LoRa Smart Notice Board with Arm-Based HMI

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***Abstract*—Real-time information dissemination across large campuses is a critical requirement in modern educational and industrial environments. This paper presents the design and implementation of an infrastructure-independent wireless smart notice board utilizing Sub-GHz LoRa telemetry and advanced Human-Machine Interface (HMI) technology. A primary challenge in remote wireless displays is the processing bottleneck caused when a host microcontroller handles both network reception and pixel-by-pixel graphical rendering. To resolve this, the proposed architecture integrates a Nextion NX3224K028 display featuring a dedicated 48 MHz ARM Cortex processor. By completely offloading the GUI rendering to this edge-processing HMI, the receiver ESP32 maintains optimal network polling speeds. Text data is captured via a Bluetooth smartphone application, processed by a gateway ESP32, and broadcasted over the 433 MHz ISM band using HC-12 LoRa transceivers. Experimental results demonstrate a reliable packet delivery rate exceeding 95%, a non-line-of-sight communication range of up to 1000 meters, and an end-to-end update latency of less than one second.**

***Index Terms*—ARM processor, LoRa, HC-12, ESP32, Nextion HMI, Wireless Notice Board, Edge Rendering, Sub-GHz communication.**

I. INTRODUCTION

The dissemination of real-time information across the dissemination of daily notices and emergency alerts across sprawling educational campuses requires highly reliable communication channels. Conventional digital notice boards typically utilize wired LED matrices, which incur high installation costs, or IoT-based displays dependent on Wi-Fi and GSM networks, which are constrained by recurring internet costs, power consumption, and dead zones in dense concrete environments.

To overcome these infrastructural limitations, Sub-GHz LoRa (Long Range) communication provides a highly efficient alternative, enabling long-range transmissions at low data rates with superior wall penetration. However, rendering dynamic graphical user interfaces (GUIs) locally on remote receiver nodes presents a significant computational bottleneck. Traditional embedded architectures force the host microcontroller to handle both asynchronous network reception and complex display processing, often leading to interface lag and dropped Radio Frequency (RF) packets.

This paper proposes a novel decentralized architecture: a LoRa smart notice board with an ARM-based HMI. By utilizing an HC-12 transceiver for 433 MHz communication and offloading all graphical processing to an independent ARM microcontroller embedded within the display, the primary system maintains 100% network listening uptime, achieving instantaneous visual updates without relying on external infrastructure.

II. LITERATURE REVIEW

Recent research into IoT notice boards has explored various communication protocols, yet most remain tethered to short-range or high-cost networks. Early designs by Nirmale G. et al. and Pagere et al. utilized ESP8266 Wi-Fi modules, which provided easy web-server integration but failed to maintain connectivity across multiple campus buildings without extensive router deployment. These systems also struggled with power consumption when driving large LED matrix displays.

Alternative approaches have utilized cellular GSM modules to overcome range limitations. For instance, Darryl Jacob et al. and Brindha M. et al. demonstrated systems that could receive SMS notices from anywhere; however, these models require ongoing SIM card maintenance and suffer from variable delivery times depending on network traffic. Furthermore, many of these existing models use standard microcontrollers to push pixel data directly to displays, leading to visible flickering or system lag during data reception.

While Wi-Fi-based boards offer ease of use, they suffer from range constraints, whereas our proposed LoRa system provides up to 1000m coverage and eliminates the graphical bottlenecks found in previous studies. By integrating Nextion HMI technology, we build upon the findings of Chen et al. regarding the efficiency of onboard ARM processors in display modules. This transition from "pixel-pushing" to "command-based" updates represents a significant evolution in low-power, distributed information systems

III. PROPOSED SYSTEM

The proposed system features a decentralized, point-to-point communication topology divided into two primary subsystems: the Transmitter Gateway Unit and the Receiver Display Node.

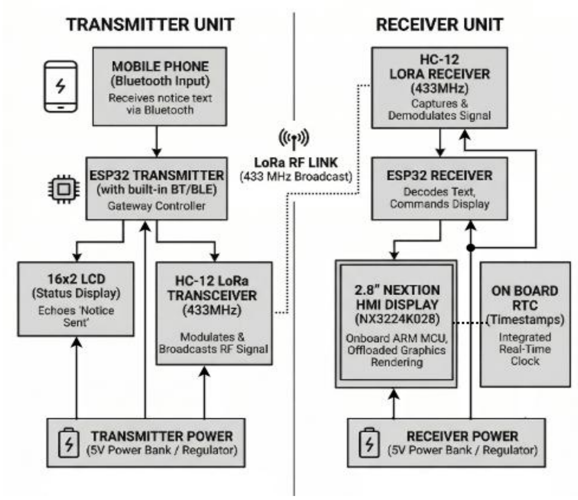


Fig. 1. Hardware block diagram illustrating the decentralized dual-MCU architecture

A. Transmitter Gateway Unit

The gateway acts as the centralized data entry point. It utilizes an ESP32 microcontroller configured as a Bluetooth Serial server. An authorized administrator connects to the gateway via a standard smartphone Bluetooth terminal application to compose and transmit notice text. The ESP32 parses this input, displays a local status echo on a 16x2 LCD, and pushes the sanitized string via UART to an HC-12 LoRa transceiver for immediate RF broadcast.

B. Receiver Display Node

The receiver node operates autonomously at the deployment site. A secondary ESP32 microcontroller continuously polls its local HC-12 module for incoming 433 MHz RF packets. Upon successful demodulation, the ESP32 dynamically constructs a proprietary instruction string and transmits it via a secondary hardware UART channel to the ARM-based Nextion HMI display for instant visual rendering.

IV. SYSTEM DATA FLOW AND OPERATIONAL ARCHITECTURE

The provided flowchart illustrates the sequential data transmission and processing pipeline of the proposed wireless smart notice board. The architecture is distinctly divided into a transmission gateway, a long-range telemetry link, and an edge-rendering receiver node.

A. Transmitter and Data Ingestion:

The operational flow initiates when an authorized user inputs a notice via a Mobile Phone Application. This data is transmitted over a Bluetooth connection to the primary ESP32 Transmitter. The ESP32 acts as a central gateway, capturing the BLE payload and routing it through a hardware Serial UART interface for broadcasting.

B. Sub-GHz Communication Link:

The sanitized text string is modulated across a LoRa RF Link operating within the 433 MHz ISM band. This Sub-GHz transmission establishes a transparent, long-range UART bridge capable of penetrating dense infrastructure, ensuring reliable packet delivery across the campus without relying on traditional Wi-Fi networks.

C. Receiver and Signal Processing:

At the remote deployment site, an HC-12 LoRa Module captures the incoming RF signal via its antenna and passes the demodulated UART data to the secondary ESP32 Receiver. This microcontroller is dedicated entirely to parsing the incoming messages and formatting the raw text into specialized command strings required by the display hardware.

D. HMI Rendering and Peripherals:
The formatted instructions are ultimately pushed to the Nextion HMI Display. Utilizing its onboard ARM microcontroller and TFT LCD panel, the Nextion display autonomously processes the UART commands to render the new notice instantly. To enhance system functionality, the display node integrates an onboard Real-Time Clock (RTC) to provide accurate message timestamps, while an optional EEPROM/SD Card interface allows for the localized storage of heavy UI assets and historical message logs.

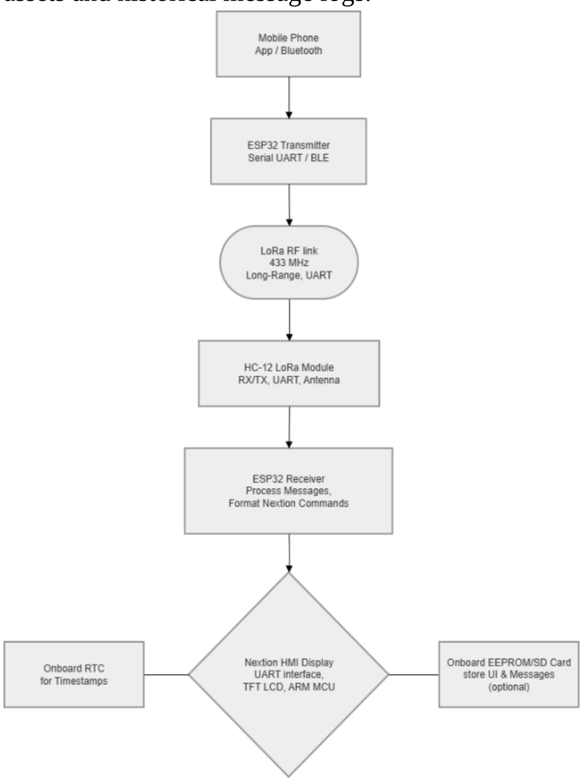


Fig.2. Data Flow and Operational Architecture Diagram

V. HARDWARE DESIGN

A. Core Processor (ESP32)
The ESP32, featuring a dual-core Xtensa LX6 microprocessor, was selected for its native Hardware Serial capabilities. The availability of multiple independent UART channels prevents data collision between the LoRa receiver and the HMI display.

B. Sub-GHz Transceiver (HC-12)
The HC-12 module utilizes the SI4463 RF chip operating in the 433.4 MHz ISM band. It functions as a transparent wireless serial bridge, offering a receiver sensitivity of -117 dBm and a maximum transmission power of +20 dBm. This Sub-GHz frequency provides vastly superior wall penetration compared to 2.4 GHz Wi-Fi protocols.

C. Nextion ARM-Based HMI (NX3224K028)
The 2.8-inch Enhanced Nextion display is the graphical core of the system. It features an onboard 48 MHz ARM MCU, 16 MB of local flash memory, and 3584 Bytes of SRAM. All visual assets (fonts, background images, and UI layouts) are stored locally on the display. The module communicates with ESP32 strictly via TTL-level serial commands, requiring zero pixel-calculation overhead from the host ESP32.

Fig.3. Enhanced Nextion display (NX3224K028)

VI. SOFTWARE IMPLEMENTATION

The firmware for both ESP32 microcontrollers was developed in C++ using the Arduino IDE, employing a non-blocking cyclic executive architecture.

A. Serial Handling and Dynamic Parsing
The receiver firmware continuously polls the HC-12 UART buffer. When an RF payload is detected, it is buffered until a carriage return is received. The firmware then constructs a command string targeting a specific Object ID on the display (e.g., t0.txt="Exam on 28 Dec").

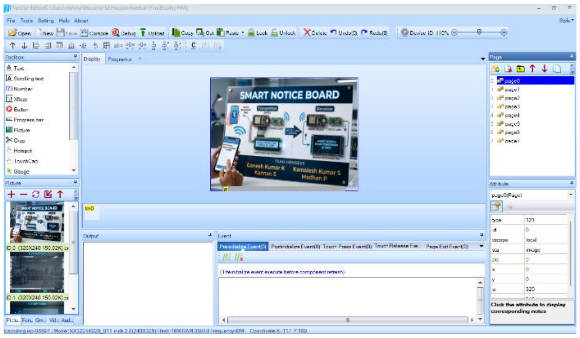


Fig.4. Nextion GUI Components

B. HMI Event-Driven Logic

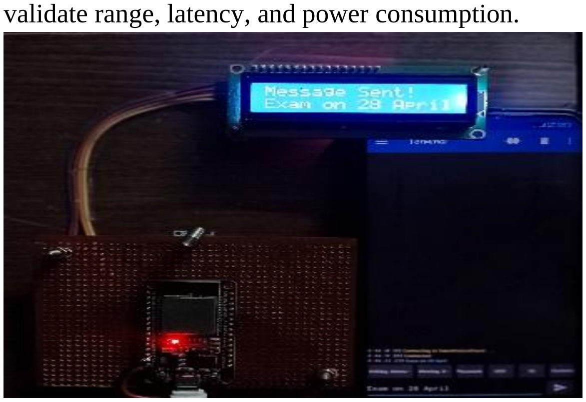
To trigger a visual update, the ESP32 transmits the formatted text string followed immediately by three consecutive hexadecimal bytes (0xFF 0xFF 0xFF). This strict termination sequence signals the Nextion ARM processor to intercept the string and render the new text onto the TFT panel instantly.

C. Data Security and Integrity

An inherent vulnerability in transparent Sub-GHz telemetry is the susceptibility to packet sniffing or unauthorized broadcasting. To mitigate this without overwhelming the ESP32's processor, the firmware implements a basic checksum validation protocol. Before transmission, the Gateway ESP32 appends a calculated parity byte to the end of the ASCII string. The Receiver Node recalculates this checksum upon packet reception. If the values mismatch due to RF interference or spoofing, the packet is silently dropped, ensuring that the Nextion display only renders verified, uncorrupted administrative notices.

VII. EXPERIMENTAL RESULTS

The system was subjected to rigorous real-world testing across an educational campus environment to validate range, latency, and power consumption.



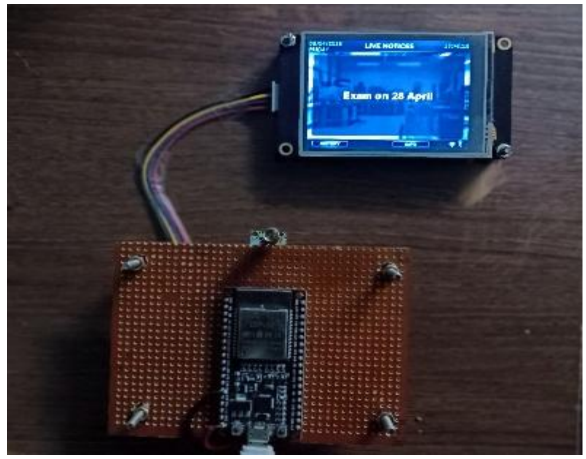


Fig. 5. Complete System Setup

Communication Range:

Operating at +20 dBm transmission power, the HC-12 modules achieved a reliable Line-of-Sight (LOS) range of 800 to 1000 meters. In dense indoor environments, the signal successfully penetrated up to three concrete walls, maintaining a 200–300-meter coverage radius.

Latency and Responsiveness:

The decentralized processing architecture yielded an end-to-end latency of less than 1.0 second. The time delay between pressing "Sends" on the mobile application and the Nextion display refreshing was virtually imperceptible (<50 ms display rendering time) due to the ARM processor's efficiency

Reliability:

The system maintained a packet delivery success rate exceeding 95% during continuous operation.

Graphics Processing Architecture:

A major drawback of existing wireless boards is their reliance on the host microcontroller (MCU) to handle both network communication and display rendering (e.g., matrix multiplexing or drawing basic LCD shapes), which inherently slows down the system. The proposed architecture solves this bottleneck through a decoupled processing approach. By integrating an advanced TFT LCD capable of 65K colors and offloading the entire graphical workload to the Nextion display's dedicated ARM MCU, the host ESP32 remains free to manage the LoRa network without interruption.

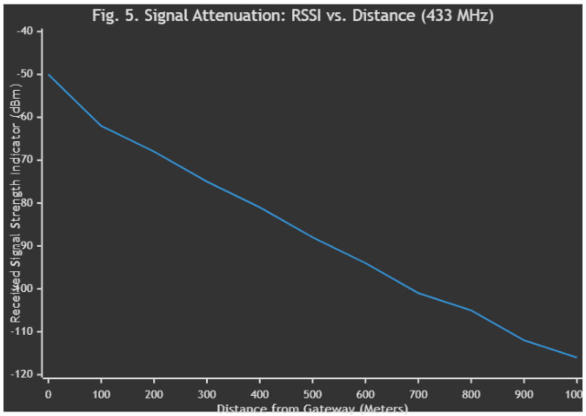


Fig. 6. Signal Attenuation: RSSI vs. Distance (433 MHz)

Cost-Effectiveness and Scalability:
A primary objective of this architecture was to eliminate the high installation costs associated with wired LED matrices. The total component cost for a single Receiver Display Node (ESP32, HC-12, Nextion 2.8" HMI, and power regulation) is approximately under $35 USD (₹2,900 INR). Because the system operates on the free 433 MHz ISM band, it incurs zero recurring internet or cellular subscription fees, making it highly scalable for massive educational institutions.

VIII. CONCLUSION AND FUTURE WORKS

A. Conclusion

This paper presented the successful development of a wireless smart notice board leveraging LoRa RF telemetry and ARM-based HMI edge-rendering. By replacing traditional host-driven pixel processing with an independent Nextion display, the system eliminated network blocking delays. The deployment of HC-12 transceivers operating in the 433 MHz band established a free, infrastructure-independent communication network capable of covering large campus environments. The resulting prototype is a scalable, low-latency, and highly reliable digital signage solution that significantly outperforms traditional Wi-Fi and GSM-based alternatives.

B. Future Work

Future iterations could expand upon this foundation by upgrading the firmware to support a multi-node mesh topology, allowing receiver nodes to act as repeaters to cover massive university layouts. Additionally, implementing solar charge controllers at the receiver nodes would make the system completely grid independent. We can upgrade the LoRa Range and by using different modules of LoRa modules which vary by range.

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