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ARCHITECTURAL FRAMEWORK OF A MISSION-CENTRIC UAV COMMUNICATION PLATFORM FOR TACTICAL OPERATIONS AND TOC INTEGRATION

АРХІТЕКТУРНИЙ ФРЕЙМВОРК МІСІЄ-ОРІЄНТОВАНОЇ КОМУНІКАЦІЙНОЇ ПЛАТФОРМИ БПЛА ДЛЯ ТАКТИЧНИХ ОПЕРАЦІЙ ТА ІНТЕГРАЦІЇ З ТОЦ

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Abstract. *In the rapidly evolving landscape of modern military operations and emergency response, Unmanned Aerial Vehicles (UAVs) have transitioned from niche tools to indispensable assets for real-time intelligence, surveillance, and reconnaissance (ISR). However, the exponential growth in UAV deployments across complex mission theaters presents significant challenges for Tactical Operations Centers (TOCs), particularly concerning the management of high-volume, mission-critical data streams under severe resource and bandwidth constraints. This paper proposes a comprehensive modular and scalable communication platform specifically engineered to optimize the interaction between heterogeneous UAV swarms and centralized TOC infrastructures.*

The proposed framework introduces a multi-layered architectural approach that includes advanced stream classification, dynamic data prioritization mechanisms, and latency-aware routing protocols. Unlike traditional Best-Effort delivery models, this system incorporates mission-aware policies that utilize semantic analysis of data packets to ensure that high-priority tactical information—such as target identification or immediate threat alerts—is processed and delivered with minimal jitter, even in contested electromagnetic environments. The integration logic is tailored to the TOC-centric workflow, ensuring seamless data fusion from multiple aerial nodes into a unified situational awareness picture.

Drawing upon established doctrinal frameworks, NATO interoperability standards (such as STANAG series), and cutting-edge innovations in U-space management, the architecture leverages tactical cloud systems and edge computing to offload processing tasks from the ground station. Special attention is paid to the resilience of the system against cyber-physical threats and electronic warfare, ensuring communication continuity during GPS-denied or degraded signal phases. By establishing a unified communication model tailored to the rigorous requirements of joint and multi-domain operations, this framework provides a robust foundation for scalable field implementation, facilitating superior decision-making without the immediate necessity for extensive simulation-based pre-validation.

Анотація. *У сучасному ландшафті військових операцій та реагування на надзвичайні ситуації роль безпілотних літальних апаратів (БпЛА) стала критично важливою для забезпечення розвідки, спостереження та збору даних у реальному часі. Проте експоненціальне зростання кількості розгорнутих БпЛА створює значні виклики для тактичних оперативних центрів (ТОЦ), зокрема у сфері управління великими обсягами критично важливих даних в умовах обмежених ресурсів та пропускної здатності каналів зв'язку. У даній роботі запропоновано модульну масштабовану комунікаційну платформу, розроблену для оптимізації взаємодії між БпЛА та ТОЦ.*

Запропонована структура охоплює ключові архітектурні компоненти, включаючи класифікацію потоків, механізми пріоритезації даних, маршрутизацію з урахуванням затримок та логіку інтеграції, орієнтовану на потреби оперативних центрів. Система включає політики, що враховують специфіку місії, для гарантування того, що найважливіші пакети даних обробляються та доставляються першочергово, що підвищує оперативну *ефективність та рівень ситуаційної обізнаності. Базуючись на доктринальних засадах, стандартах НАТО та технологічних інноваціях у сферах U-space, машинного навчання та тактичних хмарних систем, запропонована архітектура спрямована на підтримку спільних, коаліційних та багатодоменних операцій.*

Концептуальний дизайн також враховує стійкість до кіберзагроз та деградації систем, забезпечуючи безперервність зв'язку під час динамічних фаз місії, включаючи умови радіоелектронної боротьби. Шляхом встановлення уніфікованої моделі зв'язку, адаптованої до вимог ТОЦ, цей фреймворк створює основу для масштабованого впровадження в різних сценаріях місій без повної залежності від валідації на основі симуляцій.
Keywords: architectural framework, command systems, communication prioritization, TOC integration, UAV communication, unmanned systems coordination, situational awareness, tactical cloud.

Ключові слова: архітектурний фреймворк, системи управління, пріоритезація зв'язку, інтеграція з ТОЦ, комунікація БпЛА, координація безпілотних систем, ситуаційна обізнаність, тактична хмара.

I. INTRODUCTION

Inefficiencies in UAV-to-command communication have the potential to compromise mission success, particularly when Tactical Operations Centers (TOCs) are required to process high volumes of UAV-generated data during fast-paced operations. As the operational tempo and technological complexity of modern conflict zones evolve, the integration of robust and scalable communication platforms has become a strategic imperative. UAVs have emerged as indispensable assets for intelligence, surveillance, reconnaissance (ISR), target acquisition, and real-time mission updates across military and emergency domains [1], [4], [16]. However, the sheer volume of sensor feeds, telemetry, and video transmissions from UAV fleets often exceeds the bandwidth and processing capabilities of TOCs, creating bottlenecks in operational decision-making [5], [11].

The mission-critical nature of tactical operations demands that TOC processing units distinguish, prioritize, and route data streams based on situational urgency and resource availability [3], [6], [14]. Traditional communication models typically treat all incoming UAV data uniformly, failing to differentiate between life-saving intelligence and routine telemetry updates. This lack of mission awareness within the communication layer not only delays the processing of essential data but also overwhelms network buffers, leading to packet loss, latency spikes, and degraded situational awareness [2], [4], [10].

To address these limitations, this paper proposes an architectural framework centered on a mission-centric philosophy. The goal is to develop a communication platform capable of organizing, prioritizing, and routing UAV data streams in a manner that reflects operational urgency and TOC-specific constraints. By building on NATO doctrines for Unmanned Aircraft Systems (UAS) [6], as well as joint doctrine publications for coalition operations [12], the proposed framework aligns communication flow with mission hierarchy and system capabilities. Unlike approaches that depend heavily on artificial intelligence or simulations, this design emphasizes system modularity, TOC integration, and cross-layer policy enforcement to maintain agility in diverse mission environments [7], [9], [13].

Additionally, the proposed model draws on lessons learned from tactical cloud service deployments [12], military wildfire coordination networks [10], and optimization strategies for UAV routing in urban and hostile terrain [7], [9], [15]. A layered communication architecture is envisioned, incorporating stream classification modules, mission-aware prioritization engines, and fault-tolerant routing logic adaptable to mission type and command objectives [8], [11], [16]. This approach also integrates cybersecurity provisions for safeguarding UAV-to-TOC channels from potential cyber-attacks or communication spoofing attempts [2], [14].

Ultimately, the proposed platform aims to provide a flexible, doctrine-compliant solution to the persistent challenge of integrating UAV systems into TOC workflows without overwhelming limited infrastructure. It represents a step toward developing unified, resilient, and intelligent communication infrastructures suitable for both military and civil crisis management operations.

II. SYSTEM ARCHITECTURE AND COMMUNICATION LOGIC

The proposed communication platform adopts a modular and mission-oriented architectural design that enables Tactical Operations Centers (TOCs) to effectively manage data streams from diverse Unmanned Aerial Vehicle (UAV) sources. The architecture is structured around four primary layers: data acquisition, prioritization logic, communication control, and integration with TOC mission systems. Each layer performs distinct but interdependent functions that ensure timely, secure, and context-aware delivery of critical information to command staff.

At the foundation lies the data acquisition layer, which aggregates real-time telemetry, video feeds, and sensor packets from UAVs operating within a designated mission zone. This layer interfaces with UAV onboard systems and transmits data via secured tactical communication links to the TOC network [1], [4], [7]. The integrity and consistency of this inflow are critical, especially when operating in contested environments or in joint missions where the interoperability of platforms must be ensured [6], [11]. The prioritization logic layer acts as the system's core engine, evaluating incoming data streams based on predefined mission rules, operational urgency, and threat-level assessments. For instance, a live video feed from a UAV monitoring hostile troop movements near a civilian zone would receive higher priority over periodic UAV health status updates. This process utilizes configurable mission profiles, derived from doctrinal guidelines such as NATO's AJP-21 [6], to assign weights and route streams accordingly [11], [12]. Such classification schemes have proven effective in past scenarios involving natural disaster response, where UAVs were used to assess infrastructure damage and identify survivors [10], [14].

To maintain robustness in degraded environments, the communication control layer employs adaptive routing algorithms and flow management techniques. These methods minimize latency and prevent packet loss by continuously assessing bandwidth conditions, node health, and link stability [2], [3], [5]. Unlike static communication protocols, the platform's routing mechanism can reroute high-priority data through alternate paths or reduce bandwidth usage by buffering lower-priority packets [13], [15]. Such flexibility is crucial during periods of network congestion or electromagnetic interference, which often accompany real-world military engagements [8].

Cybersecurity is another key feature embedded within this layer. The platform includes access control modules, encryption protocols, and anomaly detection routines that collectively shield TOC systems from unauthorized access, spoofed UAV data injection, or denial-of-service attacks [2], [4]. These mechanisms align with recommendations issued in recent Department of Defence and AFCEA cyber doctrine updates emphasizing the protection of UAV channels in near-peer conflict scenarios [12], [16].

At the top of the stack, the TOC integration layer synchronizes filtered and prioritized data streams with operational dashboards, mission management software, and decision-support systems. This integration ensures that commanders receive the most relevant data in near-real-time, enabling precise coordination of ground forces, air support, and logistics [9], [10]. Seamless integration has been identified as essential for effective command control in recent NATO-led exercises and wildfire combat operations, where response speed is measured in seconds [10], [14].

Importantly, the architecture accommodates scalability and flexibility. Whether supporting a small forward-operating unit with limited network resources or a fully equipped joint operations center, the system can adapt its performance parameters and priority rules accordingly. The layered design also allows future upgrades, including integration with satellite relay nodes or AI-based mission analytics, without disrupting baseline functionality [5], [13], [15].

This architectural framework builds upon established best practices from both the military and civilian UAV domains. For example, lessons learned from the FAA's UTM Concept of Operations and SESAR's U-space initiatives provided critical insight into airspace management, stream deconfliction, and ground communication efficiency [13], [15]. Additionally, experience from coalition deployments during Operation Iron Guardian and various NATO exercises informed the design's emphasis on interoperability and dynamic command synchronization [1], [6].

The proposed architecture presents a balanced blend of doctrinal compliance, operational responsiveness, and technical scalability. It addresses longstanding challenges in UAV-to-TOC communication by introducing an adaptive framework that prioritizes mission-critical information and supports effective decision-making even under severe resource constraints.

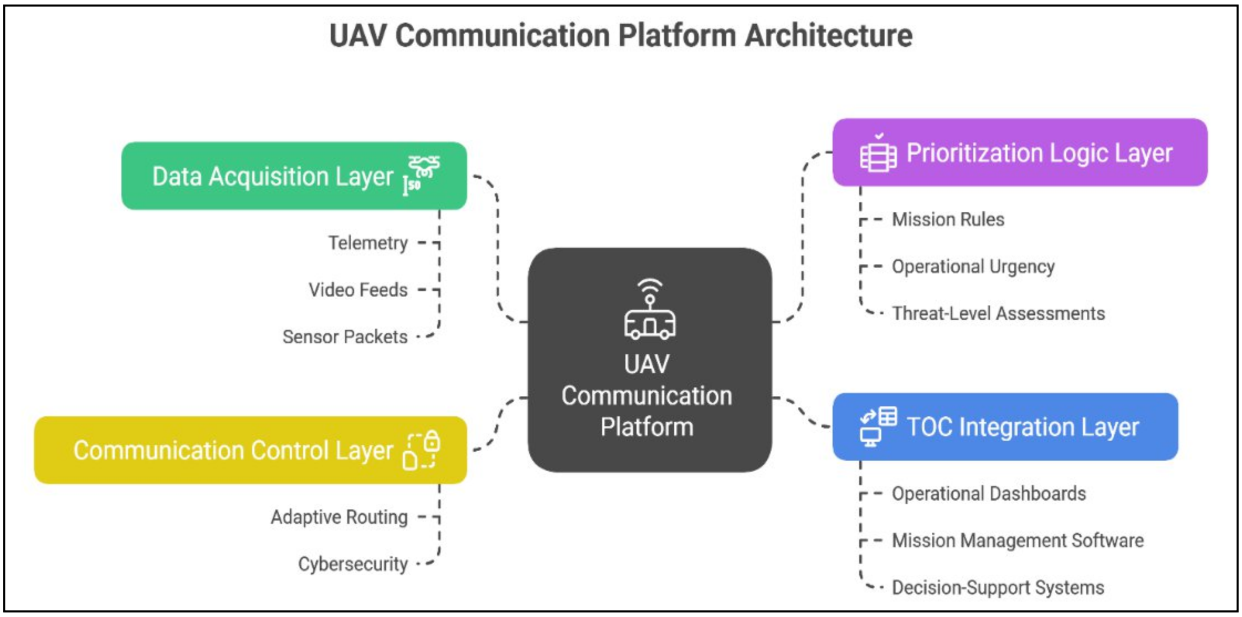

Fig. 1 – Layered Architecture of the Mission-Centric UAV Communication Platform

Figure 1 illustrates the modular architecture of the proposed UAV communication platform designed for Tactical Operations Center (TOC) integration. The system is composed of four core layers: the Data Acquisition Layer, which collects telemetry, video, and sensor data from UAVs; the Prioritization Logic Layer, which classifies and ranks data streams based on mission rules, operational urgency, and threat-level assessments; the Communication Control Layer, responsible for adaptive routing and enforcing cybersecurity mechanisms; and the TOC Integration Layer, which delivers processed data to decision-support systems, operational dashboards, and mission management tools. This layered framework ensures secure, efficient, and mission-relevant data flow from UAV assets to TOC personnel operating under dynamic battlefield or crisis conditions.

III. OPERATIONAL USE CASE

The operational effectiveness of any UAV communication platform lies not only in its design but also in its capability to function reliably within real-time tactical missions. The proposed platform demonstrates its value during joint operations involving multiple UAVs transmitting live data to a Tactical Operations Center (TOC) under pressure to deliver immediate situational awareness and mission coordination. This section outlines a realistic operational use case that reflects both the architectural integrity and mission-centric adaptability of the proposed system.

Consider a multinational joint task force deployed in a semi-urban conflict zone tasked with reconnaissance, logistics monitoring, and early warning surveillance. The area of operation is characterized by limited bandwidth, intermittent connectivity, and hostile signal environments. Within this scenario, several UAVs are dispatched to cover segmented surveillance zones, each collecting telemetry data, thermal imagery, high-resolution video, and sensor inputs relevant to ground troop movement, enemy positions, and environmental hazards [1], [4], [5].

Upon data transmission initiation, the Data Acquisition Layer of the platform aggregates all incoming streams and immediately passes them to the Prioritization Logic Layer. This second layer applies mission urgency metrics and cross-references predefined operational rules to rank the data flow. For example, live videos of unidentified armored movement near a friendly convoy will be marked as high priority based on the threat matrix assigned by the mission command protocol [6], [11].

Next, the Communication Control Layer performs secure routing and bandwidth allocation. It dynamically assigns channels with the least latency impact, while also managing authentication and encryption of mission-critical packets [2], [3], [7]. This routing logic is informed by the platform's resource-awareness engine that monitors CPU usage, memory capacity, and network performance indicators. In this case, if the TOC is experiencing congestion, lower-priority sensor logs are buffered and sent in delayed batches to prevent overload while the more urgent telemetry or visual stream proceeds with guaranteed minimal packet loss [5], [9], [12].

The final interaction occurs within the TOC Integration Layer, where the ranked data is mapped to command interfaces. Intelligence officers utilize real-time video and alerts through mission dashboards, decision support systems, and augmented visualization tools [8], [13], [15]. This interface ensures seamless situational updates and enables decisions such as rerouting supply vehicles or deploying rapid response teams based on the interpreted UAV data [14], [16].

This operational use case underscores how the layered architecture enhances mission responsiveness by systematically reducing latency, enforcing data relevance, and mitigating resource constraints. Compared to traditional systems, where data is often processed sequentially or without intelligent routing logic, the proposed platform delivers superior agility in real-world scenarios. Moreover, its alignment with standardized doctrinal frameworks like AJP-21 and FAA UTM ConOps improves its adaptability across NATO and allied mission structures [6], [15].

By embedding prioritization and interoperability at the system core, the communication platform positions itself as a critical asset for managing uncertainty in combat and crisis operations. Whether responding to wildfire outbreaks, urban combat, or humanitarian relief, the platform supports a flexible, reliable communication pipeline capable of scaling with mission demands. The case exemplifies not only the technical soundness of the design but also its operational value in missions where timely information can shape strategic outcomes.

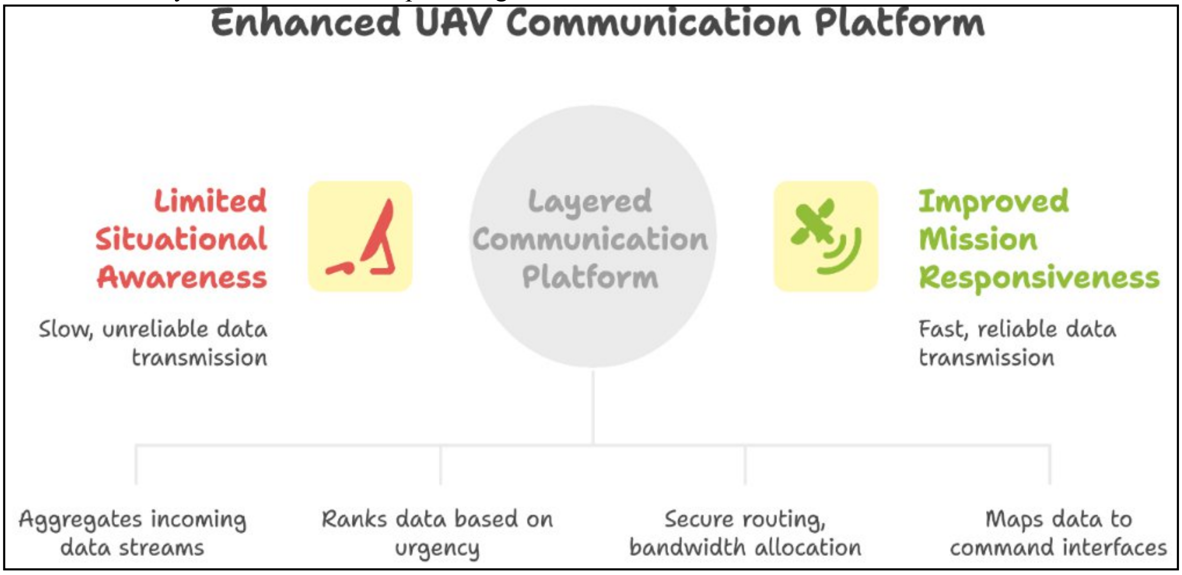

Fig. 2 – Enhanced UAV Communication Platform for Operational Responsiveness

This figure illustrates how the proposed layered UAV communication platform bridges the gap between limited situational awareness and improved mission responsiveness. On the left, systems characterized by slow and unreliable data transmission are linked to poor operational outcomes due to their inability to process incoming data efficiently. The central layered platform mitigates this by aggregating data streams, applying urgency-based prioritization, securing routing paths, and allocating bandwidth appropriately. On the right, the benefits of this approach are highlighted through fast and reliable data transmission that empowers Tactical Operations Centers (TOCs) to make timely and accurate decisions during missions. This visualization reinforces how structural improvements within the communication framework can directly translate into enhanced real-time operational effectiveness.

IV. INTEROPERABILITY AND INTEGRATION REQUIREMENTS

In contemporary military and emergency response environments, the efficiency of a UAV communication platform depends not only on its internal capabilities but also on how effectively it integrates with surrounding systems. Interoperability is essential to ensure seamless communication between diverse UAV types, Tactical Operations Centers (TOCs), ground-based control stations, and coalition force technologies. The proposed architecture must align with national and NATO standards to allow compatibility in joint and multinational missions [1], [6], [11].

One major requirement is the standardization of communication protocols, data formats, and encryption schemes. Without unified structures, data streams from different UAV manufacturers or defence units may require extensive translation layers, causing delays and inefficiencies. U-Space and UTM (Unmanned Traffic Management) frameworks, such as those defined by SESAR JU and FAA, underscore the need for common interface definitions and airspace coordination protocols [8], [13], [15]. These standards help ensure that UAVs can securely transmit telemetry, video feeds, and sensor data across national borders and operational theaters.

A second critical consideration is system modularity. As defence technology rapidly evolves, integration with emerging systems like battlefield decision-support software, AI-enhanced targeting modules, or automated threat detection platforms must occur without overhauling the entire communication infrastructure. The platform must be designed in layered modules that allow upgrading one function, such as routing or prioritization, without disrupting others [2], [5], [10].

Cybersecurity protocols are a third essential element. The communication platform must be resilient to threats such as data interception, spoofing, and denial-of-service attacks. Studies show that encryption and routing redundancy alone are insufficient unless aligned with mission-specific authentication policies and real-time threat intelligence inputs [2], [4], [12]. The system should implement authentication handshakes, dynamic IP masking, and session tracking across nodes in real time.

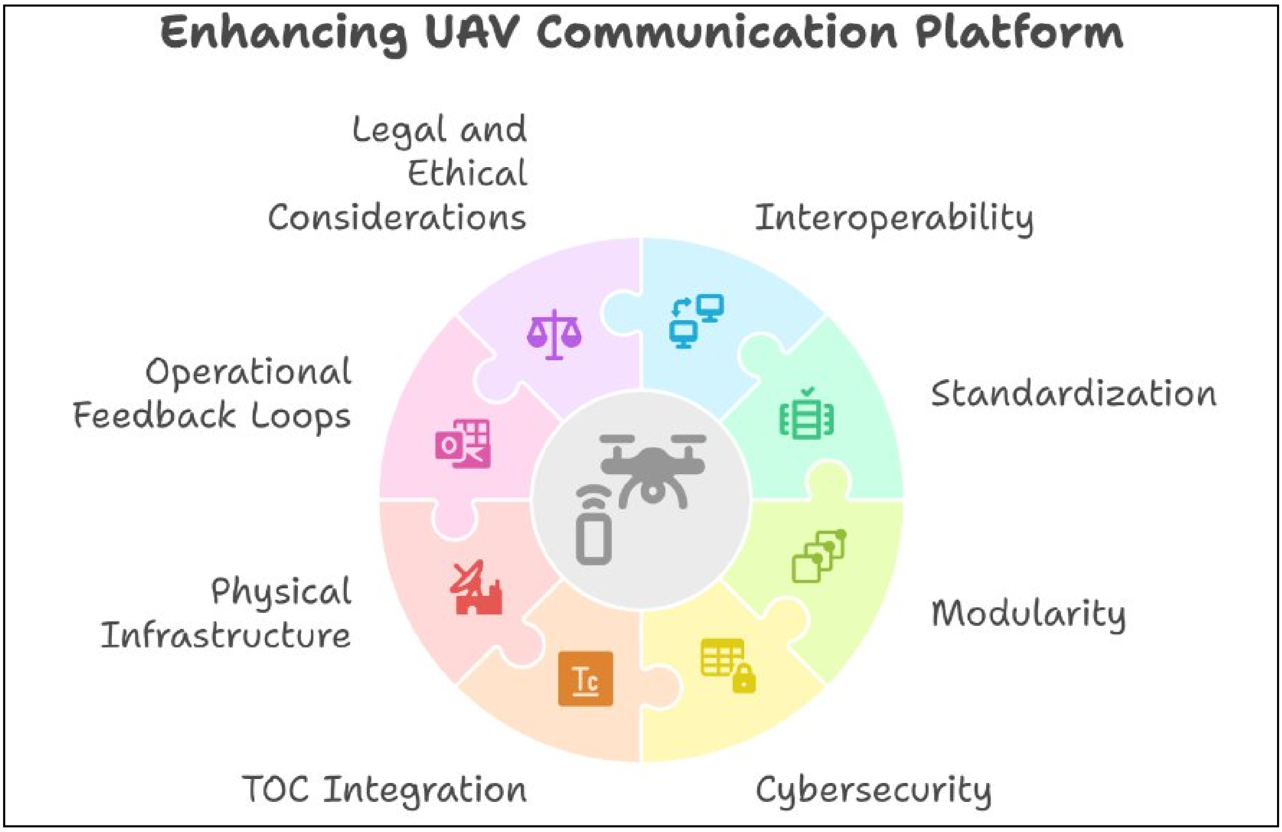

Fig. 3 – Strategic Pillars for Enhancing UAV Communication Platform Functionality

From a TOC integration perspective, the platform should support mission dashboards, logging interfaces, and visualization tools compatible with the digital ecosystems already in use at command centers [14], [16]. These interfaces must be intuitive and designed for operational stress, allowing personnel to sort and react to high-priority data feeds without navigating through system complexity.

In addition to software requirements, the physical infrastructure must be interoperable. UAVs deployed in rugged, contested environments rely on satellite uplinks, mobile ad-hoc networks (MANETs), and terrestrial signal repeaters. The communication platform must adapt its channel switching and antenna management protocols to these constraints, supporting multi-bandwidth operations and fallback options in degraded network conditions [3], [7], [9].

Operational feedback loops should also be integrated into the platform. Tactical users must be able to flag bottlenecks, prioritize sensor streams in real time, and trigger alerts that escalate through the network chain. The importance of human-in-the-loop overrides and decentralized decision control is emphasized in military doctrine documents and recent technical recommendations for TOC communication resilience [6], [10], [14].

Finally, legal and ethical interoperability must not be overlooked. Platforms deployed in coalition operations need to comply with varying rules of engagement, data retention policies, and human rights considerations. Data collected during surveillance must be auditable and traceable to ensure accountability [1], [13], [16].

The interoperability and integration requirements of the proposed UAV communication platform are foundational to its effectiveness. It must support dynamic coordination between devices, systems, and human operators, maintaining operational agility while adhering to robust security and technical standards. This architectural approach is key to sustaining situational awareness and enabling mission success in complex and resource-constrained environments.

This figure visualizes eight foundational domains that collectively shape the robustness, adaptability, and effectiveness of a modern UAV communication platform. These domains include legal and ethical considerations to ensure operations adhere to international standards, and interoperability to facilitate seamless communication with varied TOC systems. Standardization is emphasized to unify protocols across mission contexts, while modularity supports scalable and flexible platform upgrades. Cybersecurity is a cornerstone to guard against threats and ensure mission integrity. TOC integration ensures fluid data exchange with command structures, whereas physical infrastructure provides the necessary technological support for deployment. Finally, operational feedback loops enable continuous system improvement through real-time learning and adaptation. These elements function as interconnected components, reinforcing the mission-centric orientation of UAV communication systems in military and emergency environments.

V. STRATEGIC ENABLERS AND INTEGRATION CONSIDERATIONS

The success of a mission-centric UAV communication platform depends not only on technical design but also on its alignment with broader strategic enablers that ensure adaptability, operational integrity, and system-wide resilience. As defence ecosystems grow increasingly complex and data-driven, the integration of such platforms requires a layered, multidimensional approach that embeds operational, legal, ethical, and infrastructural considerations. Legal and Ethical Compliance is a foundational pillar that governs the rules of engagement for UAV operations. In both combat and civilian applications, ensuring that data collection, usage, and transmission adhere to international humanitarian laws and privacy regulations is critical. The use of autonomous systems for surveillance or targeting must comply with established doctrines, avoiding decisions that could result in unintended consequences. Platforms must include safeguards that enforce these boundaries and log operations for accountability and review.

Interoperability ensures that the UAV platform can exchange data seamlessly across different command structures, NATO coalition forces, and emergency response agencies. As modern operations increasingly involve multinational coordination, the communication architecture must support standardized protocols such as Link 16, IP-based military networks, or civilian interoperability standards depending on the mission context. This aspect guarantees a unified tactical picture and promotes situational coherence among stakeholders.

Standardization plays a crucial role in minimizing compatibility issues. From the physical interface of communication modules to the semantic structure of transmitted data, adherence to predefined standards shortens deployment timelines and reduces the risk of miscommunication. It also allows for easier maintenance, upgrades, and third-party integration, especially under joint operations or coalition-led missions.

Modularity in system architecture allows the platform to evolve with changing mission needs. Modules such as prioritization logic, encryption protocols, and signal routing components can be added, removed, or reconfigured without overhauling the entire platform. This characteristic supports mission flexibility and rapid adaptation during field operations.

Cybersecurity is not a static requirement but a continuous process that must be woven into every layer of the platform. With increasing electronic warfare threats and adversarial cyber activity, the UAV communication framework must be resilient against jamming, spoofing, and unauthorized data access. Encryption protocols, authentication mechanisms, and intrusion detection systems must be routinely updated and stress-tested in realistic simulations.

TOC Integration is vital for closing the loop between data acquisition and actionable decision-making. Real-time dashboard visualization, prioritization filters, and decision-support algorithms must be tightly synchronized with TOC systems. This ensures that critical information reaches commanders in a timely and structured format, supporting mission execution and contingency planning.

Physical Infrastructure forms the bedrock for deploying and maintaining the communication system. This includes mobile ground stations, relay towers, power supply units, and satellite uplinks that ensure the platform can operate effectively in contested or resource-limited environments. Infrastructure must be robust, portable, and compatible with tactical deployments.

Operational Feedback Loops enable continuous learning and platform evolution. By capturing and analysing data from ongoing missions, the platform can adapt its prioritization logic, bandwidth management, and routing strategies. These loops ensure that operational insights inform future system updates, contributing to a cycle of iterative improvement.

The integration of these strategic enablers transforms the UAV communication platform from a static data link into a dynamic, mission-aware intelligence node. As visualized in Figure 4, these domains are interconnected puzzle pieces that together reinforce the system's ability to support mission-critical operations, adapt to uncertainty, and maintain resilience in both military and civilian response scenarios.

This figure illustrates the key strategic enablers essential to the performance, resilience, and scalability of mission-centric UAV communication platforms. The lock-shaped architecture symbolizes the role of these components in securing and stabilizing the overall system. Each segment highlights a distinct enabler:

- Operational Feedback Loops support iterative improvement by incorporating field data into future system updates.
- Physical Infrastructure underpins reliable deployment and network connectivity in dynamic environments.
- TOC Integration ensures tight synchronization between UAV data inputs and decision-making at Tactical Operations Centers.
- Cybersecurity defends against external threats, unauthorized access, and signal interference.
- Modularity allows the platform to evolve in line with changing mission requirements.
- Standardization reduces system conflicts and supports joint mission execution through adherence to technical protocols.
- Interoperability facilitates seamless communication between allied systems and stakeholders.
- Legal and Ethical Compliance guarantees that data practices conform to legal and regulatory standards.

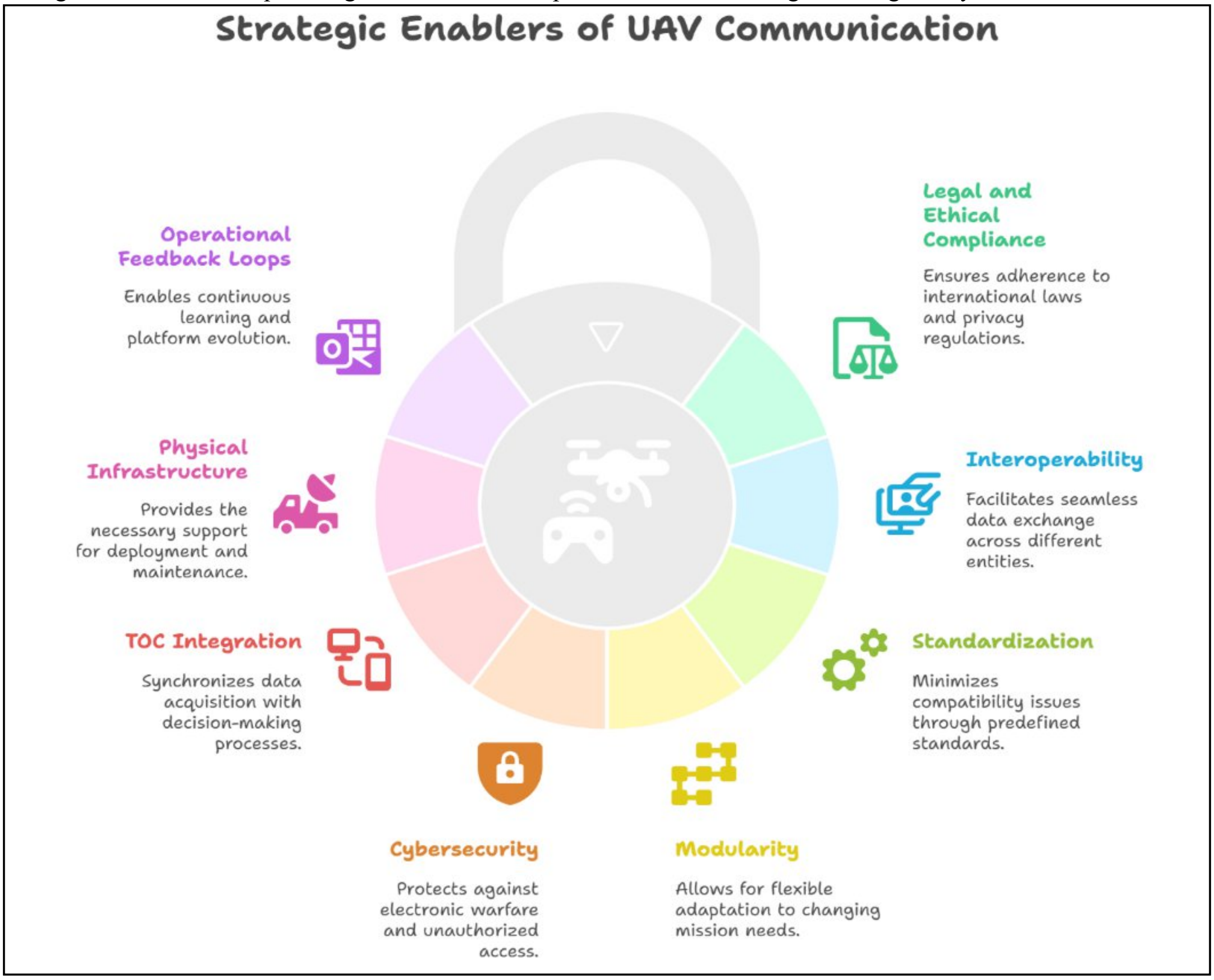

Fig. 4 – Strategic Enablers of UAV Communication

Together, these enablers enhance mission responsiveness, reduce vulnerability, and promote long-term sustainability of UAV communication in both military and emergency contexts.

VI. CONCLUSIONS

This paper presented a mission-focused UAV communication framework designed for integration with Tactical Operations Centers. The proposed architecture, structured into key layers, enables efficient data collection, prioritization, secure transmission, and seamless interface with command systems. It addresses the growing demands of modern military and emergency operations by ensuring that critical information is delivered reliably and on time.

The framework also highlights the importance of interoperability, modularity, and cybersecurity in building resilient systems. Supported by operational insights and technical requirements, this platform lays the groundwork for future developments that can enhance mission responsiveness and decision-making effectiveness. Through this approach, UAV communications can be better aligned with tactical needs, contributing to more coordinated and successful operations.

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