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Offline Mesh-Based Wireless Communication System Using ESP32 and OLED Display with ESP-NOW Protocol

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Abstract: Conventional communication systems depend on internet infrastructure and cellular networks, which may become unavailable during disasters, in remote areas, or in military field operations. This paper presents the design and implementation of an Offline Mesh-Based Wireless Communication System using two ESP32 microcontrollers, a 4×4 matrix keypad for input, and a 0.91-inch OLED display (SSD1306) for real-time message rendering. The system leverages ESP-NOW, a lightweight, connectionless peer-to-peer protocol developed by Espressif Systems, enabling direct MAC-address-based data transfer without requiring a Wi-Fi router or internet access. Each node is configured as both transmitter and receiver, facilitating bidirectional communication. The prototype achieved message delivery latency below one second, a stable open-space range of approximately 60 metres, and continuous operation exceeding three hours on a 10,000 mAh power bank. The system is low-cost, portable, and can be extended to a multi-node mesh topology, demonstrating practical utility for disaster management, rural connectivity, defence communication, and IoT-based offline control systems.

Each ESP32 node is configured to operate as both atransmitter and receiver, allowing bidirectional text communication between users. The system incorporates a Nokia-style multi-tap text input mechanism through the matrix keypad and displays transmitted and received messages on the OLED display. Experimental evaluation was conducted under open-air, indoor line-of-sight, andwall-obstructed environments to analyze communication performance. The prototype achieved message delivery latency below one second, communication ranges of up to 60 metres in open environments, reliable message delivery exceeding 99%, and continuous operation for more than three hours using a 10,000 mAh portable power source.

Keywords — ESP32, ESP-NOW, Offline Communication, Mesh Network, OLED Display, SSD1306, Peer-to-Peer, Embedded Systems, IoT, Disaster Communication

I. INTRODUCTION

Modern communication relies heavily on centralised infrastructure such as mobile towers, internet service providers, and Wi-Fi routers. When these fail—during natural calamities, in remote geographical regions, or in contested military environments—people are left entirely without a means of exchanging information, often at great cost to human safety and coordination [1].

Mesh networking is an increasingly recognised solution to this dependency. In a mesh network each node acts simultaneously as sender and relay, forming a self-healing, decentralised topology that continues to function even when individual nodes go offline [2]. Recent advances in low-cost, Wi-Fi-capable microcontrollers—most notably the ESP32 by Espressif Systems—have made it feasible to deploy compact, battery-powered mesh nodes for a fraction of the cost of traditional radio equipment [3].

This paper presents the Offline Mesh Chat System (OMCS), a hardware–software prototype that enables direct, infrastructure-free text communication between two ESP32 nodes. The system uses Nokia-style multi-tap input via a 4×4 matrix keypad and renders messages on a 0.91-inch SSD1306 OLED display over I²C. The wireless link is provided by ESP-NOW, Espressif's proprietary, low-latency Layer-2 protocol.

II. LITERATURE SURVEY

Existing offline communication research broadly spans three technology families: Bluetooth, LoRa, and Wi-Fi-based microcontroller solutions.

1) Bluetooth Mesh: Short-range Bluetooth systems have been demonstrated for disaster-relief messaging [4]. While simple to deploy, practical indoor range rarely exceeds 30 m, and connection management adds latency.
2) LoRa: Long-range LoRa nodes achieve kilometre-scale links but are bandwidth-constrained (< 50 kbps), making real-time text messaging impractical [5].
3) Wi-Fi Microcontrollers: ESP8266 and ESP32 projects have created local chat servers accessible via mobile browser, but they still require a router to establish the connection [6]. More recent work applied ESP-NOW for sensor telemetry between ESP32 nodes [7], a capability this paper extends to interactive human messaging with full I/O peripherals.

No prior ESP32-based system combines Nokia-style multi-tap keypad input, persistent incoming-message display, and bidirectional ESP-NOW messaging in a single, router-free prototype, representing the novel contribution of this work.

III. SYSTEM DESIGN

A. *Hardware Architecture*

The complete hardware bill of materials for each node consists of: (1) ESP32 DevKit V1 microcontroller; (2) 4×4 membrane matrix keypad; (3) 0.91-inch I²C OLED display (SSD1306, 128 × 32 px); (4) USB or 3.3 V regulated power supply.

The ESP32 DevKit V1 features a dual-core Tensilica LX6 processor clocked at up to 240 MHz, 520 KB SRAM, 4 MB flash, built-in 2.4 GHz 802.11 b/g/n Wi-Fi, and Bluetooth 4.2. Its dual-core architecture allows communication handling and user-interface rendering to proceed in parallel [8].

The keypad is interfaced via a row-column matrix scan using 8 GPIO pins (rows: 19, 18, 5, 17; columns: 16, 4, 0, 2). Software debouncing is implemented with a 20 ms delay loop. Nokia-style multi-tap mapping is handled with an 800 ms tap-timeout window to distinguish repeated presses on the same key.

The OLED communicates over I²C (SDA → GPIO 21, SCL → GPIO 22) at the default slave address 0x3C. The SSD1306 controller renders 128 × 32-pixel monochrome output, adequate for displaying two lines of 21 characters each at text size 1 using the Adafruit GFX font [9].

The current prototype has four principal limitations. First, the 0.91-inch OLED restricts visible text to approximately two rows of 21 characters; long messages are truncated without scrolling. Second, the system lacks message encryption; an attacker within Wi-Fi range could potentially capture ESP-NOW frames. Third, no message history is stored—all exchanges are ephemeral. Fourth, breadboard construction introduces occasional contact failures under vibration or extended use; a PCB implementation would improve durability.

B. *Communication Protocol — ESP-NOW*

ESP-NOW is a connectionless, MAC-address-based protocol operating at the Wi-Fi Physical Layer (IEEE 802.11). Key characteristics are [10]:

• Payload up to 250 bytes per frame
• Latency typically < 10 ms in clear-channel conditions
• No association or handshake overhead
• Supports up to 20 unicast peers and one-to-many broadcast

In OMCS, each ESP32 registers the peer MAC address of its counterpart at startup. The sending node invokes esp_now_send(); the receiving node fires a callback (onDataRecv) in which the incoming payload is extracted, the source MAC is formatted, and the OLED is updated. A symmetrical send callback (onDataSent) refreshes the display with a confirmation banner.

C. *Message Structure*

The data packet is a C struct:

```
typedefstruct{  uint8_t senderMac[6];  char msg[250];} espNowMessage;
```

The 6-byte MAC field allows the receiver to display the originating address without parsing the ESP-NOW metadata separately.

D. *Software Flow*

On power-up both nodes initialize the OLED, configure Wi-Fi in STA mode, and register the ESP-NOW peer. The main loop continuously polls the keypad and checks a tap-timeout counter. Control keys are: # (send), * (backspace), A (toggle case), B (clear buffer), D/C (space). When an incoming message is being displayed the compose buffer is hidden; any keypress clears the incoming flag and starts a fresh compose session.

IV. RESULTS & DISCUSSION

The prototype was tested across four scenarios: open-air (campus courtyard), indoor line-of-sight, through-wall (one brick partition), and battery endurance.

Table I – Performance Metrics

Metric	Result
Avg. message latency	< 1 second
Open-air range	~60 m
Indoor (LOS) range	~40 m
Through-wall range	~30 m
Battery life (10 Ah)	> 3 hours
Message delivery rate	~99% (< 60 m)
Keypad accuracy	No missed keys
OLED refresh rate	Real-time (< 50 ms)

The system delivered sub-second latency across all test scenarios within range limits. Through-wall range degradation (~50% versus open-air) is consistent with 2.4 GHz attenuation in masonry construction [11]. Battery results confirm suitability for extended field deployment.

Comparison with alternative technologies (Table II) highlights that ESP32 / ESP-NOW offers the best balance of range, data-rate, and cost for interactive offline text communication.

Table II – Technology Comparison

Technology	Range	Data Rate	Cost	Offline
Bluetooth	~30 m	3 Mbps	Low	Yes
LoRa	~5 km	50 kbps	Medium	Yes
Zigbee	~75 m	250 kbps	High	Yes
ESP-NOW	~60 m	1 Mbps	Low	Yes

V. . FUTURE SCOPE

Future enhancements include: (1) true multi-node mesh using ESP-NOW broadcast with store-and-forward routing; (2) AES-128 payload encryption using the ESP32's hardware cryptographic accelerator; (3) NVS-flash message history enabling asynchronous retrieval; (4) a larger 1.3-inch or colour TFT display; (5) solar-charged Li-ion power with deep-sleep power management; and (6) integration with LoRa for long-range relay between mesh islands.

VI. CONCLUSION

This paper presented the design, implementation, and empirical evaluation of an Offline Mesh-Based Wireless Chat System built on ESP32 microcontrollers communicating via the ESP-NOW protocol. The system demonstrated sub-second message latency, a usable range of 60 m in open space and 30 m through a masonry wall, message delivery reliability above 99%, and battery autonomy exceeding three hours—all without any internet infrastructure. The Nokia-style multi-tap keypad combined with a persistent OLED display provides an accessible human interface. The prototype offers practical value for disaster relief, military communication, rural connectivity, and education, while serving as a springboard for more capable decentralized mesh networks.

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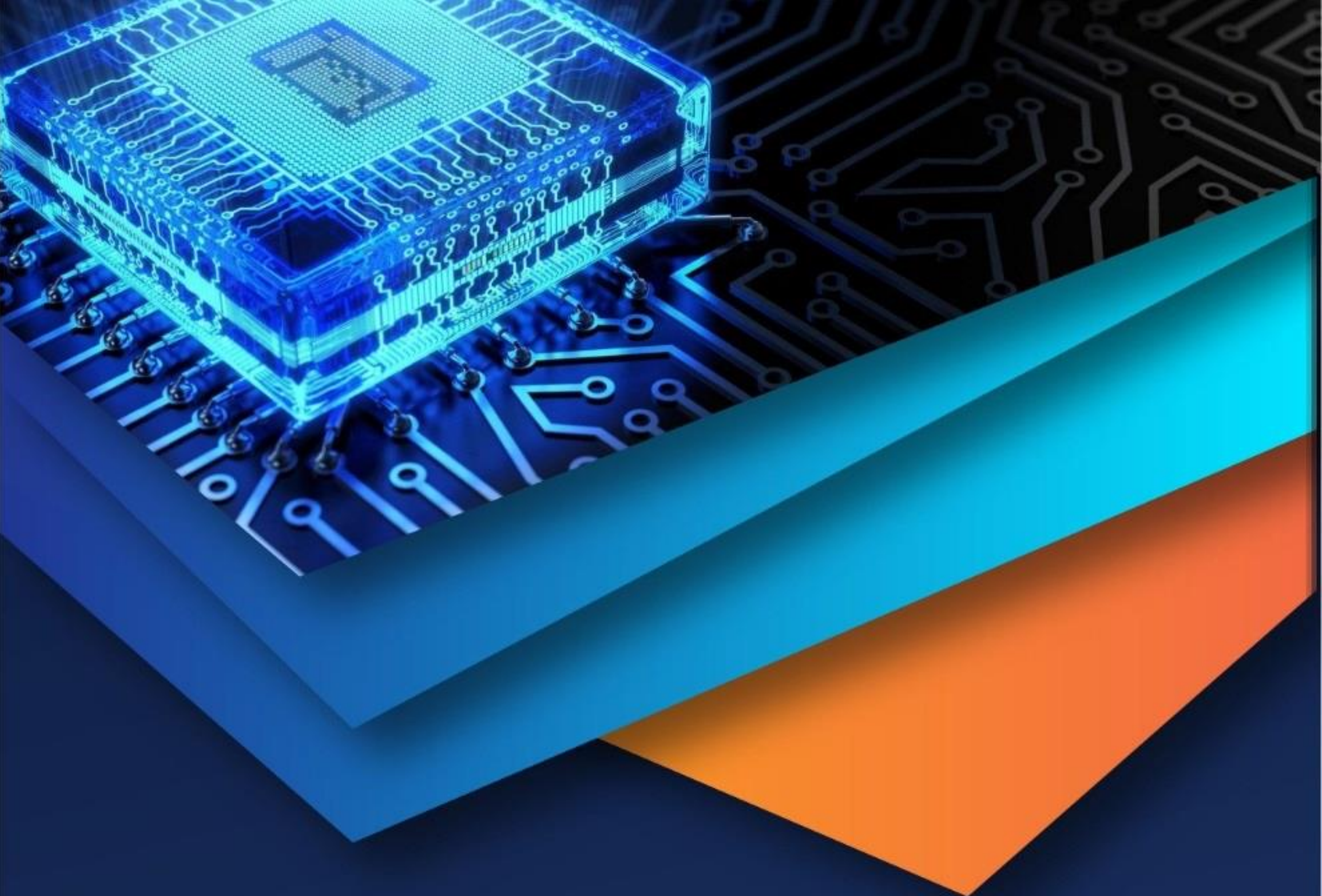

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