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Automatic Packet Reporting System's Payload Design for Development of Backup Communication System and Disaster Risk Reduction Management †

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Abstract

We developed two distinct automatic packet reporting system (APRS) payload designs to establish a reliable backup communication system for disaster risk reduction and management. The payloads are designed to perform a significant key operation, primarily APRS digital repeating (DP), enabling continuous communication access even in areas where conventional ground-based infrastructure is damaged by natural disasters through the relay of APRS packets to extend communication coverage. A detailed framework is designed using the standard amateur packet radio (AX.25 protocol). It specifies the structure of APRS data frames and packets, which are used to transmit alerts, emergency status updates, and text messages. This structure ensures that important information is transmitted reliably and effectively during an emergency. The designs for the APRS payloads share a common overall operating system architecture but differ in their very high frequency transceiver modules used for the amateur radio (Radiometrix BiM1H very high frequency (VHF) Narrowband Transceiver and Dorji DRA818V VHF Band Voice Transceiver Module).

Keywords: APRS; digital repeating (DP); AX.25 protocol; APRS packets; APRS payload

1. Introduction

Communication is the foundation of society, allowing for daily interactions and coordination. Traditional wireless systems, such as radiofrequency (RF) broadcasts, cellular networks, and fiber optics, rely on ground infrastructure, which is especially susceptible to outages during emergencies or natural disasters. Recent typhoons in the Philippines have devastated networks and impeded rescue attempts and public safety [1,2]. When dependable communications are most needed for real-time data sharing, alarms, and relief coordination, breakdowns cause delays and increased hazards. Satellite-based technologies, specifically an automatic packet reporting system (APRS), provide a reliable alternative. APRS employs digital packet radio to send real-time data, emergency warnings, and position information over long distances without base support. This ensures communication continuity during emergencies, reducing reaction times, speeding up recovery, and increasing overall resilience. In disaster-prone areas such as the Philippines, an APRS

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payload in a CubeSat serves as a critical backup, transmitting distress signals and weather updates independently.

Researchers have supported APRS's potential by studying an APRS-GPS tracker for amateur radio operators, enabling data relay without cell or internet during disasters [3]. A low-cost APRS payload was developed for nanosatellites acting as digipeaters (signal repeaters) using digital signal processing, Amateur X.25 (AX.25) protocol, and inter-integrated circuit interfaces [4]. Indonesia's Surya Satellite-1 integrates APRS on amateur bands for disaster mitigation [5], while the BIRDS-2 project tested a CubeSat APRS digipeater at 145.825 MHz with off-the-shelf parts, proving its value despite uplink challenges [6]. Yet, APRS faces limitations in reliable two-way communication, including inconsistent uplinks/downlinks and disruptions in remote areas. New strategies must focus on better data throughput, network hardening, and interference avoidance to enhance emergency backups and reduce disaster risks.

We designed an advanced APRS payload for CubeSat to enable APRS packet transmission as a backup emergency channel. For the payload, APRS specifications are defined for short messaging systems (SMSs), status, and alerts, and electrical interfaces are integrated with CubeSat subsystems. The developed APRS payload is implemented with transceivers for improved interoperability.

2. Methodology

A distinctive and enhanced APRS payload is designed to transmit data through APRS packets, providing an alternative communication method during widespread communication outages. The study aims to explore multifaceted adaptive architectures to support the integration of APRSs into emergency communications and disaster risk reduction, including capabilities for SMS and status reporting during crises. By implementing APRS digital repeating (DP), a more reliable and efficient APRS payload is established.

2.1. System Process

The developed payload receives APRS packets in text messages, emergency status, and alert data through its integrated transceiver. Once the payload receives the said information, the terminal node controller (TNC) of the payload's DP system performs packet validation and decoding to determine the data type of the packets before proceeding with the packet modification and encoding for the DP operation. This allows real-time and efficient transmissions of SMS and emergency status and alert information to be broadcast to improve overall communication reliability during crises. It enables the system to integrate and support different transceivers for scalability and enable reliable packet delivery (Figure 1).

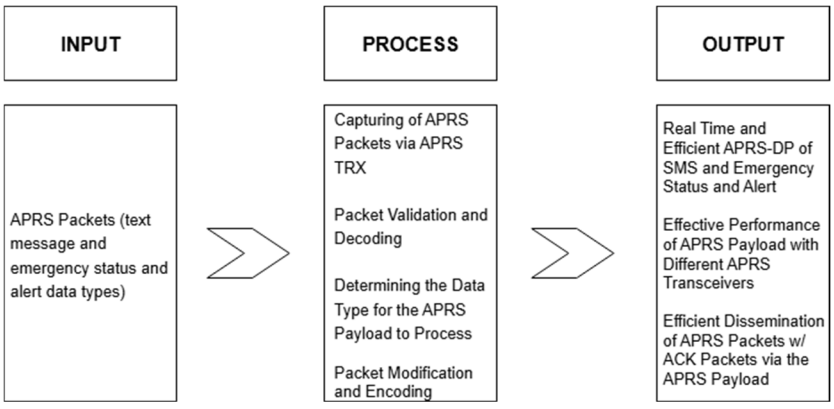


Figure 1. Simplified system process.

The workflow of the payload is demonstrated in Figure 2. The system begins with initialization, which turns on subsystems, followed by a self-diagnostic check to ensure that all components work properly. If a fault is detected, it notifies the ground station and enters safe mode. Otherwise, it switches to listening mode to detect incoming APRS packets. After receiving a packet, the system decodes it and checks for errors. Valid packets are processed in DP mode, where they are changed, acknowledged, and retransmitted. Invalid packets are deleted, and the machine switches back to listening mode. This method prioritizes dependable communication by allowing rapid error handling and retransmission, improving the stability and efficiency of satellite-based APRSs in crucial situations.

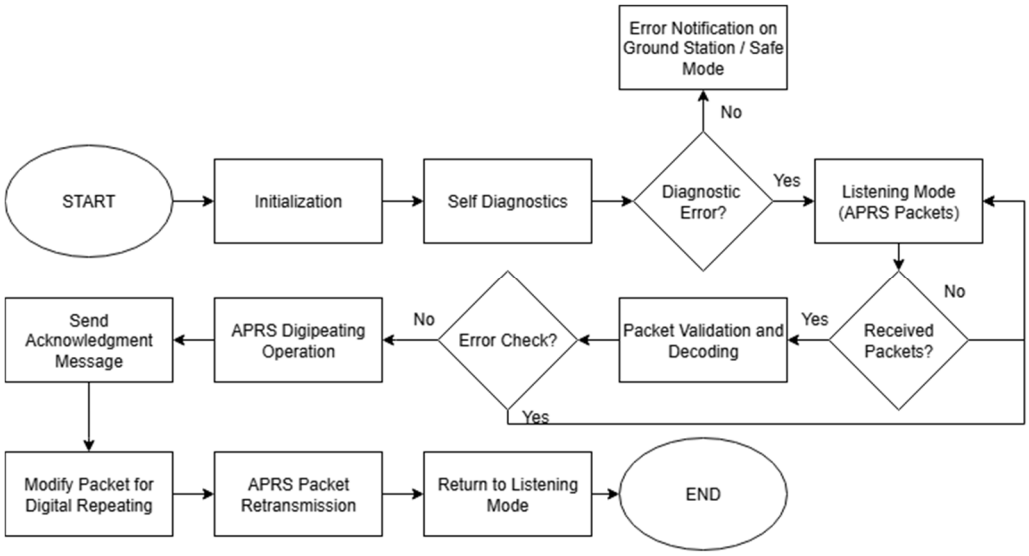


Figure 2. Process workflow.

2.2. APRS Payload Specification

APRS relies on the AX.25 protocol, a data link layer adaptation of X.25 tailored for amateur radio, which ensures reliable transmission over radio frequencies through error detection, correction, and addressing [7]. In APRS, AX.25 facilitates efficient transfer of position data, sensor readings, and messages, operating in a connectionless mode without guaranteed delivery. However, APRS enhances this with a higher-level messaging system that supports short messages and acknowledgements for improved reliability. As depicted in Figure 3, a typical AX.25 data frame in APRS is bounded by flags (0x7E) and includes a destination address (target callsign with optional SSID, where non-zero indicates digipeater paths), source address (sender's callsign and SSID, potentially denoting display symbols), up to eight digipeater addresses for relaying (updated per path), a control field (usually 0x03 for user interface frames), protocol identification (ID) (0xF0, indicating no Layer 3), an information field starting with a data type identifier for APRS payload, and a frame check sequence for integrity verification.

	AX.25 UI-FRAME FORMAT								
	Flag	***Destination Address***	***Source Address***	***Digipeater Addresses (0–8)***	***Control Field (UI)***	***Protocol ID***	***INFORMATION FIELD***	***FCS***	***Flag***
Bytes:	1	7	7	0–56	1	1	1–256	2	1

Figure 3. AX.25 data frame protocol.

The APRS payload's text message (SMS) format, as depicted in Figure 4a, includes four essential fields: a data type identifier (a colon (:) to signify SMS data), a 9-character

addressee field (padded with spaces if shorter), up to 67 readable American Standard Code for Information Interchange (ASCII) characters for the message text (excluding |, -, and ~), and an optional message ID (left curly brace followed by up to 5 alphanumeric characters) for requesting acknowledgment or rejection. If no acknowledgment ("ack") or rejection ("rej") is received, the sender resends the packet until it is canceled or times out. For emergency status and alerts, Figure 4b outlines the use of general bulletins or announcements. General bulletins, preceded by "BLN" and a numeral, broadcast time-sensitive information such as weather updates to a large audience. They are limited to 67 legible ASCII characters (excluding | and ~) and are delivered numerous times hourly without acknowledgment, which delays receipt confirmation. In contrast, announcements, which use "BLN" with an uppercase letter, provide less urgent, preemptive details for potential emergencies, are similarly limited to 67 characters, and are delivered less frequently to reduce network overload while promoting effective communication.

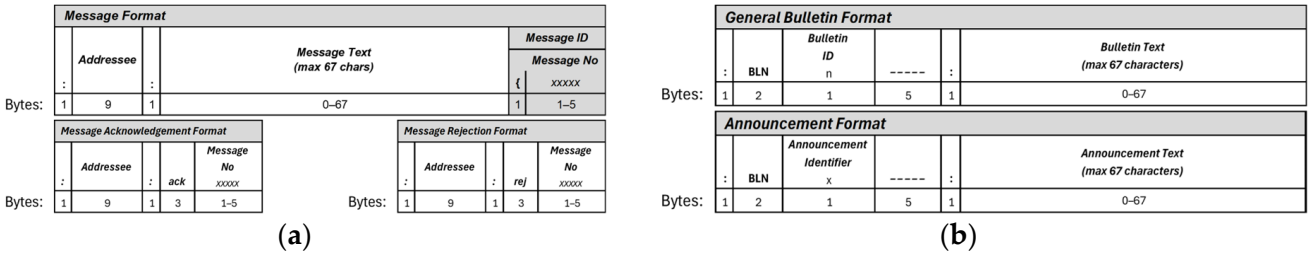


Figure 4. AX.25 protocol's data frame: (**a**) APRS packet message format; (**b**) APRS packet bulletin/announcement format.

3. Results

The APRS payload is designed in the DP and S&F systems, with an emphasis on hardware improvements to improve CubeSat mission performance and dependability. Upgraded transceivers provide quicker data throughput, increased signal sensitivity, and longer operational lifespans, allowing for reliable connections even in severe environments. Circuitry improvements use new materials to reduce power consumption, minimize thermal stress, and enhance compactness, all while accounting for CubeSat limits such as restricted power and space. These developments ensure that the payload exceeds performance expectations, making it critical for effective real-time data relay and telemetry in satellite networks.

3.1. Design Block Diagram

The block diagram in Figure 5 depicts the incorporation of an APRS payload into a CubeSat architecture, supporting DP and Store-and-Forward (S&F) functions. The APRS payload is shown as a modular system that interfaces with the CubeSat's major subsystems: the onboard computer (OBC), communication (COM), and electrical power subsystem (EPS). This setup ensures efficient packet transmission, enhancing the satellite's communication range and reliability. Such a design of the CubeSat's subsystems was adapted from the BIRDS project's open-source bus system design.

The APRS payload block, indicated in blue, has critical components that control the real-time relay of digital packets and delayed transmission following data storage (S&F). The APRS-DP/AX.25 module is at the core of this process, as it encodes and decodes AX.25 protocol frames used for APRS communication. This module communicates directly with the APRS reporting system transceiver (TRX), which transmits and receives APRS packets through CubeSat's very high frequency (VHF) antenna. The TRX, connected via the RF signal channel, translates digital information from the module into VHF communication

signals, allowing CubeSat to communicate with ground stations and other satellites in the APRS network. Both the DP and S&F system are developed. However, given the limitations implied by the ground testing, the DP functionality will be solely investigated.

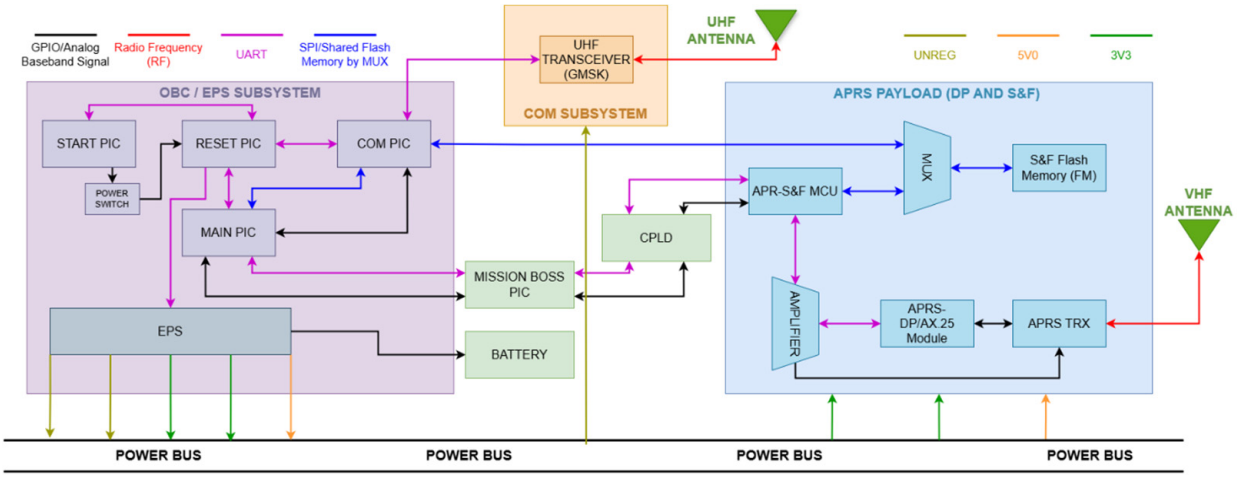
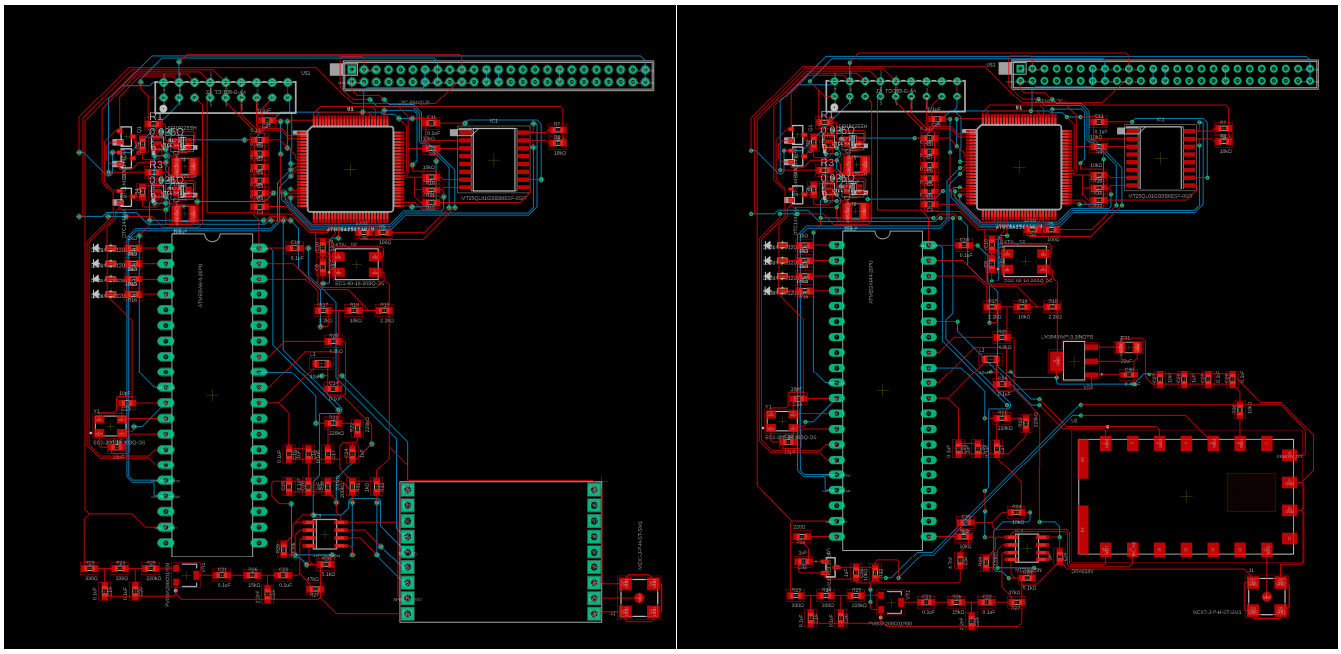


Figure 5. CubeSat subsystems.

The electrical interface between the APRS payload and the CubeSat components is critical for efficient communication and data processing. The power is distributed via the power bus lines (unregulated, 5 V, and 3.3 V) provided by EPS, guaranteeing that the APRS payload's components, including the microcontroller unit (MCU), TRX, and AX.25 module, acquire stable voltages for continuous operation. The APRS payload communicates with the OBC subsystem through a universal asynchronous receiver/transmitter (UART), which enables the main peripheral interface controller to control high-level commands as well as coordinate functions between the APRS MCU and other components, such as flash memory. Furthermore, the ultra-high frequency TRX in the COM subsystem enhances the APRS payload's VHF communication by synchronizing transmission schedules and reducing signal interference, enhancing the CubeSat's overall communication system.

3.2. Prototype Design

The research presents two distinct APRS payload designs aimed at evaluating the efficiency, effectiveness, and performance of respective transceivers in supporting the core functions of the payload, particularly in performing DP operations (Figure 6). Both payload designs share a common architecture in terms of power management, APRS S&F system design, and the APRS-DP TNC (with TinyTrack4 firmware). The power system provides 3.3 V for APRS-S&F and 5 V for APRS-DP operations, drawing from the CubeSat's on-board computer (OBC) and EPS, with regulation based on active mode. Pin connectors enable integration with subsystems such as COM for telemetry and power, while pin headers support programming and debugging via UART, serial peripheral interface, and I^2C lines. Furthermore, the primary difference between the two lies in the transceiver model connected to the APRS-DP MCU, allowing a comparative analysis of how each transceiver impacts the system's ability to perform its intended communication functions.



(**a**) (**b**)

Figure 6. APRS Payload Design with: (**a**) Payload Integrating BiM1H Transceiver; (**b**) Payload Integrating DRA818V Transceiver.

Printed Circuit Board (PCB) Layout Design

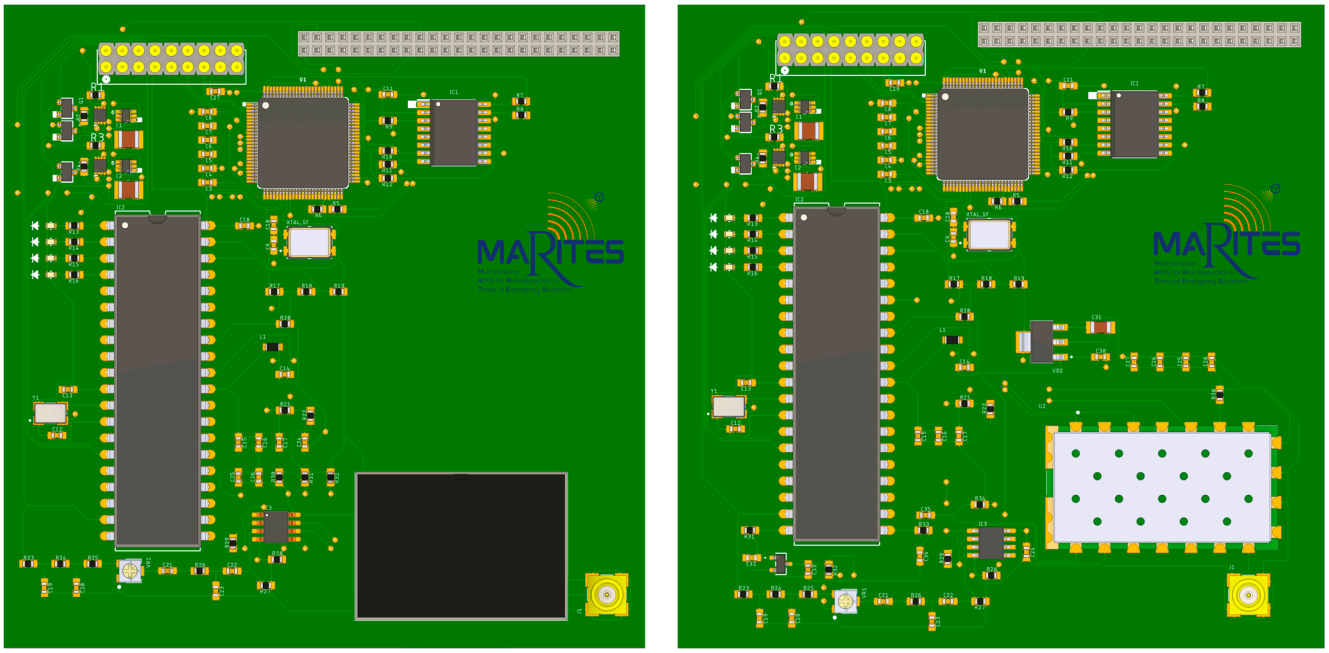
The integration of the Radiometrix BiM1H very high frequency (VHF) (BiM1H) transceiver module into the APRS payload is shown in Figure 6a, highlighting the layout and placement of components essential for ensuring reliable RF communication and overall system functionality. In contrast, the complete PCB layout for the payload incorporating the DRA818V transceiver module is presented in Figure 6b. This layout illustrates the component arrangement and routing specific to the DRA818V-based design, ensuring optimal electrical performance and compatibility with the overall system. Both PCB layouts reflect careful consideration of form factors, signal integrity, and subsystem interfacing tailored to the respective transceiver module employed.

3.3. APRS Payload Device Setup

The designed payloads are 100 mm wide and long, providing compact dimensions that enable seamless integration into CubeSat platforms, where space limits need efficient, low-profile components to preserve overall mission viability and structural integrity. The associated PCB designs have a standard thickness of 1.6 mm and use a 2-layer rigid stack-up arrangement with copper traces and solder mask coatings (with outer copper weight of 1 oz) on both the top and bottom sides for improved environmental protection and reliable electrical performance. This high-performance composite substrate is made of flame-retardant fiberglass-reinforced epoxy laminate material, which adheres to the rigorous Underwriters Laboratories (UL) 94V-0 standard for plastic material flammability. It is mainly made of woven fiberglass cloth impregnated with epoxy resin, which gives it remarkable mechanical durability, moisture resistance, and electrical insulation qualities that are especially useful in aerospace applications.

PCBs were manufactured with a green solder mask and white silkscreen, adhering to IPC Class 2 standards for general electronics reliability. The vias were tented, with a minimum via hole size of 0.3 mm in diameter (0.4/0.45 mm drill size), and the boards featured an electroless nickel immersion gold (ENIG) surface finish with a gold thickness of 1 µm. Figure 7 illustrates the PCB setups for the APRS payloads, including their

corresponding components that constitute the payload's power management, APRS-DP system, and APRS-S&F system designs. The setup also incorporates a specific integrated transceiver, enabling seamless operation of the APRS-DP system.



(**a**) (**b**)

Figure 7. APRS payload design with (**a**) payload integrating BiM1H transceiver and (**b**) payload integrating DRA818V transceiver.

4. Conclusions and Future Work

We designed an advanced APRS payload for CubeSat to enhance satellite communication resilience by establishing APRS as a reliable backup emergency channel. The research ensures efficient data exchange and system compatibility. This development bolsters the safety and operational efficiency of CubeSats and interoperability of the global amateur radio and satellite networks. It is necessary to validate and refine the payload for real-world deployment. This involves a thorough analysis of payload power consumption to improve energy efficiency, functionality tests to ensure operational performance, VHF end-to-end connectivity tests to confirm seamless communication links, and long-range communication tests to assess reliability over long distances. These tests enable any necessary adjustments to handle potential obstacles for practical deployment. The results of this research provide breakthroughs in CubeSat technology, improving emergency response capabilities and encouraging collaborative advancements in the sector.

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Abbreviations

The following abbreviations are used in this manuscript:

APRS	Automatic Packet Reporting System
DP	Digipeating (Digital Repeating)
VHF	Very High Frequency
S&F	Store-and-Forward
TNC	Terminal Node Controller
TRX	Transceiver

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