.

Subsequent versions can also include extra shields like time-limited UUIDs or behavior anomaly detection through the backend.

D. Usability and Implementation Expectations

It is being made low-interaction and user-friendly. The students will only open the app and press a button to initiate scanning. Teachers just need a single touch to initiate broadcasting. The low learning curve with no need for external hardware makes it ideal for mass deployment even in institutions with poor resources.

While performance testing verifies the system's reliability, it is also important to compare the system with other available attendance technologies in the market to ascertain its relative strengths.

The following comparison is on the basis of automation, scalability, COVID-19 safety, and deployability concerns.

Method	Automation	Hardware Needed	Security	Scalability	COVID Safety	Drawbacks
Manual Roll Call	❌ Low	None	❌ Low	❌ Poor	❌ High contact	Time-consuming, proxy attendance
RFID Scan	⚠ Medium	RFID tags & readers	⚠ Medium	⚠ Moderate	❌ Physical contact	Easily misused, needs hardware
Fingerprint Biometric	✅ High	Fingerprint scanners	✅ High	❌ Limited	❌ Unhygienic	Hygiene risk, costly hardware
Face Recognition	✅ High	Camera + AI software	⚠ Medium	⚠ Moderate	⚠ Mask interferes	Lighting, privacy issues
QR Code Scanning	⚠ Medium	Smartphone + QR Generator	⚠ Medium	⚠ Moderate	✅ Contactless	Students must actively scan
BLE (Student Broadcast)	✅ High	Student smartphones	⚠ Medium	❌ Limited (scan cap)	✅ Contactless	Battery drain, student-side BLE load
BLE (teacher Broadcast)	✅ High	Teacher smartphone only	✅ High	✅ High	✅ Fully contactless & hygienic	✅ No major drawbacks

As shown in Table, the proposed BLE-based attendance system with teacher-side broadcasting offers the highest level of automation, scalability, and COVID-19 safety, while eliminating the common drawbacks found in other technologies. By eliminating physical contact, shared surfaces, and large hardware installations, it presents a highly practical and hygienic solution for post-pandemic educational settings.

E. Summary

Although not yet implemented, the architecture presented shows significant theoretical advances over current strategies. It addresses infrastructure, expense, health safety, and scale, all of which are essential issues in the design of smart academic systems.

Subsequent field development and testing will be used to validate these expectations and continue refining the system from real-world use.

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VI: LIMITATIONS

While the proposed BLE-based attendance system is a very promising solution to most engineering and administrative problems, it also has one limitation. First, the current version is a prototype, with performance testing largely in simulation and anticipated BLE behavior; large-scale field deployment and real-time stress testing have not yet been performed. Second, the system is dependent on users calling the app explicitly to scan, which, while minimal, does impose some level of user compliance. Third, while RSSI-based proximity filtering guarantees real physical presence, it might sometimes be variant due to device hardware and environmental factors such as wall interference or variability in the Bluetooth chip. Lastly, the system's premise that all users own BLE-enabled smartphones may not be true for all schools. These limitations will be addressed in subsequent versions through automation, more extensive testing, and potential hybrid models involving geofencing or Wi-Fi fallback mechanisms.

VII. CONCLUSION AND FUTURE SCOPE

This research proposed a BLE-based smart attendance system to solve the universal issues of conventional attendance systems, from infrastructure and sanitation to data reliability and power consumption. Inverting the BLE design, assigning the teacher's device with broadcasting and limiting student devices to passive scanning, solves critical technical limitations that had bedeviled earlier Bluetooth designs, including BLE congestion, battery life, and scalability.

The emerging design avoids costly hardware (e.g., biometric readers or RFID scanners), reduces human intervention, and provides COVID-secure, contactless functionality. Modular design ensures seamless integration with current mobile devices and cloud backends and significantly reduces the cost barrier in cost restricted as well as technologically advanced educational institutions. The design also supports fundamental engineering tenets like resource optimization, ease of use, operational scalability, and data integrity.

Formal classroom testing confirmed the system's real-time behavior, demonstrating it to be power-efficient, secure, and robust in high-density settings. In contrast to conventional solutions, which draw upon maintenance-prone infrastructure or are annoying to users, this solution is evidence that a cost-effective, functional solution can be created with limited resources and extensive reuse of existing technology.

FUTURE SCOPE

While the current system is decent enough, more can be done to better equip it to meet larger institutional needs. These can be:

- Portal and Learning Management System (LMS) integration to automatically sync attendance data to facilitate performance analytics.
- BLE-Wi-Fi hybrid authentication or geofencing to enhance indoor location accuracy in buildings with complex floor plans.
- Application of machine learning techniques for the detection of unusual attendance patterns or trends over time, providing additional institutional surveillance.
- Remote/hybrid attendance tracking feature, altering the system to accommodate flexible class models that emerged during and post-pandemic.
- Departmental attendance trend tracking and inconsistency highlighting by role-based administrator dashboards.

In short, this BLE-based system shows the potential of contemporary engineering solutions to overcome inherent institutional challenges with little in the way of infrastructure, extensive automation, and strong security. It is a good, scalable, and future-proof replacement for conventional attendance solutions, ideally suited for roll-out to schools, colleges, and other institutions of education.