

# Design and Implementation of a Real Time Data Transmission System Using Unmanned Aerial Vehicles

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**Abstract**— In dynamic outdoor operating conditions, reliable real-time telemetry achieved by unmanned aerial vehicles (UAVs) is difficult to reach due to mobility, variable radio coverage, and limited onboard energy. This paper describes the creation and integration of a basic environmental monitoring module mounted on a UAV platform, integrating environmental sensing and cellular connectivity through an LTE Cat-4 modem and cloud visualisation with ThingSpeak. The prototype was launched into flight on 15 January 2026 using a commercial quadcopter as well as the MTEL LTE network for an approximately 10-minute outdoor mission. The experimental results confirm continuous cloud updates with predominantly successful HTTP transactions (primarily status 200) and a range of end-to-end HTTP upload latency spanning from ~ 1.5–1.8 s during normal circumstances to up to ~ 25 s in transient network delays. Following the acquisition, measured RSSI stabilized to around -51 dBm, and the modem exhibited normal mobility behaviour, switching between LTE Band 1 (2100 MHz) and Band 3 (1800 MHz), neither of which resulted in persistent link interruption. Low-cost UAV platforms enable practical near-real-time cloud monitoring whenever LTE is available, whereas for time-critical applications, latency variation should be taken into account.

**Keywords**—cloud-based monitoring, data transmission, onboard system, real-time communication, UAV, wireless communication

## I. INTRODUCTION

Today, environmental monitoring and natural disaster prevention rely on timely sensor data. Nevertheless, reliable real-time communication remains challenging in dynamic and remote environments where traditional monitoring approaches are limited [1]. UAVs are becoming increasingly important as airborne sensing platforms due to their mobility and rapid deployment capabilities, while integrating onboard sensing, processing, and communication within a compact modular structure is constrained by payload, power consumption, and link stability under varying network conditions [2], [3]. To address these challenges, this work presents an integrated onboard sensing and LTE Cat-4 communication module combined with cloud-based monitoring, validated through real outdoor flight experiments. The main contribution is the experimental validation of UAV telemetry that combines environmental sensing with communication-performance monitoring, providing insight into latency behaviour, signal stability, and cloud delivery reliability during UAV mobility. The objective of this work is to experimentally validate whether a low-cost

UAV-mounted sensing unit using LTE Cat-4 can provide continuous cloud telemetry with acceptable end-to-end latency and link stability during real outdoor flight.

## II. RELATED WORK

Research on UAV-assisted communication systems has evolved along several complementary directions, mainly involving sensing integration, cellular connectivity, and cloud-based telemetry solutions.

A considerable number of studies investigate the use of UAVs as mobile sensing platforms combined with Internet-of-Things technologies. In such systems, UAVs enable rapid deployment and flexible spatial coverage, which is particularly useful for environmental monitoring and smart-city scenarios [2], [6], [8]. The integration of onboard sensing with IoT communication frameworks further supports distributed data collection over wide geographic areas while maintaining compatibility with cloud infrastructures [1], [7]. Although these studies demonstrate the potential of UAV-based sensing, many contributions remain limited to architectural proposals or simulations rather than validation in real flight conditions.

Another critical research line involves the provision of cellular technologies for UAV connectivity. LTE and emerging 5G systems provide wide coverage, mobility support, and the advantage of existing commercial infrastructure, making them appealing to aerial communication platforms [3], [4], [9]. Measurement-oriented studies have investigated the propagation features, interference behavior, and mobility management for aerial users, highlighting that commercial cellular networks can support UAV communication with acceptable performance levels [11], [12]. Compared with alternatives such as Wi-Fi or LoRaWAN, cellular solutions offer greater operational range and reduced dependence on local infrastructure, which is essential for mobile aerial deployments in remote environments [10].

The third line of work addresses cloud integration and telemetry reliability. Connecting UAV platforms with IoT cloud services enables real-time visualization, data storage, and remote monitoring capabilities [1], [6]. However, many existing implementations rely on laboratory setups or simulation-based evaluation, and only limited experimental results are available that quantify communication performance metrics such as latency variation, signal

stability, and end-to-end data delivery reliability during real UAV mobility.

Motivated by these observations, the present study provides an experimental validation of a low-cost UAV telemetry architecture that combines environmental sensing, onboard processing, LTE-based communication, and cloud monitoring. The system is evaluated through real outdoor flight experiments in order to obtain practical insight into communication behavior under dynamic operating conditions.

### III. SYSTEM ARCHITECTURE AND DESIGN

#### A. Overall System Architecture

The proposed system architecture is designed to provide real-time monitoring of UAV mobility and environmental parameters. The system is implemented on an unmanned aerial vehicle (UAV) platform.

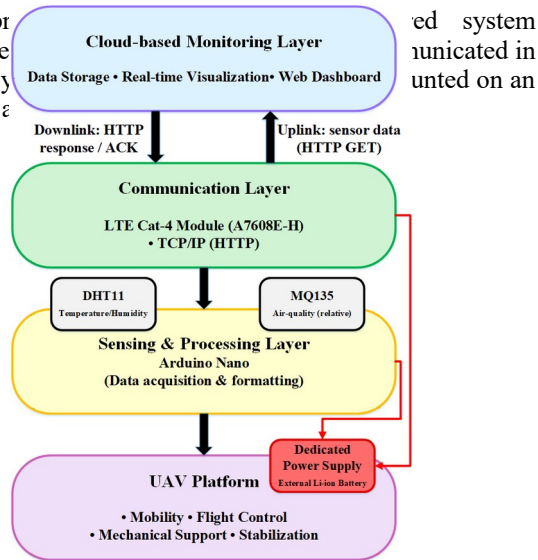


Fig. 1. Schematic representation of the system architecture

From Fig. 1, it can be noted that the architecture consists of a sensing and processing layer, a communication layer, and a cloud-based monitoring layer. The sensing layer measures environmental parameters through integrated sensors, and the resulting data is analyzed and prepared for transmission by the onboard module. As a system, it operates based on the communication layer established between the onboard module and a remote server, independent of local ground infrastructure — it is capable of continuously transmitting data and information when the UAV is active. The collected data is passed to the cloud-based monitoring layer, where it is processed and saved for real-time visualization and web-based access by users.

#### B. Hardware Components

The hardware architecture of the proposed system is carefully designed to work with the functional limits of UAV-based systems, such as payload weight, energy requirements, and system reliability. The developed onboard sensing and communication module (hereafter referred to as the onboard module) consists of an Arduino Nano microcontroller, a DHT11 temperature and humidity sensor, an MQ135 gas sensor, and an LTE Cat-4 communication modem. At the core of the sensing layer is the Arduino Nano microcontroller. This microcontroller has been chosen as it is small, low-power-consuming, and capable of capturing and processing real-time sensor data. The onboard controller manages sensor

interfacing, schedules different data sampling sessions, and prepares the captured measurements for transmission to the communication module. The environmental data is recorded by lightweight, low-cost sensors, directly interfaced to the microcontroller. For the implemented system, ambient temperature and humidity are determined with a DHT11 sensor, and air quality is measured with an MQ135 gas sensor. Wireless data communication is provided by an LTE (Long-Term Evolution) Cat-4 communication module for high-bandwidth operation during UAV flight. The module interfaces serially with Arduino Nano; it also complies with general Internet communications protocols that permit measurements made through its sensors to be sent to a remote cloud server. All hardware of the developed system runs on a rechargeable lithium battery (capacity 1200 mAh) separate from the onboard power system of the UAV. Such a separated power layout provides safety while integrating all devices used for UAV platforms. The low-cost sensors selected have measurement limitations that should be taken into account during UAV operation. The DHT11 sensor has moderate accuracy ( $\pm 2$  °C for temperature and  $\pm 5\%$  for relative humidity), while adequate for trend monitoring, it does not provide high-precision environmental measurements. For instance, the MQ135 gas sensor requires an initial warm-up period for stable operation, as this sensor can only detect relative air-quality variations rather than absolute gas concentrations. Airflow, UAV's motion, and vibration in flight can similarly affect fluctuations in the sensor readings. Nevertheless, for real-time monitoring and evaluating the communication performance, the chosen sensors ensure adequate reliability and repeatability.

#### C. Communication and Data Flow

The communication subsystem provides dependable real-time transmission of sensor data between the UAV-mounted system and a remote cloud monitoring platform.

The overall communication and data flow sequence of the proposed system is illustrated in Fig. 2.

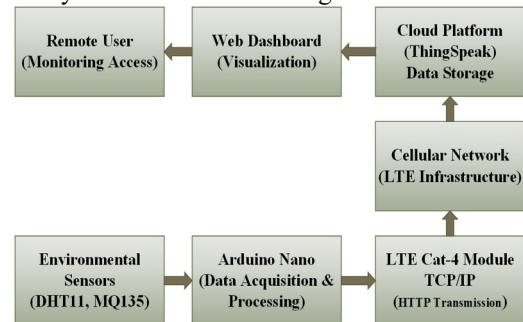


Fig. 2. Communication and data-flow architecture of the UAV system

The onboard module reads the data from the sensors periodically, performs basic processing on the collected data, and organizes the processed data into a standard package that contains the measured parameters and the necessary metadata, such as the device identifier and timestamp. This package is then delivered to the communication subsystem for transmission over the mobile network. Therefore, the LTE connection allows the system to be operated independently of local ground infrastructure, and its deployment to remote or temporarily inaccessible areas is appropriate. On the cloud, the data is processed internally and is used to feed the monitoring platform with input data stored within, for both presentation on the web and real-time visual feedback.

#### D. Design Considerations and Constraints

Several practical limitations of aerial platforms impose constraints on the design of the proposed UAV-assisted monitoring system. Such design considerations must be addressed in order to ensure reliable real-time operation with a simple, low-cost, and versatile architecture. Because of the payload limitations, the hardware chosen should be compatible with the carrying capacity of a UAV [2]. Energy is also a factor, so low-power sensing and processing units were operated, and sampling and transmission intervals were tuned to match the energy consumption with the time needed to deliver the data. Another challenge that can hinder continuous data transmission during flight is sustaining stable wireless communication, particularly when network coverage is variable [3]. The onboard communication subsystem's power consumption is mainly dominated by the LTE Cat-4 module and varies depending on the transmission conditions and the network. Current during LTE transmission (approx 370–670 mA), with short peaks up to 2 A, and standby consumption is ~2 mA according to module specifications. Due to short flying time and periodic data uploads, the energy needed was within the constraints of the dedicated 1200 mAh storage battery in the tests. The results suggest that cellular-based telemetry is feasible for short-duration UAV missions, but further power enhancement is required for long-endurance missions.

#### IV. COMMUNICATION TECHNOLOGY AND STRATEGY

##### A. Communication Requirements

The communication subsystem of UAV-based monitoring applications should satisfy critical requirements on latency, reliability, coverage, and energy efficiency to achieve near-real-time data delivery during flight operations. An effective communication method, which should work independently of the local network infrastructure, provides connectivity across a broad geographic area and maintains compatibility with cloud monitoring services. This independence is particularly important for deployment in remote or dynamically changing environments where fixed communication infrastructure may not be available. While the proposed architecture inherently supports multi-user cloud access, the data transmission in the implemented system was configured to a single ThingSpeak channel associated with one API key, ensuring controlled, secure, and authorized data access during experimental validation.

##### B. Cellular Communication Technology

Cellular communication is implemented within the onboard module for the support of direct Internet connectivity between the UAV-mounted module and the remote cloud platform. LTE technology offers sufficient data rates, mobility support, and wide-area coverage required to keep the UAV connectivity during its operation [3]. A Cat-4 LTE modem was chosen as a compromise between communication performance, energy consumption, and hardware availability. Operating over vast geographical distances using existing commercial cellular infrastructure, the system can operate without requiring dedicated ground

communication equipment [4].

##### C. Data Transfer Protocols

Onboard module and cloud platform data are transferred using standard Internet protocols to maintain interoperability and reliability. At the transport layer, Transmission Control Protocol (TCP) is utilized to provide reliable end-to-end communication, and the Hypertext Transfer Protocol (HTTP) is used to transfer it to the cloud server through the client-server request/response architecture between the two devices [5], [6]. The measurements of the sensor are formatted using lightweight structured messages and sent together with metadata such as device identification and timestamps. This method enables compatibility with web-based cloud services and easy access to IoT monitoring platforms [7].

#### V. SYSTEM IMPLEMENTATION

##### A. Onboard Hardware Integration

The system's self-contained onboard module contains sensing, processing, communication, and power subsystems mounted on the commercially available UAV. Hardware, including Arduino Nano microcontroller, environmental sensors, LTE communication module, and a dedicated rechargeable battery are integrated for validation of the design concept. The physical integration of the sensing and communication module mounted on the UAV platform is shown in Fig. 3.



Fig. 3. Onboard hardware integration of the proposed UAV-based sensing and communication module

The onboard module is positioned on the UAV to ensure stable operation without interfering with propulsion, navigation, or control systems. The integration approach thus ensures reliable data acquisition and wireless transmission in real-time flight.

##### B. Embedded Software Implementation

The embedded software running on the onboard controller is responsible for sensor data acquisition and core data processing, as well as for wireless data transmission over the LTE communication module. The software architecture is cyclic execution-based, allowing readings of the sensors to be captured at predefined time intervals and transferred to low-latency cloud platforms. This includes setting up a serial interface within the onboard module, setting up the DHT11 sensor driver, which will store temperature and humidity measurements. At the same time, the analog input channel connected to the MQ135 air quality sensor has been configured for periodic sampling. Once the system initialization is done, a brief communication test is conducted to check and verify the operational status of the LTE module and its ability to connect to the mobile network. Under normal operation, the main program loop automatically receives information from connected sensors in a sequential manner. Upon the detection of an error, a transmission cycle is simply skipped before advancing the intended measurement. This

approach keeps the upload of unreliable data out of the system, which increases the overall robustness of the system. The valid sensor readings are grouped into a compact data set and formatted for transmission to the cloud platform via an HTTP request. Alongside environmental sensing, the firmware collects communication-layer telemetry continuously during each upload cycle in the system. HTTP transaction latency is the elapsed time between issuing an HTTP GET command and receiving the corresponding +HTTPACTION response. The HTTP status code is then extracted from that response, meaning the server has accepted the transmitted data. HTTP status codes returned by the server were logged (+HTTPACTION), where 200 indicates successful uploads, while non-200 codes were treated as transient events during flight. RSSI was derived from AT+CSQ according to the 3GPP mapping and logged in dBm for link-quality evaluation.

The LTE operating band was extracted from AT+CPSI? network status reports. From the length of the transmission URL (Uniform Resource Locator), the estimated uplink rate is determined, and based on the measured latency, which can be used to estimate effective throughput during the operation of an unmanned aerial vehicle (UAV).

### C. Communication Module Configuration

The LTE communication module provides Internet connectivity for continuous data transmission from the onboard sensing system to the cloud platform during UAV missions. Communication between components of the onboard module is achieved through a serial interface, so that the microcontroller can perform command-based control network-related tasks such as registration, session creation, and transmission of data. During initialization, the LTE module is configured with the required APN parameters to establish cellular network connectivity. Once complete, the module will connect to the provider's network as well as complete the registration to the provider's network. The module will then package sensor data into HTTP requests sent to the cloud to be stored and visualized. Overall, the LTE modem will interface with commercial cellular networks and provide ubiquitous, infrastructure-independent communication ideal for UAV monitoring. To accommodate the collection of further communication metrics, a set of AT commands extending the basic setup of connectivity is used. The basic value for cellular signal input is from the AT+CSQ command, which then gets converted to RSSI in dBm for logging purposes. The command AT+CPSI? returns detailed network status, including current LTE band operation. This allows correlation of transmission performance with the operating LTE frequency bands. The remote server's HTTP-based uplink is instrumented to measure response latency and HTTP status codes, allowing evaluation of data delivery effectiveness throughout the flight. The integration of the collected measurements with telemetry data and environmental sensor readings enables a comprehensive evaluation of the system.

## VI. EXPERIMENTAL RESULTS AND EVALUATION

### A. Experimental Setup

The experiments aimed to verify onboard environmental data collection and real-time transmission to a remote cloud platform with low latency. All the experiments were performed by applying the developed sensing and communication module to a commercial unmanned aerial vehicle (UAV). The hardware consisted of the developed onboard sensing and communication module mounted on a commercial UAV platform. A cloud platform was set up on the receiving end to receive the data and show the measurements in real time via a web-based interface. Flight experiments were conducted outdoors under favorable weather conditions to ensure safe and stable operation. During each test, the UAV flew at low to moderate altitudes along representative monitoring flight paths. Throughout each flight, the sensor measurements were taken at standardized time intervals and sent to the cloud platform that acted as a constant transmission channel. The cellular communication link was a commercial LTE network, so the system operated without local ground infrastructure. Variations in signal strength did occur naturally as the UAV was in flight mode, offering practical circumstances for assessing communication performance while the UAV was in motion. Transmitted data was monitored in real-time during the experiments on the cloud-based dashboard and stored for offline analysis later. These visualizations are displayed within graphs in the following section.

### B. Measurement Results

The flight experiment conducted on 15 January 2026 was analyzed to evaluate the real-time performance of the proposed UAV telemetry system under outdoor operating conditions. Measurements were made during a continuous flight lasting approximately 10 minutes, which translates to the nominal battery endurance of the used UAV platform (Xiaomi V198GPS Drone Quadcopter). The system was sending data periodically to the cloud regarding the temperature, humidity, and air quality.

The temperature begins at approximately 2–3 °C, increases towards around 12–13 °C, and decreases in the last moments of the flight. This reaction is representative of the spatial variation of ambient temperature throughout the UAV's range at various locations and altitudes. Timestamped entries also indicate that the cloud platform provided a medium for real-time measurements.

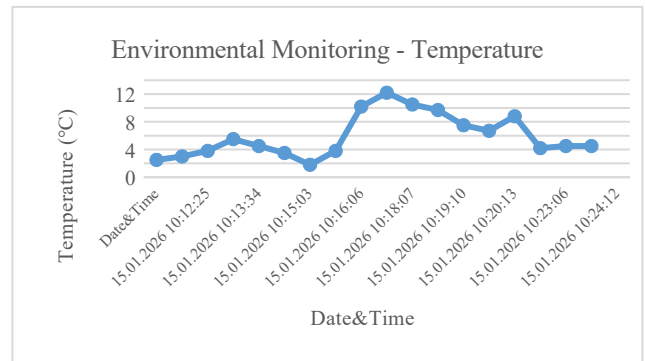


Fig. 4. Temperature measurements recorded and transmitted to the cloud platform during the UAV flight on 15.01.2026.

Temperature values are shown in Fig. 4

Relative humidity remained in the 60–75% range throughout the flight, indicating stable measurements with no visible packet loss in the time-stamped cloud records (Fig. 5).

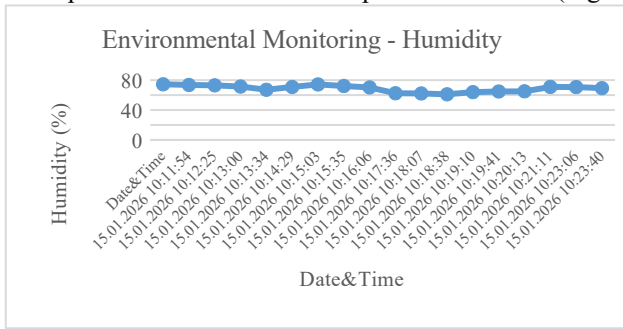


Fig. 5. Humidity measurements recorded during the UAV flight test on 15.01.2026.

The MQ135 sensor worked reliably throughout the experiment in continuous data transmission to the cloud without any disturbance. The data revealed a gradual improvement in air quality during the flight, indicating spatial variations. The air-quality measurement data are summarized in Fig. 6.

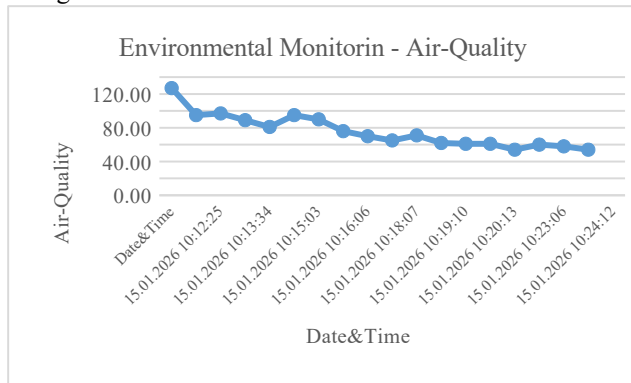


Fig. 6. Air-quality sensor readings obtained from the MQ135 sensor during the UAV flight on 15.01.2026.

While MQ135 outputs can only provide a notion of relative air quality, not absolute gas concentrations, trend analysis makes it possible to assess your environmental quality consistently. Cloud logs also indicate that the measurements were uploaded in a regular fashion at the specified sampling interval. There were slight signal disturbances for UAV movements; however, no data loss was found. The overall results corroborate reliable onboard sensing and continuous real-time cloud transmission with realistic flight conditions.

### C. Communication Performance Results

Communication-layer metrics were monitored and recorded via the ThingSpeak telemetry platform during the flight study. The performance of the uplink communication under different signal conditions was analyzed by measuring latency, with the majority of the transmission requests resulting in an HTTP status code 200. The MTEL mobile network was the one used while testing.

The uplink rate was roughly calculated from the URL size and the measured latency, thus showing how the quality of the wireless signal has a great impact on the data transmission performance.

The HTTP upload latency measured during UAV flight is shown in Fig. 7.

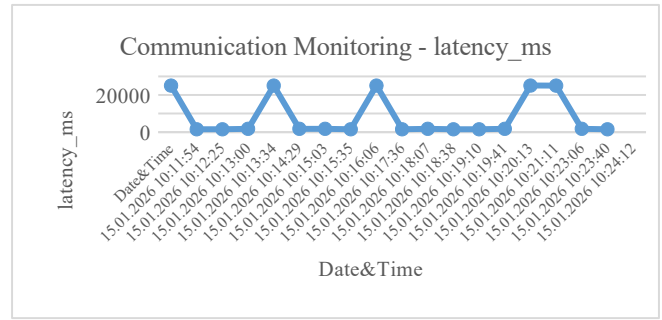


Fig. 7. Measured HTTP transaction latency for each data upload cycle during the UAV flight experiment

Latency was observed to be between approximately 1 s and 20–25 s, depending on varying signal conditions and network load, as can be expected for LTE-connected UAV operation. No missing or zero-latency events were found, indicating uninterrupted connectivity. Despite these variations in latency, data delivery to the cloud platform was successful, thereby confirming the reliability of the transmission during flight. Overall, the latency behaviour supports the use of the system in environmental observation and situational awareness contexts, but missions requiring immediate response might be more sensitive to delay variations.

The estimated uplink rate shown in Fig. 8 remains relatively stable throughout the flight.

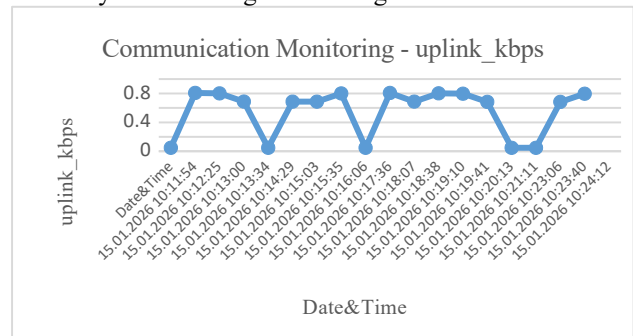


Fig. 8. Estimated uplink data rate (kbps) for each data upload cycle during the UAV flight experiment

Short-term drops in uplink rate correspond to latency increases, after which performance recovers, indicating no persistent link interruptions. On average, the uplink performance measured demonstrates that the LTE-based communication link delivers proper and uninterrupted data throughput for periodic sensor data transfer to the cloud platform during UAV operation.

The MTEL mobile operator RSSI (dBm) readings calculated from the AT+CSQ command are shown in Fig. 9. Initial -999 dBm readings represent temporary firmware placeholders before valid signal reports. Right after initialization, RSSI readings are valid and around -51 dBm steady throughout the rest of the flight.

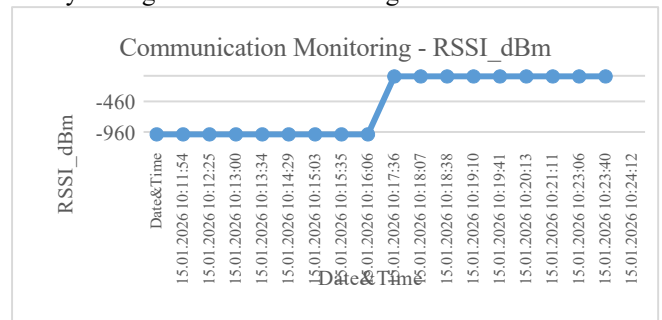


Fig. 9. Measured RSSI values during UAV flight

This results in stable LTE signal reception and consistency of network coverage around UAV operation. No signal loss or long-term degradation was observed, confirming stable LTE coverage during UAV mobility.

The recorded LTE operating bands during the flight are shown in Fig. 10.

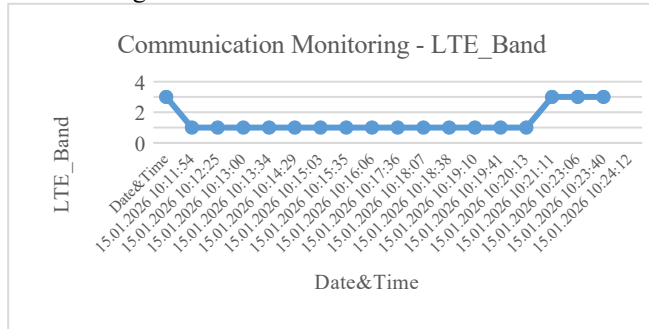


Fig. 10. Recorded LTE operating bands during UAV flight using MTEL cellular network

The SIM module initially operated on LTE Band 3 (1800 MHz). As the flight progressed, the module automatically switched to LTE Band 1 (2100 MHz) and later reconnected to Band 3 toward the end of the experiment. The cellular data signals related to the drone flight and measurement point locations show the coexistence of Band 1 (2100 MHz) and Band 3 (1800 MHz) at this phase, which is the expected LTE cell selection and reselection behavior during UAV mobility. The band changes seen demonstrate that the UAV was allowed to keep multisector LTE coverage, and thus the connectivity was not interrupted at any time during the entire flight.

Fig. 11 illustrates the HTTP response codes recorded after each data upload via the +HTTPACTION command. The predominance of status code 200 confirms that the ThingSpeak cloud service correctly handled the incoming data. Consequently, dependable transmission of application-layer data was achieved during the entire experimental period. Occasional status code 0 events reflect temporary LTE latency or buffering delays rather than loss of connectivity. Importantly, once such events unfold, subsequent transmissions return valid status codes as scheduled, demonstrating automatic link recovery. A final status code 300 indicates temporary server redirection due to consecutive request handling. Overall, monitoring the HTTP status has revealed that the LTE-based communication subsystem was able to deliver excellent end-to-end performance. Only a few short delays occurred, which did not disrupt the continuous streaming of the real-time data updates from the cloud.

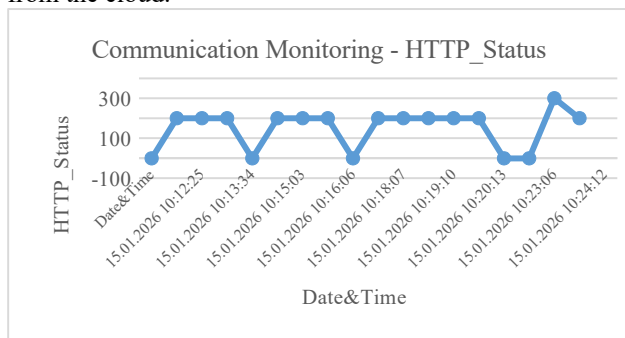


Fig. 11. HTTP response status codes recorded during UAV data transmission to the ThingSpeak cloud platform

## VII. CONCLUSION

In the present work, we proposed a UAV-assisted framework to achieve real-time environmental data transmission using a low-cost onboard sensing and communication module, and a cloud-based visualization system. The proposed system demonstrates the integration of sensor-based environmental sensing with onboard data processing, wireless communications, and cloud-based visualization in a compact yet lightweight system for easy deployment of UAVs. With real-world flight experiments, it was found that it is actually possible to collect reliable sensor data during the flight of a UAV. Remote observation in near-real time became feasible. In the future, the system can be further upgraded through the integration of additional sensors and the use of more precise measurement devices. Furthermore, there is an opportunity to research and implement advanced communication technologies, such as 5G networks or low-energy wide-area communication protocols, in order to ensure greater coverage, improved efficiency, and increased scalability of the system. Further investigation under different environmental and operational scenarios and over longer operating time frames would yield valuable results. The proposed architecture is suitable for various real-time monitoring applications.

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