This System is a decentralized, low-power wireless communication architecture designed to enable reliable, real-time information exchange across geographically distributed campus zones without dependence on conventional internet infrastructure. The system is implemented using a network of ESP32 microcontroller units integrated with Semtech SX1278-based RA-02 LoRa transceivers and SSD1306 OLED displays, forming a peer-to-peer broadcast communication topology.

Each node operates as a self-contained communication endpoint, hosting a local IEEE 802.11 b/g/n Wi-Fi access point and an embedded HTTP web server. This allows authenticated end-users to connect locally and interact through a browser-based dashboard for message creation, transmission, and monitoring. Messages are structured into compact, fixed-format data frames consisting of a unique message identifier (Message ID), message type (control field), source node ID, destination node ID, and encrypted payload.

Data transmission between nodes is achieved using LoRa (Chirp Spread Spectrum – CSS) modulation, implemented through the RA-02 module operating in the 433 MHz ISM band. The wireless link is configured with selectable spreading factors (SF7–SF12), bandwidth (125 kHz), and forward error correction coding rates (4/5 to 4/8) to balance communication range, latency, and reliability. Typical operational parameters yield communication ranges of 2–10 km line-of-sight with receiver sensitivities reaching –148 dBm.

To ensure communication integrity, the system implements lightweight cryptographic protection, where messages are encrypted at the source node and decrypted at the receiver nodes using a symmetric pre-shared key mechanism. Duplicate suppression is achieved through message ID caching, preventing replay and packet flooding effects. Target-based packet filtering ensures that only intended nodes process and display the data.

The system supports multiple operational modes, including broadcast announcements, attendance request/acknowledgment protocols, and high-priority emergency alert dissemination. Emergency packets are treated with the highest scheduling priority and are capable of pre-empting routine display operations.

A dedicated Admin Node integrates an SPI-based microSD storage subsystem to provide non-volatile logging of transmitted and received packets, acting as a forensic audit trail and system activity recorder. Log entries are time-stamped and stored in append-only format to help detect tampering and unauthorized alterations.

Internally, the system uses a multitier embedded software architecture consisting of hardware abstraction, communication middleware, and application logic layers. The continuous execution model follows an event-driven loop that monitors HTTP requests, button-based hardware interrupts, LoRa receive interrupts, and display updates in real time.

The architecture is designed to be scalable, fault-tolerant, and infrastructure-independent, supporting rapid deployment and minimal operational cost, making it highly suitable for smart campus environments, disaster-resilient networks, and geographically distributed institutional communication systems.

System Design