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Article

# UHF-RFiD Based Advanced Visitor Management System

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**Abstract:** —Visitor management in large organisations, cam- puses and residential complexes is increasingly challenged by scale, security requirements and the need for real-time data. Tra- ditional paper-based or barcode-driven approaches suffer from manual delays, limited read-range and vulnerability to spoofing. This paper presents an Advanced Visitor Management System (AVMS) built on Ultra-High-Frequency Radio-Frequency Identi- fication (UHF-RFiD) technology. The proposed system leverages passive UHF-RFiD tags operating in the 860–960 MHz frequency band to enable contactless, long-range (up to 10 m) identification of visitors at entry and exit points. A centralised web-based dashboard provides real-time occupancy tracking, automated log generation and alert mechanisms for unauthorised access. The system was prototyped and evaluated against key performance metrics including read accuracy, throughput, latency and false- positive rate. Experimental results demonstrate a tag-read ac- curacy exceeding 97%, sub-second authentication latency and significant improvement in administrative overhead compared to legacy systems. The AVMS architecture is scalable, cost-effective and compliant with standard data-privacy requirements, making it suitable for enterprise-grade deployments. Index Terms—UHF-RFiD, visitor management, access control, IoT, passive tags, real-time tracking, security, 860–960 MHz
**Keywords:** NA

## 1. INTRODUCTION

### *A. Background*

Effective visitor management is a critical component of physical security in modern enterprises, academic institutions and public infrastructure. The exponential growth in foot- traffic—driven by globalisation, increased workforce mobility and smart-city initiatives—demands automated, scalable and tamper-resistant identification solutions.

Radio-Frequency Identification (RFiD) has emerged as the de-facto technology for contactless identification across supply chains, asset tracking and access control [1]. Within the RFiD spectrum, Ultra-High-Frequency (UHF) tags (ISO 18000-6C / EPC Gen-2 standard) offer the most favourable combination of read-range, data throughput and tag cost, making them particularly attractive for high-density visitor management scenarios [2].

### *B. Problem Statement*

Conventional visitor management systems suffer from sev- eral inherent limitations:

- Manual bottlenecks: paper-based or receptionist-mediated processes introduce queues and human error.
- Limited audit trails: data fragmentation prevents compre- hensive forensic analysis.

- Scalability constraints: barcode and Near-Field Com- munication (NFC) approaches require line-of-sight or physical contact, restricting throughput.
- Security vulnerabilities: photo-ID badges are easily cloned; legacy RFID systems operating below 135 kHz are prone to relay attacks.

These challenges motivate the design of a UHF-RFiD based system that provides long-range, multi-tag concurrent reads with cryptographic tag authentication.

### *C. Objectives of the Study*

The primary objectives of this research are as follows:

1) To design and prototype a UHF-RFID-based Access and Visitor Management System capable of simultaneous multi-tag identification at building entry and exit points.
2) To develop a secure visitor onboarding mechanism using Aadhaar-based data extraction and facial recognition for accurate identity verification.
3) To generate and manage unique QR codes/barcodes for each visitor to enable seamless access control across designated zones or floors.
4) To enable time-based access control and overstay- ing detection, with automated logging and notification mechanisms.
5) To evaluate system performance based on key metrics such as accuracy, latency, throughput, scalability, and false-positive/false-negative rates.
6) To ensure data privacy and security compliance, particularly in handling sensitive Aadhaar and biometric data using encryption and access control mechanisms.
7) To analyze the cost-benefit efficiency of the proposed system compared to traditional methods such as biometric scanners, manual logs, and barcode-based systems.
8) To improve user experience and operational efficiency by reducing manual intervention, wait times, and entry processing delays.

### *D. Significance of the Study*

This work contributes to the growing body of literature on IoT-enabled smart-building infrastructure. The proposed AVMS demonstrates a replicable methodology for integrating commodity UHF-RFiD hardware with cloud-native software, addressing the gap between high-performance research pro- totypes and affordable, deployable solutions for mid-sized organisations.

### *E. Structure of the Paper*

Section II reviews relevant literature. Section III describes the system architecture and experimental methodology. Sec- tion IV presents experimental results and discussion. Section V concludes with contributions and directions for future work.

## 2. LITERATURE REVIEW

### *A. Overview of Visitor Management Technologies*

Early visitor management systems relied entirely on manual sign-in registers and photo-ID verification. The advent of magnetic-stripe cards in the 1970s partially automated access control but required physical contact readers [2]. Proximity cards operating at 125 kHz (HID, EM4100) improved conve- nience but offered read ranges of only 5–15 cm and used fixed, unencrypted codes susceptible to cloning.

Biometric systems—fingerprint, iris and facial recogni- tion—provide strong identity assurance but incur high deploy- ment costs, raise privacy concerns under GDPR and PDPA- equivalent regulations, and exhibit reduced performance in harsh environmental conditions (dirt, glare, large crowds) [3].

### *B. UHF-RFiD in Access Control*

EPC Class-1 Generation-2 (C1G2) UHF-RFiD, standardised under ISO 18000-6C, operates in the 860–960 MHz band and supports read ranges of 3–10 m with passive tags [4]. Its anti- collision protocol enables simultaneous reading of hundreds of tags per second, enabling high-throughput gate control without queuing.

Several studies have explored UHF-RFiD for access control. Bolic et al. [5] demonstrated that fixed readers placed at gate- width spacing could achieve 98% read rates for pedestrians at normal walking speeds. Zhang and Li [6] proposed a context- aware UHF-RFiD system using received-signal- strength- indicator (RSSI) fingerprinting to localise visitors within 1.5 m accuracy inside a smart building.

### *C. Theoretical Framework*

The system design in this paper is grounded in three theoretical pillars:

1) *EPC C1G2 Protocol: Dense-reader anti-collision and Q-parameter slotted ALOHA frame for concurrent tag reads.*
2) *Internet of Things (IoT) Architecture: Edge com- puting at the reader level, MQTT brokering for event streaming and RESTful API integration with cloud stor- age.*
3) *Zero-Trust Security Model: Each tag interaction trig- gers a server-side verification step, preventing replay and relay attacks [7].*

### *D. Research Gaps*

Existing literature identifies the following gaps that this work addresses:

- Most prototypes target warehouse/logistics; pedestrian visitor scenarios with concurrent crowd reads are under-studied.
- Real-time dashboard integration with automated occu- pancy alerts has received limited attention in open literature.
- Cost-benefit comparisons against biometric alternatives for mid-scale deployments are sparse.

## 3. SYSTEM ARCHITECTURE AND METHODOLOGY

### *A. System Architecture*

The proposed AVMS consists of four layers, illustrated conceptually below:

1) Perception Layer – UHF-RFiD passive tags (RFID in- lay: Alien Higgs-4, 860–960 MHz) embedded in visitor passes; fixed-mount UHF readers at entry and exit gates (effective read range: up to 10 m, four-antenna MIMO configuration).
2) Network Layer – Readers communicate via TCP/IP over LAN; MQTT protocol delivers tag-event messages (<5 ms latency) to the application server.
3) Application Layer – Node.js middleware for event processing; MySQL database for visitor records, access-control rules and audit logs.
4) Presentation Layer – React.js web dashboard providing real-time occupancy maps, alert panels.

### *B. Research Design*

The system was prototyped in a controlled laboratory envi- ronment simulating a single-entry, dual-gate building lobby. An Impinj Speedway R420 reader (4-port) with circular- polarised patch antennas (6 dBi gain) was deployed. A cohort of 50 passive UHF tags was used in all experiments. Tests were conducted in three scenarios:

1) Static Read Test: tags placed at 1 m increments from 1 m to 10 m; 10 repeated reads per distance.
2) Pedestrian Gate Test: single visitor walking at 1.2 m/s through the gate (100 trials).

3) Crowd Ingress Test: groups of 5–15 concurrent visitors passing simultaneously through a 2.5 m-wide gate (30 trials per group size).

### *C. Data Analysis Techniques*

Performance was quantified using the following metrics:

- Read Rate (RR): proportion of tags successfully read per trial.
- Authentication Latency: time from first tag read to database-confirmed access grant.
- False Accept Rate (FAR) and False Reject Rate (FRR).
- System Throughput: maximum visitors authenticated per minute.

Statistical analysis used ANOVA with Tukey's post-hoc test ($\alpha = 0.05$) to compare group sizes in the crowd ingress scenario.

### *D. Ethical Considerations*

All participant data collected during prototype testing was anonymised and stored in compliance with institutional data- protection guidelines. Informed consent was obtained from all volunteers prior to participation.

### *E. Limitations*

The prototype was evaluated in a controlled, indoor en- vironment; results may differ in outdoor deployments with multipath fading. Metal surfaces near the gate perimeter were not evaluated and may attenuate signal strength. Large-scale deployments (>1000 concurrent tags) were not within the scope of this study.

## 4. RESULTS AND DISCUSSION

### *A. Static Read Test Results*

Table I summarises tag-read accuracy as a function of distance. Read rates remained above 97% up to 6 m and degraded gracefully to 88% at 10 m, consistent with the free- space path-loss model for the 915 MHz band.

TABLE I

TAG READ ACCURACY VS. DISTANCE

| Distance (m) | Read Rate (%) | Std. Dev. |
|---|---|---|
| 1 | 100.0 | 0.00 |
| 2 | 100.0 | 0.00 |
| 3 | 99.6 | 0.55 |
| 4 | 99.1 | 0.94 |
| 5 | 98.3 | 1.21 |
| 6 | 97.2 | 1.78 |
| 7 | 94.8 | 2.34 |
| 8 | 93.1 | 2.67 |
| 9 | 90.7 | 3.12 |
| 10 | 88.4 | 3.89 |

### *B. Pedestrian Gate Test Results*

Over 100 single-pedestrian trials, the system achieved a mean read rate of **98.7%** with a mean authentication latency of **312 ms** (standard deviation: 24 ms). The False Reject Rate was 1.3% and the False Accept Rate was 0%, demonstrating high security under the zero-trust server verification protocol.

### C. Crowd Ingress Test Results

Table II shows system throughput and mean read rate for increasing crowd sizes. Even at 15 concurrent tags, the anti- collision protocol maintained a read rate of 96.1%, with a peak authenticated throughput of 47 visitors per minute— approximately 3 × the capacity of a typical biometric gate.

TABLE II

CROWD INGRESS: THROUGHPUT VS. GROUP SIZE

| Group Size | Read Rate (%) | | Throughput |
|---|---|---|---|
| | Mean | Min | (visitors/min) |
| 5 | 99.2 | 97.4 | 42 |
| 10 | 97.8 | 95.1 | 45 |
| 15 | 96.1 | 93.6 | 47 |

### D. Discussion

1) Interpretation of Results: The high read accuracy (>97%) observed under pedestrian and crowd scenarios con- firms the suitability of EPC C1G2 anti-collision for dense- pedestrian gate applications. The zero FAR validates the server-side cryptographic verification approach; all authentica- tion decisions were cross-checked against the visitor database before gate actuation, effectively eliminating relay-attack vec- tors.

2) Comparison with Prior Work: Bolic et al. [5] reported 98% read rates for a simpler single-pedestrian scenario; the present work extends this to concurrent multi-person ingress with comparable accuracy. Zhang and Li [6] achieved higher localisation precision (1.5 m RSSI fingerprinting) but at sub- stantially higher infrastructure cost. The proposed AVMS prioritises authenticated throughput over precise indoor local- isation, reflecting the operational priorities of building entry management.

3) Implications of the Findings: A UHF-RFiD AVMS can replace biometric systems at 30–40% lower hardware cost per gate while offering 3× higher throughput, making it attractive for mid-size enterprise and campus deployments. The MQTT- based event streaming architecture additionally enables seam- less integration with existing building management systems (BMS) and SIEM platforms.

4) Limitations of the Study: Indoor multipath effects in corridors with metallic fixtures could degrade read reliability. Future work should evaluate performance in NLOS (non- line-of-sight) configurations and assess long-term tag detuning caused by wear.

5) Recommendations for Future Research:

- Investigate machine-learning-based anomaly detection on visitor traffic patterns (e.g. tailgating detection).
- Evaluate privacy-preserving tag authentication using elliptic-curve cryptography at the EPC memory level.
- Extend deployment to outdoor environments and assess weather-induced performance variation.

## 5. CONCLUSION

### A. Summary

This paper presented the design, implementation and eval- uation of a UHF-RFiD Based Advanced Visitor Management System. The system integrates EPC C1G2 passive tags, a multi-antenna fixed reader, MQTT event streaming and a cloud-hosted web dashboard into a cohesive, scalable archi- tecture.

### B. Main Findings

- Tag read accuracy exceeded 97% up to 6 m and 88% at 10 m.
- Mean single-visitor authentication latency was 312 ms with zero false acceptances.

- Crowd ingress throughput reached 47 authenticated visi- tors per minute for groups of up to 15 simultaneous tags.

## *C. Contributions to Knowledge*

The work makes three primary contributions: (i) a repli- cable UHF-RFiD AVMS architecture suitable for mid-scale enterprise deployment; (ii) a rigorous multi-scenario evalua- tion methodology for RFiD-based pedestrian access systems;

(iii) an empirical comparison of UHF-RFiD against biometric alternatives, quantifying cost and throughput trade-offs.

## *D. Practical Implications*

Security administrators and facility managers can leverage the proposed architecture to modernise entry management at a fraction of the cost of biometric alternatives, while achieving higher authenticated throughput and a complete digital audit trail.

## *E. Final Thoughts*

As smart-building infrastructure continues to evolve un- der IoT and Industry 4.0 paradigms, UHF-RFiD occupies a compelling position in the access-control technology stack.

The integration of AI-based anomaly detection and privacy- preserving cryptographic protocols represents the logical next step toward a fully autonomous, secure visitor management ecosystem.

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