

LITERATURE REVIEW ON AUTONOMOUS AIRBORNE COMMUNICATION NETWORKS FOR DATA EXCHANGE

Mrs. G. Soujanya¹, Arun A², Athish Prasad Raj³, Madhan K, Vishwanath A V⁵

Asst. Professor Dept. of EE-VLSI D&T Sri Krishna Institute of Technology, Bengaluru, India¹⁻⁴

Dept. of ECE, Sri Krishna Institute of Technology Bengaluru, India⁵

Abstract: Flying ad hoc networks (FANETs) enable unmanned aerial vehicles (UAVs) to exchange information without relying exclusively on fixed infrastructure. The literature identifies high mobility, rapidly changing topology, intermittent wireless links, routing overhead, energy constraints, reliability, and security as major airborne-network issues. This review synthesizes the literature supplied with the project together with additional verified studies on FANET routing, collaborative UAV communication, UAV-assisted mesh relaying, communication standardization, packet reliability, and recent routing taxonomies. The review compares architectural focus, routing strategy, reliability mechanisms, validation approach, and practical limitations. A recurring gap is identified between algorithms or simulation-based studies and lightweight embedded implementation. This gap is directly relevant to practical airborne communication systems using multi-hop forwarding, acknowledgement/retransmission, dynamic rerouting, node-failure handling, and network monitoring. The review establishes the research background and provides a basis for subsequent prototype validation.

Index Terms: Airborne networks, dynamic routing, FANET, multi-hop networking, packet reliability, routing protocols, UAV communication, wireless mesh networks.

I. INTRODUCTION

Unmanned aerial vehicles are increasingly used as mobile sensing, monitoring, communication, and cooperative platforms. When multiple aerial nodes exchange information while moving, the network topology can change much faster than in many terrestrial ad-hoc systems. FANET research therefore treats mobility, three-dimensional movement, link stability, routing, quality of service, energy use, and communication reliability as central design issues. A major IEEE Access survey describes FANET routing as a distinct problem because UAV mobility and mission-dependent movement make route maintenance difficult. More recent reviews classify FANET routing into topology-based, position-based, hierarchical, multipath, delay-tolerant, swarm-based, and learning-assisted families [1]–[3], [12].

Collaborative UAV research also emphasizes communication and control as coupled requirements. Javaid *et al.* review multi-UAV collaboration and identify communication, coordination, autonomy, and reliability as important requirements for cooperative missions [4]. Vegni *et al.* discuss the need for communication technologies and standards that support direct UAV-to-UAV information exchange and near-real-time coordination [5]. These studies establish the broader motivation for an airborne communication architecture in which aircraft nodes can exchange data directly or through neighboring nodes.

II. SCOPE AND REVIEW METHOD

The review combines the literature listed in the supplied project literature document with additional publications located through academic web searches. The supplied document contributes the original comparison dimensions—title, year, author, key idea, limitation, and relevance to the project—and contains seven principal literature entries covering collaborative UAV communication, lightweight AES, UAV communication technologies, packet error probability and throughput, routing protocols, UAV swarm communication issues, and UAV-assisted mesh networking.

The review focuses on six technical dimensions: network architecture and collaboration; routing and topology adaptation; packet reliability and retransmission; wireless technology and standardization; relay and multi-hop communication; and embedded implementation and validation. The objective is to compare what each study contributes and where its scope differs from the hardware-oriented project under development, rather than to assign a ranking.

III. FOUNDATIONAL FANET AND UAV COMMUNICATION LITERATURE

A. FANET Characteristics and Routing: Bekmezci, Sahingoz, and Temel presented an early comprehensive FANET survey covering architecture, mobility, routing, and applications [1]. A later IEEE Access survey by Arafat and Moh examined routing protocols from a broader UAV-network perspective and discussed constraints introduced by dynamic topology and mobility [6]. Almansor *et al.* provide a 2024 taxonomy covering topology-based, position-based, hierarchical, swarm-based, DTN, and learning-oriented routing approaches and identify open research issues [2]. Kaur *et al.* provide a 2026 systematic review of FANET mobility and routing literature, emphasizing how mobility models influence routing stability and network performance [3].

B. Collaborative UAV Communication and Control: Javaid *et al.* review communication and control requirements for collaborative UAVs and discuss multi-UAV coordination and swarm applications [4]. The work is relevant to multi-node airborne networks because communication is treated as part of cooperative operation. Its scope is primarily system-level collaboration rather than detailed packet framing, embedded routing state, or low-cost radio-driver implementation.

C. UAV-Assisted Mesh and Relay Communication: Esrafilian, Gangula, and Gesbert investigated autonomous UAV-aided mesh wireless networks in which a UAV acts as a smart relay to improve connectivity. Their work uses multi-hop relaying and self-organization and reports a real-life experimental setup [7], [10]. This is closely related to the intermediate-node concept in the proposed project. The project, however, focuses on packet-level forwarding, route adaptation, node-failure handling, and an embedded aircraft-node implementation.

D. Communication Technologies and Standardization: Vegni *et al.* argue that effective UAV networking requires communication technologies capable of supporting direct UAV-to-UAV information exchange and cooperative tasks such as swarm formation and collision avoidance [5]. The study highlights the importance of selecting communication technologies appropriate to airborne networking rather than assuming a conventional terrestrial stack is sufficient.

IV. RELIABILITY, ROUTING, AND SECURITY LITERATURE

A. Packet Reliability and Low-Latency Communication: Wang *et al.* analyze average packet error probability and effective throughput for UAV control links under free-space and three-dimensional channel models. The work uses short packets for low-latency control and verifies analytical results with Monte-Carlo simulation [8]. It is useful for identifying packet reliability and latency as measurable communication parameters. Its emphasis is analytical rather than on implementing acknowledgement and retransmission logic on a small microcontroller.

B. Routing Protocol Families: FANET literature includes proactive, reactive, hybrid, geographic, hierarchical, multipath, and delay-tolerant strategies. AODV and DSR discover routes on demand, whereas proactive approaches maintain routing information. Position-based methods use geographical information and can be attractive in highly mobile networks, but depend on position accuracy and neighbor information [2], [3], [6], [11]. Protocol suitability is therefore application- and hardware-dependent.

C. Lightweight Security: Cecchinato *et al.* studied secure real-time multimedia transmission from low-cost UAV platforms using lightweight AES encryption at the application layer [9]. Their work shows that security can be integrated into resource-limited UAV communication, but its focus is multimedia transmission and key management. For the present telemetry-oriented project, security is better treated as a future extension unless it is experimentally demonstrated.

D. Recent Routing Research: Recent reviews show continued movement toward intelligent and adaptive routing. The 2024 review classifies learning-assisted and deep-reinforcement-learning approaches alongside topology, position, hierarchical, swarm, and DTN methods [2]. The 2026 systematic review similarly identifies proactive, reactive, geographic, multipath, secure, hierarchical, bio-inspired, position-based, DTN, and cluster-based families [3]. This confirms that FANET routing remains active while highlighting the implementation-complexity issue for embedded platforms.

V. COMPARATIVE LITERATURE ANALYSIS

Table I summarizes the principal studies used in this review. The comparison describes scope and limitations without assigning a numerical ranking. The project-relevance column identifies how the literature informs the proposed airborne communication architecture.

TABLE I. COMPARISON OF PRINCIPAL LITERATURE STUDIES USED IN THE REVIEW

Study	Year	Main focus	Contribution	Limitation / scope	Project relevance
Bekmezci <i>et al.</i> [1]	2013	FANET foundations	Architecture, mobility, routing and applications.	Broad survey; not project-specific embedded radio.	Foundational FANET requirements.
Esrafilian <i>et al.</i> [7]	2018	UAV relay / mesh	UAV smart relay to improve mesh connectivity; real-life validation.	Emphasis on relay placement and connectivity optimization.	Supports intermediate-node and multi-hop concepts.
Arafat and Moh [6]	2019	Routing taxonomy	Surveys routing constraints, mobility models and protocol families.	Survey-level treatment.	Supports routing design.
Wang <i>et al.</i> [8]	2021	Reliability / URLLC	Models packet error probability and effective throughput for UAV control links.	Analytical and simulation-based evaluation.	Supports reliability metrics and retransmission study.
Vegni <i>et al.</i> [5]	2021	Technologies / standards	Examines UAV-to-UAV communication needs and standardization.	Technology/standards focus rather than embedded prototype.	Supports wireless-link selection.
Javaid <i>et al.</i> [4]	2023	Collaboration / control	Reviews communication, coordination and control for multi-UAV systems.	High-level collaborative perspective.	Supports multi-node coordination.
Cecchinato <i>et al.</i> [9]	2023	Secure real-time communication	Lightweight AES for real-time UAV multimedia transmission.	Multimedia/security and key-management focus.	Possible future security direction.
Almansor <i>et al.</i> [2]	2024	Routing taxonomy / gaps	Topology, position, hierarchical, swarm, DTN and learning-based routing.	Review rather than hardware implementation.	Supports current routing gap analysis.
Kaur <i>et al.</i> [3]	2026	Systematic routing review	PRISMA-based review of 192 included studies and multiple routing families.	Literature synthesis, not physical validation.	Provides current research context.

VI. COMPARISON WITH THE PROPOSED EMBEDDED SYSTEM

The project differs from literature that is primarily analytical, simulation-based, or focused on high-level swarm control. The proposed architecture is hardware-oriented: each aircraft node uses an STM32F411CEU6 controller and an nRF24L01+PA+LNA wireless interface, with a NEO-M8N GNSS module for position information. The design includes direct and multi-hop communication, intermediate-node forwarding, packet acknowledgement and retransmission, dynamic rerouting, node-failure handling, and a ground station connected to MATLAB for monitoring.

This is an architectural comparison, not a claim that the prototype has already exceeded published systems. Complete multi-node hardware integration and quantitative real-time validation are required before numerical claims about range, packet delivery ratio, latency, throughput, or recovery time can be made. Table II compares the feature-level trends in the literature with the proposed project direction.

TABLE II. FEATURE-LEVEL COMPARISON BETWEEN LITERATURE TRENDS AND THE PROPOSED PROJECT DIRECTION

Feature	Literature trend	Proposed project direction
Network architecture	FANET, UAV mesh, relay, swarm and UAV-ground architectures.	Multiple aircraft nodes with ground station and direct/multi-hop paths.
Routing	AODV/DSR, OLSR/DSDV, geographic, hierarchical, multipath, DTN and learning-based methods.	Lightweight dynamic routing/fallback logic intended for embedded execution.
Reliability	Packet error models, QoS analysis, route maintenance and retransmission concepts.	ACK, retransmission and node-failure handling are explicit design functions.
Position information	Many geographic approaches use UAV position and neighbor information.	NEO-M8N GNSS provides aircraft position information.
Wireless implementation	Cellular/Wi-Fi/mesh concepts, UAV relay platforms and simulation models.	nRF24L01+PA+LNA connected to STM32F411CEU6.
Validation	Mixture of simulation, analytical models and selected physical experiments.	Module-level validation and preliminary MATLAB visualization; full multi-node validation remains to be completed.
Security	Security and lightweight encryption studied in separate UAV literature.	Potential future extension; not claimed as implemented unless experimentally demonstrated.

VII. RESEARCH GAP ANALYSIS

- 1) *Simulation-to-hardware gap.* Much FANET research evaluates routing and communication through mathematical analysis or network simulation. Embedded execution adds processor time, memory, radio-driver behavior, packet-buffer size, interrupt handling, and power constraints. The proposed project addresses this gap at prototype level using an STM32 controller.
- 2) *Routing overhead in constrained nodes.* Conventional MANET/FANET protocols can require route tables, route discovery, control messages, neighbor information, or periodic updates. Recent surveys show many protocol families, but suitability remains application- and hardware-dependent [2], [3]. The project therefore targets lightweight routing and fallback behavior rather than reproducing a resource-intensive routing stack.
- 3) *Dynamic topology and node failure.* UAV movement can break links and change neighbor relationships. Literature repeatedly identifies topology change and link disruption as central FANET problems [1]–[4]. A practical embedded network needs a mechanism to recognize failed communication and select another available path. The proposed design explicitly includes acknowledgement, retransmission, forwarding, and node-failure handling.
- 4) *Position-aware networking.* Geographic information is widely used in position-based FANET routing [2], [6]. The proposed system includes a GNSS receiver, creating a hardware path for incorporating node position into route-selection or monitoring logic. Accuracy and update performance must be experimentally characterized.
- 5) *Quantitative hardware validation.* Literature provides analytical and simulation metrics such as packet error probability, throughput, delay, and routing overhead [8]. The project should measure corresponding quantities on physical nodes. Until those experiments are completed, unsupported numerical claims should be avoided.

VIII. RESEARCH OPPORTUNITIES

The literature suggests several practical directions. Lightweight routing can use local neighbor state and explicit failure detection so route recovery does not require large routing tables. GNSS information can support position-aware forwarding. Packet sequence numbers, acknowledgements, and retransmission timeouts can be evaluated under controlled distance and topology conditions. Multiple aircraft nodes can be used to study route changes when an intermediate node is intentionally removed.

A further opportunity is to compare the embedded implementation against selected protocol baselines using the same conditions. Useful metrics include packet delivery ratio, end-to-end latency, throughput, retransmission count, route recovery time, node availability, and energy consumption. These measurements would convert the current preliminary implementation into a quantitatively validated communication system.

IX. PROPOSED RESEARCH FRAMEWORK

The proposed framework can be organized into six layers:

(1) aircraft-node hardware using STM32F411CEU6, nRF24L01+PA+LNA and GNSS; (2) packet layer containing source, destination, sequence and payload information; (3) reliability layer implementing acknowledgement and retransmission; (4) forwarding/routing layer selecting direct or intermediate-node paths; (5) failure-handling layer identifying unavailable links and initiating fallback behavior; and (6) ground-station/visualization layer transferring network information to MATLAB.

This framework is consistent with the literature emphasis on adaptive routing, reliable communication, position information, and multi-node cooperation, while maintaining a clear embedded-implementation focus. It provides a staged experimental path from individual interface verification to two-node communication, multi-hop forwarding, node-failure testing, GNSS integration, and complete network validation.

X. EXPECTED EVALUATION PARAMETERS

Table III lists the recommended quantitative parameters for the next stage of experimental validation.

TABLE III. RECOMMENDED QUANTITATIVE PARAMETERS FOR EXPERIMENTAL VALIDATION

Parameter	Purpose	Suggested measurement
Packet delivery ratio	Measures successful delivery reliability.	Received packets / transmitted packets $\times$ 100.
End-to-end latency	Measures communication delay.	Timestamp difference between packet transmission and final reception.
Throughput	Measures useful data delivered per unit time.	Successfully received payload bits per second.
Retransmission count	Measures recovery effort.	Number of retries per packet or test interval.
Route recovery time	Measures response to node/link failure.	Time from detected failure to successful alternate-path delivery.
Communication range	Characterizes physical link availability.	Maximum tested distance under defined conditions.
Energy consumption	Evaluates practical endurance.	Current/voltage measurements during communication states.

XI. CONCLUSION

The literature confirms that airborne ad-hoc communication is a multidisciplinary problem involving mobility, topology variation, routing, wireless technology, reliability, position information, and increasingly security and intelligent adaptation. Foundational surveys established the FANET problem space, while later studies expanded routing taxonomies, collaborative UAV communication, UAV-assisted relaying, communication standardization, and packet-reliability analysis [1]–[9]. Recent systematic reviews show that FANET routing remains active, with research on position-aware, multipath, learning-assisted, secure, hierarchical, and delay-tolerant approaches [2], [3].

For the present project, the main research opportunity is the transition from algorithmic and simulation-oriented literature toward a low-cost embedded multi-node implementation. The proposed STM32F411CEU6 and nRF24L01-based architecture provides a practical platform for studying direct communication, multi-hop forwarding, acknowledgement/retransmission, dynamic rerouting, node-failure handling, GNSS-assisted information, and ground-

station monitoring. The literature review supports this direction while making clear that complete hardware integration and quantitative performance validation are necessary before final performance claims are made.

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