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Fusion of LoRa RFID and AI Base Smart Security Recognition Systems for Rural Areas

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Abstract

This paper has suggested and tested a low-cost standalone attendance monitoring system that has RFID and LoRa integration that can be applied to those regions that have poor connectivity with the internet or GSM, i.e., remote campuses or plantations. RFID is an option that allows highly secure off-line user authentication and LoRa Data can be relayed to a cloud database. Indoor and outdoor testing revealed reproducible indoor functioning at two levels and up to 133.17 meters outside with ordinary antennas. The findings showed that signal strength (RSSI) and clarity (SNR) were very dependent on the distance and the obstruction in the environment. The ESP32 microcontrollers and LCD modules integrate the system enhancing efficiency, user interaction, as well as cost-effectiveness. All in all, the system provides a convenient and flexible system of monitoring attendance in infrastructure limited setting.

Keywords: *Attendance Monitoring, RFID, LoRa Module, ESP32, Smart Card, RSSI, SNR.*

1. Introduction

Internet of Things (IoT) is taking a revolutionary approach in various sectors, such as education, agriculture, and industry, as well as smart infrastructure [2,3]. In the agricultural and plantation industries, IoT is growingly used to improve the amount of efficiency in the industry, especially in workers monitoring and its attendance control. Conventional attendance recording, which is usually manually done by supervisors, is time consuming, prone to human

error and prone to fraud. It is not only an inefficient method of doing it and it would be more so in large remote agricultural fields where one cannot so reliably collect the data.

To overcome issues of connectivity in regard to remote area settings, the combination of LoRa (Long Range) with RFID (Radio Frequency Identification) is an effective, scalable, and autonomous tracking tool that can be used to track attendance without using the internet or GSM networks [1,5]. LoRa also allows transferring data over long distances (up to 10 km in cities and 50 km in rural locations) that makes it suitable to large accessible plantations, and low energy usage allows the traveling over distances in the long term [4,8]. At the same time, RFID means fast and non-contact identification via embedded smart cards with employee-specific information including unique IDs, expiration dates, and other information [6,7].

In contrast to Bluetooth or Wi-Fi, with its low range and intensive power consumption, LoRa can help to transfer the data effectively between remote areas and centralized servers or gateways on the basis of MQTT protocols. Moreover, RFID systems employed in this project are circuitous, and therefore they do not need much internet connection and continuous update of their databases with central databases. The RFID tag is locked using dynamic encryption key to mitigate tampering and replication of the data, maintain data integrity and privacy [9]. This paper puts forward an analogue of this LoRa and RFID-hybrid in a door-access and attendance system. Once an employee swipes his/her RFID card, the information goes to the RFID reader which is analyzed by an ESP32 microcontroller and sends it through a LoRa module to a Raspberry Pi gateway. The gateway will relay the information to a cloud database where it can be checked through custom web application subsequently on a real-time basis. Outdoor and indoor field test was carried out. The initial findings, however, suggest that LoRa has a practical range that may be constrained by physical barriers, say walls and buildings, and therefore its transmission distance is less than 150 meters out of doors, and even shorter in-doors, which are in contrast to the theoretical expectations [10].

2. Related Work

Numerous other past studies have been done to investigate the use of various attendance recording technologies including RFID, Computer Vision, and IoT frameworks. These products are meant to automate, secure, and streamline attendance surveillance procedures in education and other institutions.

2.1. Use of RFID Technology

Attendance systems, based on RFIDs, have been growing in popularity over the past years because they are cheap and simple. As an example, [7] created a system designed with an Android app that functions Near Field Communication (NFC) to scan RFID tags that can track the presence of students. This system was used to capture attendance in the classrooms, but it was also applicable in religious or extracurricular areas. Nevertheless, the hardware compatibility was a primary restriction because NFC can be obtained only on not all smartphones, and this limitation reduces its accessibility.

In order to overcome the problems of cost and compatibility, less expensive systems based on a standard cost RFID reader attached to an Arduino microcontroller have been implemented [12]. Such systems normally contain an LCD which serves to show real time data and the records of the collected attendance are relayed to a computer where the records are stored as a central database.

2.2. Integration of RFID with Computer Vision

In order to address the impact of problems such as proxy attendance, other systems combine RFID with facial recognition. In that vein, [9] suggested a two-level system to be able to ascertain the physical presence of the students that involved an RFID and Face ID. Other developments incorporated a thermal scan that would recognize high temperatures as an indication of possible COVID-19 when the check-in was not confirmed yet [17]. Such hybrid models are more secure and monitor health conditions but may be affected by environmental factors such as the lighting, expression, or occlusion [20].

2.3. IoT-Based Attendance Systems

Cloud integration in IoT-based systems has made real-time attendance track continuously. In [14] pointed out the presence monitoring based on using the RFID and LoRa communication to avoid the use of conventional networks. Parental monitoring and the use of analytics tracking by the administration on the cloud is also made possible by these systems. One of the implementations mentioned by [13] demonstrated that the usage of IoT and AI along with in-room cameras achieved facial recognition accuracy of more than 89 percent at different distances. These systems, however, require stable internet connections and expensive design including high resolution cameras and cloud storage systems.

2.4. Smart and Mobile Attendance Systems

The purposes of other models are to facilitate user interaction and administration. As in the example provided by Ula et al., cited in the synopsis, RFID-based classroom attendance model

was established, where readers were associated with classroom computers to provide auto check-in operations, triggered by the scan of the student card ID. Likewise, in [18] tested RFID with Arduino and Node.js to monitor lateness, real-time update databases, and send notifications through the use of email.

In [16] proposed a mobile application Smart-Present, using NFC, QR code, and Bluetooth beacons to solve such problems as lost records or late-night check-ins. The system had both flexibility and automation in retrieval of attendance statistics and behavior reports by the teacher.

2.5. LoRa-Based Communication Integration

Although the systems described above are mostly reliant on Wi-Fi or GSM networks, there are some recent changes, indicating LoRa (Long Range) communication to be a more suitable alternative to monitor attendance in remote or large-scale locations [19,22]. The long-range, low-power capabilities of LoRa are appropriate to be used in agriculture, plantations, or even in those areas where traditional infrastructure cannot be reliable or even absent (as in case of the disaster recovery).

When used together with LoRa, RFID can be applied to perform offline validation of attendance and exchange data asynchronously with central systems. The UID and the time logs are secure and encrypted information that are embedded in the RFID tag and sent through LoRa to a gateway built of a Raspberry Pi. With this system, there is no need to make constant database queries online, which reduces operating overheads and increases the stability of restricted settings [23,24].

3. Methodology

The suggested system will be organized under three key modules, i.e. Front-End Service, Gateway Service, and Back-End Service, that interacts so that the attendance monitoring will be safe, standalone, and long-range via LoRa and RFID technology. Modular IoT framework enabled with decentralized communication is the basis of the system architecture [23,26].

3.1. Front-End Service

The front-end module comprises hardware components that directly interface with the user and process RFID data at the source. Key components include:

- **ESP32 Microcontroller**: A low-power, cost-effective MCU that processes input signals and manages data flow.

- **PN532 RFID Reader**: Reads user data from RFID cards and verifies it offline using a pre-set dynamic encryption key [27].
- **RTC (Real-Time Clock)**: Provides timestamp functionality even in the absence of internet or network synchronization.
- **LCD Display**: Visually communicates transaction status, user identification, and access results.
- **Solenoid Door Lock**: Acts as a physical actuator to permit or deny access based on RFID validation.
- **Relay Module**: Regulates power distribution to connected components.
- **LoRa Shield**: Transmits verified data over long distances to the gateway, including UID, MAC address, RSSI, SNR, and time of access [25].

The system process starts with a user showing the PN532 reader to his RFID card. The ESP32 has card verification locally with offline key validation. Upon authentication of the UID, the system opens the system through the solenoid lock and refreshes the LCD with the employee information. At the same time, the transaction is relayed through the LoRa module to the gateway node. In case of failure in authentication, an error message is disclosed on the LCD. RFID cards are provisioned by means of a supplementary desktop application. The application accesses the database in the cloud and stores information related to the users to RFID cards to ensure that the process of authentication is possible in offline mode and synchronized with the core user records.

Such decentralized authentication mechanism is easier to secure, less reliant on servers and better to perform in rural or lack of infrastructure settings [28].

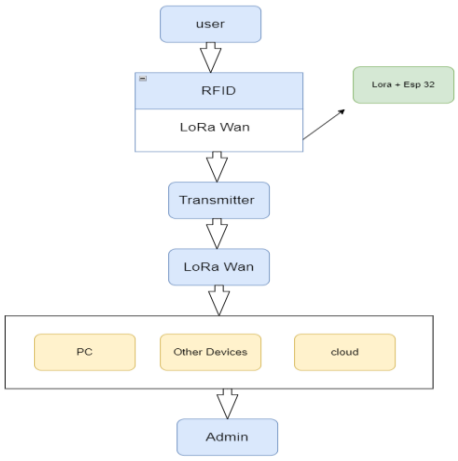

Figure 1. Basic Model

3.2. Gateway Service

The gateway acts as a communication bridge between the front-end devices and the cloud-based storage system. It is typically implemented using a **Raspberry Pi with LoRa HAT**, configured to:

- Receive transaction data sent via the LoRa module from ESP32 units.
- Parse, verify, and package the data using the **MQTT (Message Queuing Telemetry Transport)** protocol lightweight, efficient protocol well-suited for constrained devices and low-bandwidth networks [30].
- Forward validated data packets to the cloud infrastructure for permanent storage, analytics, and monitoring.

This architecture ensures asynchronous data delivery, eliminating the requirement for real-time internet connectivity at the user level while maintaining centralized record management.

3.3. Back-End (Cloud) Service

While not fully described in the original excerpt, the **Back-End Service** typically includes:

- **Cloud Database**: Stores attendance records, user profiles, access logs, and system status data.
- **Web Interface**: Allows administrators to monitor activity, manage user accounts, and generate reports.
- **Security Mechanisms**: Ensures that all data received is authenticated and encrypted to prevent tampering or unauthorized access [29].

Together, this modular, standalone communication framework allows the system to function reliably in rural, agricultural, or infrastructure-deficient regions, with offline RFID authentication and long-range data transmission via LoRa.

3.4. System Implementation

The system suggested is already developed both on hardware and software to erect an independent, safe, and effective solution of the attendance tracking based on the use of LoRa and RFID. It has the capability to transmit data over larger distances and perform offline authentication, particularly in underdeveloped or remote locations when deployed [33,34].

3.5. Hardware Implementation

Its hardware structure is made up of a user-friendly RFID framework and long-range information transfer utilizing LoRa. As indicated in the project documentation, Figure 2: The process of scanning the RFID smart card on the PN532 sensor is exposing the user data on the

card holder including: card UID and number and employee digits. The said data is relayed through the LoRa32 T-Highrow (915 MHz) LoRa SHIELD connected to an ESP32 microcontroller.

After passing through successful authentication, the Solenoid Door Lock unlocks the door through the relay activation. Simultaneously, the transaction of attendance, which includes metadata as RSSI, SNR, timestamp, and device MAC address, is relayed to the LoRa Gateway, generally implemented with the help of Raspberry Pi and Dragino LoRa HAT [32]. The gateway captures information in the cloud so that administrators can watch it in real-time. The system is also equipped with the device registration module that connects the location metadata to the particular device and the filter module that enables users to track the origin and route of every data exchange on the network [30,31].

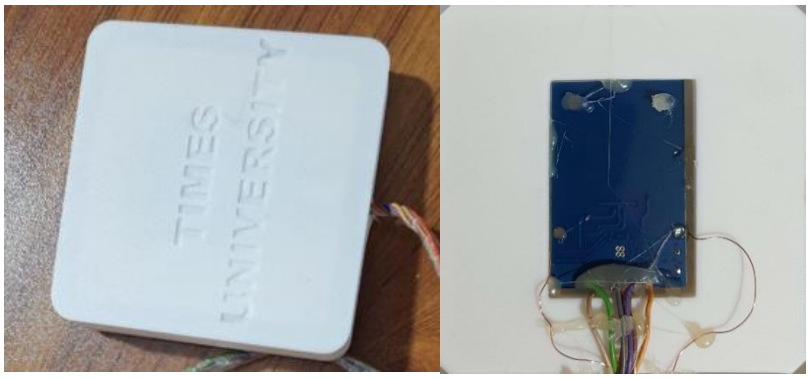

Figure 2. RFID Reader

3.6. Software Implementation

The software environment comprises three interconnected components:

3.6.1. Web-Based Dashboard

As shown in Figure 3, the web-based dashboard is a central interface to the system administrators and gives a complete analysis of the attendance monitoring system. It is shown the activity of LoRa sender units, statistics of attendance of employees in the graphical form depending on the name of employees, major LoRa communication parameters such as RSSI (Received Signal Strength Indicator) and SNR (Signal-to-Noise Ratio). Being able to provide real-time feedback on the performance of the system, as well as user activity, these visual analytics tools present a unique advantage in the form of the dashboard to the administrator, especially when dealing with a large-scale implementation [37,38].

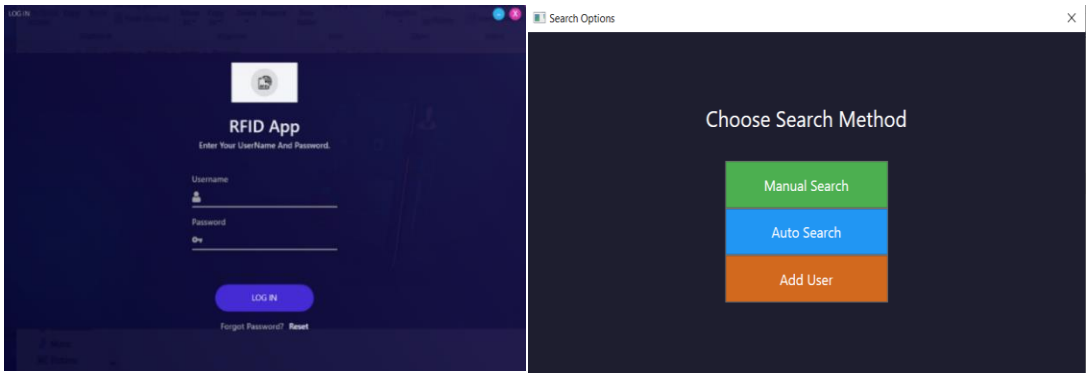

Figure 3. Web-Based Dashboard

3.6.2. Desktop-Base Application

Java and Swing GUI framework are used in the development of the desktop-based application. It connects to an ACR122U RFID reader, which allows managing attendee access credentials of employees. The program helps a user to write fresh employee data to RFID smart cards, read the information of cardholder and access a full list of the number of registered employees. The interface is designed into three operational tabs as follows: Personalization: where employee details can be input into the portal i.e. name of the employee, ID number of employee, gender of the employee, expiry date of his/her card; Reading: where RFID data is read and checked and finally Employee List: which contains current employee records which are found in the web-based database. It is a desktop assistant that not only increases autonomy but also security, as one is able to write and check their information offline, without continuing to use any server. Furthermore, there is encryption and protecting sensitive data by tagging encrypting keys to precise areas or blocks of RFID, guaranteeing the data security and its confidentiality [39,40].

3.6.3. Controller and LoRa Code Implementation

The C/C++ code is used to program the front-end controller, which is in charge of core functions, including reading RFID, opening the solenoid door lock, and sending acceptable data through LoRa module. The LoRa receiver on the gateway side runs under C and runs on a Raspberry Pi with LoRa HAT. As shown in Figure 4, the packets that come in are handled by the receiver script and the data is first validated. This is a validation to see that the characters received are well within the standard ASCII of between 0 and 127. Values of the data beyond this range will not be valid or will be corrupted and thus discarded. Verified and clean data packets are only then sent to the cloud database to be stored and further analyzed, which guarantees the integrity of data but also reliability of the whole system.

Figure 4. Transmitter & Transreceiver

4. Results and Discussion

Test Scenario

In order to test the reliability and performance of the proposed LoRa-RFID standalone communications system, a set of a controlled experiment was carried out in an indoor and outdoor setting. This was aimed at the evaluation of important communication parameters such as Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), and lag time. The lag time was calculated as the variance between the moment in which the information was sent and the moment the LoRa receiver recorded the packet.

Indoor Testing

Tested inside one building with reinforced concrete buildings and floors that has multiple stories in the building. The height of every floor of the test site is 3 m and with 16 rooms on each floor and the room size is 64 m 2 each room giving 1024 m 2 per floor. The floor thickness was around 30 cm and the structural interference of materials used (concrete and steel) was projected to influence LoRa signal propagation. The layout of the building is given in Figure 5 and the description of the testing scenarios carried out indoors related in Table I.

As the test results showed, the favorable RSSI indoor performance corresponded with the placement of the transmitting LoRa device to the 3rd floor, directly above the receiving node. Such siting permitted a greater penetration of the signal in the vertical direction, perhaps because there were fewer horizontal obstructions than in situations where the terminals occupying the same floor but separated by several walls of concrete. These findings align with other reports of issues with LoRa propagation in indoor setup, during which material density and floor plan massively impact signal dynamics.

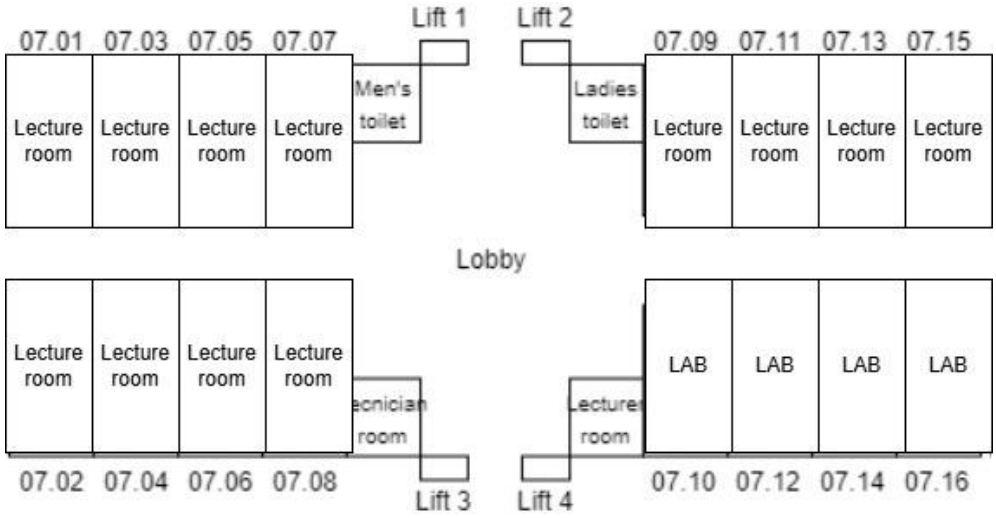

Figure 5. layout Of The Building

Indoor Testing Procedure

1. The LoRa receiver was positioned on the 3rd floor of the building throughout all indoor test scenarios to maintain a consistent reference point for signal reception.
2. In the first test scenario, the LoRa sender was placed on the 1st floor, and the RFID card was scanned at the door access prototype a total of five times to evaluate transmission stability and RSSI/SNR variations across multiple attempts.
3. In the second test scenario, the LoRa sender was relocated to the 2nd floor, and the RFID scanning process was repeated five times under the same conditions.
4. In the third scenario, the LoRa sender was placed on the same floor as the receiver (3rd floor), and the RFID was again scanned five times to assess the optimal transmission condition within the indoor environment.

The test results show that the minimum lag time between the reception and sending of data was registered when the LoRa sending device was nearer to the receiving unit on the 3rd floor especially when conducting tests on the 4th floor. This closeness helped in faster transmission and reception of data and this proved that proper vertical orientation and less obstructions can help in improving transmission efficiency of data both indoors.

Figure shows the comparison of mean RSSI values measured in every floor illustrating variations in the strength of the signal depending on the position of the sender. Figure represents a mean of SNR (Signal-to-Noise Ratio) at each test condition, demonstrating the degree of structural interference of signal clearness. Lastly, Figure shows the average time difference taken by the receiving LoRa device in different test floors, further showing that

when the devices are in close proximity to each other, then the frequency of the message being passed is lesser and faster.

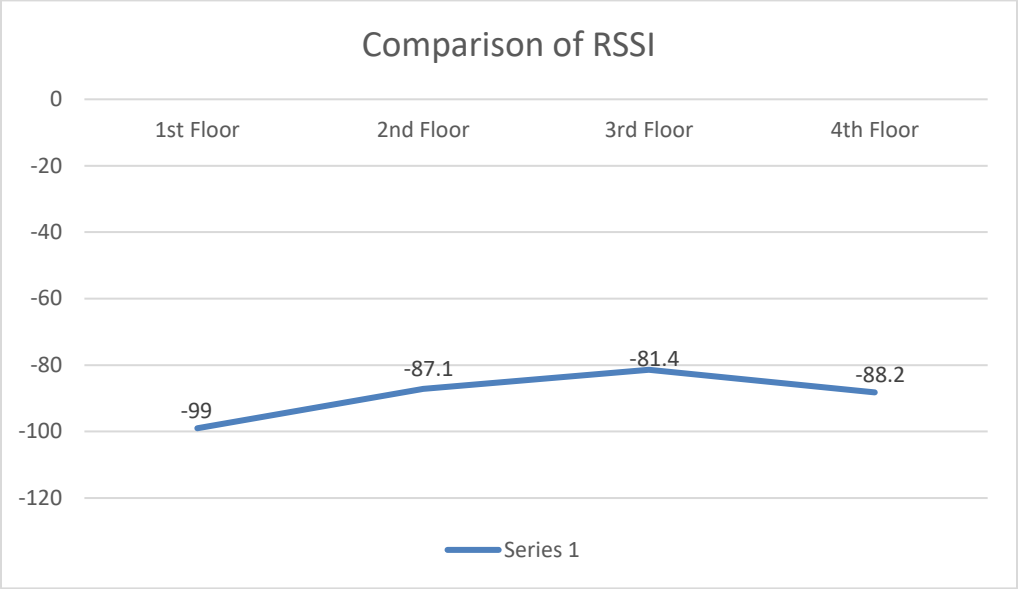

Figure 6. Comparison of RSSI

Outdoor Testing

The outdoor testing process on the other hand was run in order to gauge how the LoRa communication system would perform in an open area, which would not have any significant structural impediments like concrete ceilings or concrete walls. In the verification scenario, the LoRa sender as well as the LoRa receiver were designated different positions and strategically positioned at different distances outside the building.

This test was carried out to measure the effect of distance and open air interferences on such key transmission parameters as RSSI, SNR, and lag time. The outdoor environment unlike the indoor has a clear line of sight, something that is likely to have increased signal strength and stability. In the test process, the RFID cards were read on the terminal at the fore end and the output information was sent to the gateway gadget through the LoRa module.

The outcome of this outdoor testing scenario was utilized to compare the transmission performance of the inside and the outdoors environment. The results obtained during this step can be seen in the following Figures, which show with several environmental variables and differences in physical separations of the sender and the receiver, the quality of signals and the response time differs.

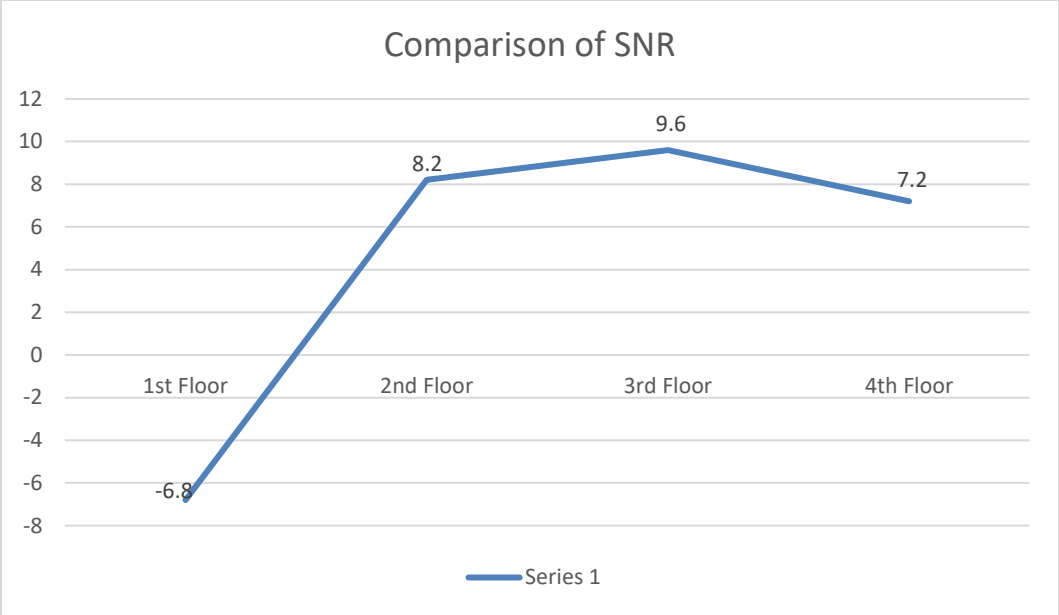

Figure 7. Comparison of SNR

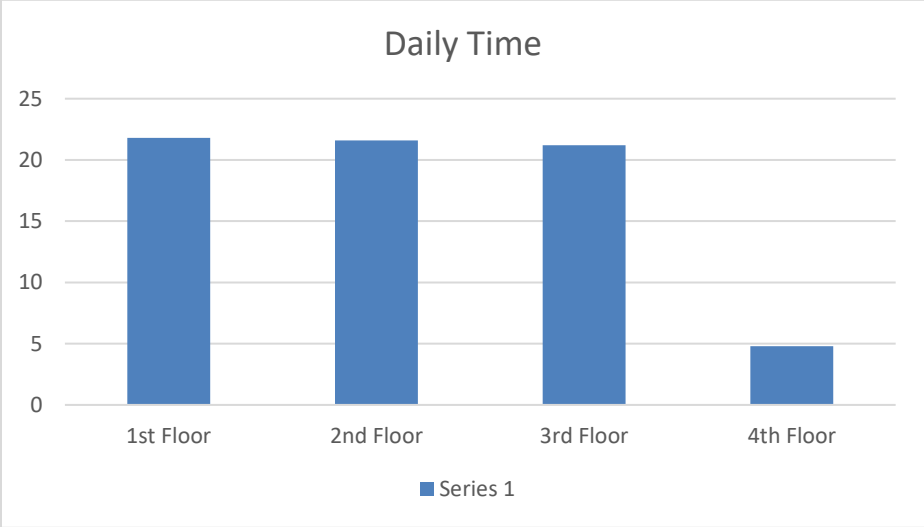

Figure 8. Daily Time

Outdoor Testing Scenarios

The following test scenarios were conducted to assess the performance of the proposed LoRa-RFID system in an outdoor environment:

1. **Positioning the LoRa Receiver**: The LoRa receiver was placed at the nearby admission office, serving as a fixed receiving point throughout all outdoor tests.

2. **Scenario 1 – Sender**: The LoRa sender was positioned admission office, and the RFID card was scanned at the door access prototype five times to observe consistency in transmission and reception metrics.
3. **Scenario 2 – Sender**: The LoRa sender was moved to lecture room, and the RFID card was again scanned five times to evaluate performance over a greater distance from the receiver.
4. **Lag Time Calculation**: For each scenario, the lag time was calculated by measuring the difference between the time of RFID tag scan (transmission) and the time the data was received by the LoRa gateway. This helped determine the responsiveness and transmission delay under varying distances.
5. **Comparison of Signal Quality**: The RSSI (Received Signal Strength Indicator) and SNR (Signal-to-Noise Ratio) values were recorded and compared across each test location to evaluate signal degradation and noise interference in open-air conditions.

These scenarios were designed to simulate real-world outdoor deployments where communication range and environmental interference are critical to system reliability.

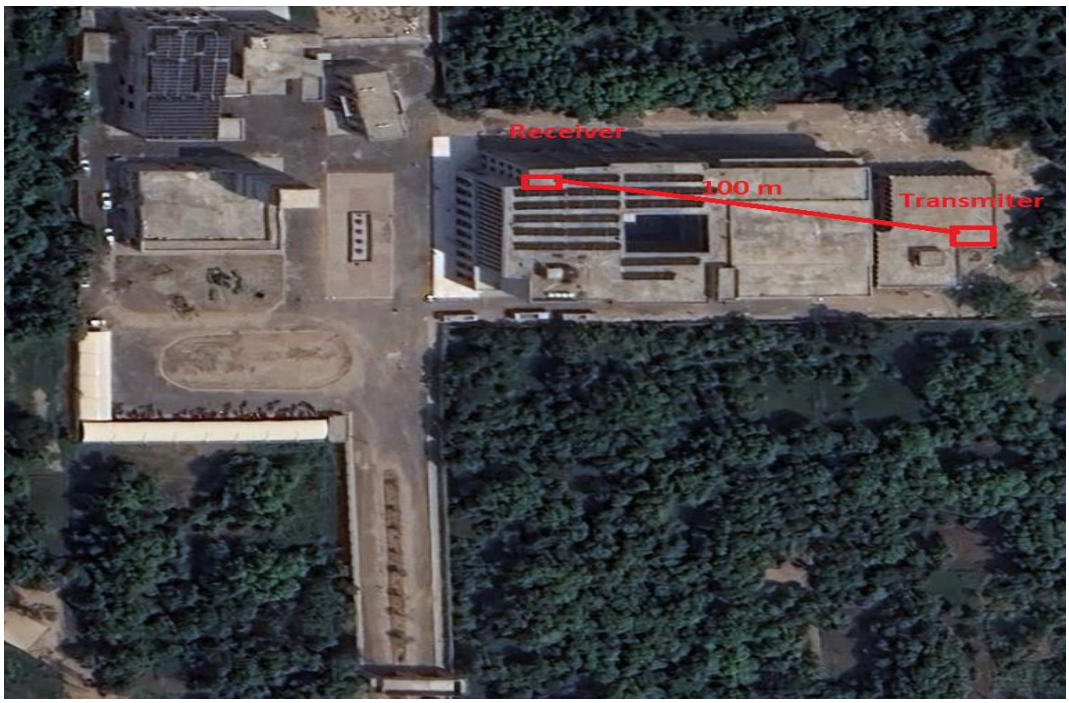

Figure 9. Drone view of Building

The outdoor testing was done by placing the LoRa devices in strategic locations within the open spaces on the campus to determine the performance under medium-range measurements. The receiver LoRa was located in Admission office (02), as the fixed receiver during the outdoor tests.

In the first case, the LoRa transmitter was placed at the place, CS Faculty Room (03), about 48.26 meters away from the receiver. In the second case, transmitter was shifted to Lecture room (01) which is 47.50 meters away from the receiving unit. Both distances were checked and verified with the help of Google maps visualization as presented in Figure.

These tests sought to determine the stability and reliability characteristics of LoRa communication in outdoor environments and properties towards the signal strength (RSSI), clarity (SNR), and latency (lag times), within a realistic deployment range.

Going by the collected data at the different spatial locations and distances, and tabulated in Table III, the level of signal quality is very much evident as shown by the RSSI and the SNR values; the signals have better quality as the source transmitting device nears the receiving LoRa gateway. In indoor applications the greatest reliable transmission range was employed with a vertical distance of two floors between the transmitter and the receiver. The applicability of this technique is limited mostly because of the structural barriers including reinforced concrete floors and walls that levels of LoRa signals considerably.

When testing on outdoors, the data transmission distance was tested to the maximum possible as 133.17 meters, the device that emitted the data was placed on the ground and the standard LoRa antenna was used. In this circumstance, the system did not support any reliable communication past this. These findings indicate the actual operation of the LoRa module, which applies to low-end hardware and standard deployment techniques, cannot cover the maximum transmission distance of up to 10 kilometers that are frequently mentioned in the literature [4,8].

Other factors like the antenna height, the elevation of the terrain, line-of-sight of the signals between the antenna, and the antenna gain may be very imperative towards attainment of the longer distances as advertised by the manufacturers. Figure shows the position of the LoRa receiver during the tests and Figure shows the position of the transmitters where the transmitters should be visualized with its vertical and horizontal positions, which are also shown in Figure.

6. Conclusion

This paper was able to evaluate an isolated attendance monitoring system based on the LoRa and RFID technologies and proved that private attendance monitoring based on the RFID and LoRa technologies could be successfully used both indoors and outdoors. Findings revealed that both the strength (RSSI) and clarity (SNR) of signals greatly tend to fluctuate due to the

distance and hindrance in between the devices. In an indoor setting, it was reliable to communicate between two floors, whereas under open conditions, the maximum range of 133.17 meters is tested when using standard antennas, and this is quite inadequate compared to the theoretical 10 km because of environmental limitations, such as a poor antenna height and lack of a clear line of sight. Lagged signal was observed to rise by about 0.2 seconds as a consequence of distance. RFID system was also efficient in terms of off-line storage and retrieval of data thus improving access of live servers. Moreover, the union of ESP32 microcontrollers, RFID and LCD modules provided low costs, low energy consumption and convenience in the use. In general, the system gives a potential, cost-effective solution to the remote tracking of attendance in areas lacking infrastructure.

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