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Research Article

A Review of Reconfigurable Intelligent Surface-Enhanced UAV Networks for Real-Time Applications

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ABSTRACT

The advancement of wireless networks has created a need for advanced solutions to support ultra-reliable, low-latency communication, especially in challenging environments. Combining Reconfigurable Intelligent Surfaces (RIS) with Unmanned Aerial Vehicles (UAVs) has emerged as a promising approach to improving wireless performance in dynamic and obstructed environments. This paper offers a thorough review of RIS-enhanced UAV systems, emphasizing their use in real-time applications. We present a systematic review of the state of the art in RIS-UAV integration, addressing system models, performance metrics, optimization techniques, and key challenges. The paper also discusses three primary RIS deployment architectures: (i) drone-mounted RIS, (ii) ground-based RIS assisting UAVs, and (iii) hybrid UAV-RIS systems, and evaluates their performance in real-time applications. Furthermore, we propose future research directions, including AI-driven optimization, real-time communication requirements, energy efficiency, and standardization efforts to enable seamless integration of RIS-UAV systems in next-generation networks such as 5G, 6G, and beyond..

Keywords: Unmanned Aerial Vehicles, Reconfigurable Intelligent Surfaces, Real-time Communications, 6G, Beamforming, and Machine Learning

INTRODUCTION

As mobile data traffic grows exponentially, driven by the proliferation of Internet of Things (IoT) devices and their applications, conventional communication infrastructures are being strained beyond capacity. This challenge has grown from the limitations of existing communication systems, which often struggle in dynamic environments with large-scale device deployments and mobility. As a result, the need for ultra-reliable, low-latency communications (URLLC) has become a focal point in research on next-generation wireless networks. The integration of Reconfigurable Intelligent Surfaces (RIS) and Unmanned Aerial Vehicles (UAVs) offers a promising solution to these challenges. RIS, which consists of large arrays of passive elements that can intelligently reflect signals, has been shown to improve coverage and signal quality while minimizing interference [1] – [4].

On the other hand, UAVs provide flexible, on-demand connectivity, making them ideal platforms for extending coverage in areas with limited or unreliable terrestrial infrastructure [5]–[7]. In this paper, we present a comprehensive survey of the integration of RIS-enhanced UAV networks, with a focus on real-time applications. The review explores the potential of RIS to improve UAV communication by adjusting electromagnetic wave propagation to mitigate obstacles such as buildings and trees, as well as environmental interference. The main goal is to offer invaluable insights into the design, deployment, and optimization of RIS-assisted UAV systems, with an emphasis on real-time communication needs [8] – [11].

Recent research has increasingly investigated the integration of RIS and UAVs as a complementary framework for enhancing wireless coverage, reliability, energy efficiency, and service continuity in dynamic environments. Unlike conventional UAV-assisted communication, where the UAV mainly acts as an aerial base station, relay, data collector, or edge server, RIS-assisted UAV communication introduces an additional degree of freedom by reconfiguring the wireless propagation environment. This capability is particularly relevant for real-time applications, where latency, reliability, outage probability, channel aging, and mobility-induced link degradation must be jointly addressed. Early RIS-UAV studies mainly focused on joint trajectory and passive beamforming optimization, where the UAV position and RIS phase shifts are optimized to improve received signal quality and system throughput. More recent works have extended this direction toward real-time and mission-critical scenarios by considering short-packet communication, outdated channel state information (CSI), deep reinforcement learning (DRL), non-orthogonal multiple access (NOMA), mobile edge computing (MEC), and multi-UAV/multi-RIS coordination.

For instance, Xie et al. [12] studied drone-mounted intelligent reflecting surfaces for B5G IoT networks and jointly optimized beamforming, phase shifts, and drone deployment. Ullah et al. [13] proposed a DDPG-based UAV-RIS mobility optimization framework for future wireless networks. Khennoufa et al. [14] analyzed the error performance of UAV-mounted RIS-NOMA systems under practical constraints, including hardware impairments and imperfect successive interference cancellation. Lin et al. [15] investigated RIS-equipped-UAV wireless-powered communications with outdated CSI, which is directly relevant to highly mobile and delay-sensitive environments. Hammouti et al. [16] proposed an energy-efficient approach for aerial RIS networks, focusing on phase-shift optimization and trajectory design to enhance system performance. Their work provides valuable insights into the energy-efficient operation of UAVs, which is critical for extending the operational time of aerial platforms in real-time applications. Hu et al. [17] considered IRS-assisted UAV short-packet communication, in which low latency is addressed through finite-blocklength transmission and the joint optimization of UAV speed, trajectory, transmit power, and passive beamforming.

Beyond single-UAV or single-RIS settings, recent studies have also considered more scalable architectures. Dhuheir et al. [18] proposed a multi-UAV, multi-RIS, QoS-aware aerial communication framework that uses DRL and particle swarm optimization to improve throughput and coverage through path planning and RIS phase configuration. Such works indicate a shift from static RIS-aided link enhancement toward adaptive, learning-driven, and multi-agent RIS-UAV network design. Nevertheless, most existing works still assume simplified CSI acquisition, ideal RIS hardware, limited control-signaling overhead, or offline-trained optimization policies. These assumptions restrict their direct applicability to real-time services, where UAV mobility, RIS reconfiguration latency, user scheduling, finite blocklength effects, and edge-computing delay must be jointly considered.

From a standardization perspective, RIS and UAV communications are also becoming increasingly relevant to future 5G-Advanced and 6G networks. European Telecommunications Standards Institute (ETSI) has determined RIS use cases, deployment scenarios, key performance indicators, and operational requirements related to system/link performance, spectrum, coexistence, and security [19]. ETSI has also reported implementation and practical considerations for RIS deployment, including unit-cell design, switching methods, RIS controller architecture, measurement methods, and field-trial requirements [20].

In parallel, the 3rd Generation Partnership Project (3GPP) has specified support for UAS in cellular systems, including service requirements for command-and-control (C2), payload communication, UAV identification, tracking, and Quality of Service (QoS) handling [21]-[22]. The 3GPP UAS application enabler layer further defines protocol procedures for UAS application communication between the UAV user equipment and the UAS application server, as well as communication among user equipment over cellular interfaces [23]. These standardization efforts provide the protocol-level foundation for integrating RIS-assisted UAV systems into future cellular infrastructures. Despite these advances, existing surveys and technical studies often treat RIS-UAV integration from isolated perspectives, such as outage performance, energy efficiency, trajectory optimization, or physical-layer security. A dedicated review focusing on real-time RIS-UAV network design remains necessary. Such a review should jointly consider deployment architecture, real-time performance requirements, CSI acquisition and feedback delay, UAV mobility, RIS phase-control latency, hardware constraints, optimization complexity, and standardization compatibility. To bridge these gaps, we introduce a novel structured survey of RIS-enhanced UAV networks for real-time applications, classifying recent works by deployment architecture, communication objective, optimization method, performance metric, and practical implementation challenges.

As shown in Fig. 1, the terrestrial communication infrastructure in the emergency area is partially or completely destroyed. A UAV equipped with an RIS flies over the area to quickly establish a reconfigurable, intelligent communication link with ground users, ensuring real-time connectivity for mission-critical operations. On the other hand, the UAV monitors surveillance, security, or environmental data. The GRIS system improves communication with the ground station, enhancing signal quality and coverage in complex environments to ensure uninterrupted data collection and transmission.

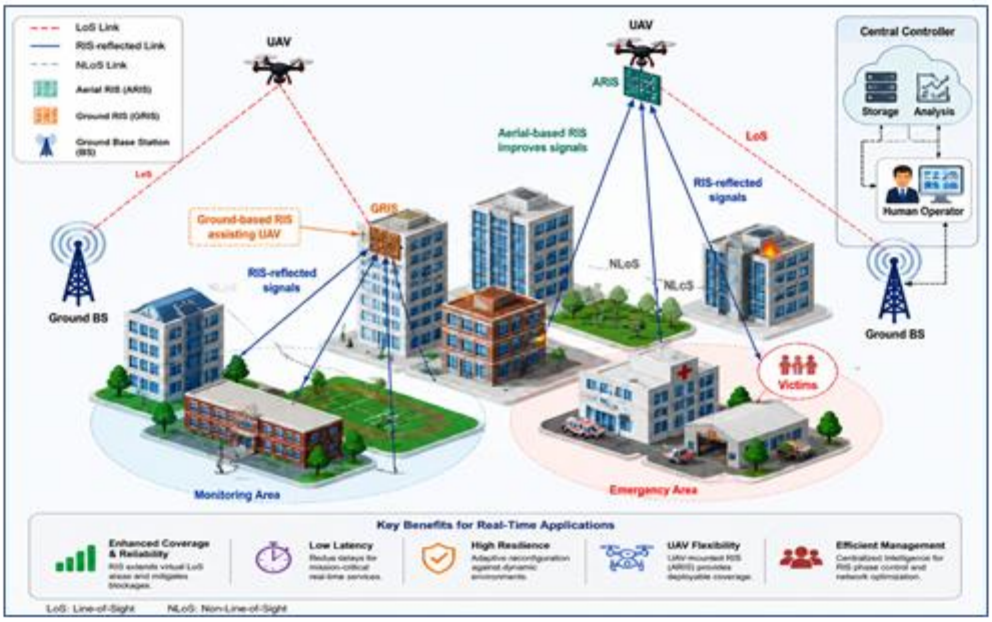

FIG 1: Motivating Scenario

In the tables 1 and 2, we list all the essential acronyms and symbols and their abbreviations used throughout this review.

TABLE 1: List of acronyms and their abbreviations used in this review

Acronym	Abbreviations
5G	Fifth-Generation Mobile Network
6G	Sixth-Generation Mobile Network
A2A	Air-to-Air
A2G	Air-to-Ground
AI	Artificial Intelligence
B5G	Beyond Fifth-Generation
BER	Bit Error Rate
BS	Base Station
CSI	Channel State Information
DRL	Deep Reinforcement Learning

DQN	Deep Q-Network
EE	Energy Efficiency
FSO	Free-Space Optics
IoT	Internet of Things
ISAC	Integrated Sensing and Communication
JSC	Joint Sensing and Communication
LoS	Line-of-Sight
MARL	Multi-Agent Reinforcement Learning
MEC	Mobile Edge Computing
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
MPC	Model Predictive Control
NLoS	Non-Line-of-Sight
NOMA	Non-Orthogonal Multiple Access
OP	Outage Probability
QoS	Quality of Service
RIS	Reconfigurable Intelligent Surface
RF	Radio Frequency
RL	Reinforcement Learning
SE	Spectral Efficiency
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise Ratio
TH	Throughput
UAV	Unmanned Aerial Vehicle
URLLC	Ultra-Reliable Low-Latency Communication

TABLE 2: List of frequently used symbols and their abbreviations

Symbol	**Abbreviations**
P_t	Transmit power
σ^2	Noise power
γ	Received SNR/SINR
γ^{th}	SNR/SINR threshold
P_{out}	Outage probability
R	Achievable data rate
R^{th}	Target data rate threshold
T	Mission duration or transmission interval
Φ	RIS reflection-coefficient matrix
θ_n	Phase shift of the nth RIS element
β_n	Amplitude reflection coefficient of the nth RIS element
G_{BR}	Channel from base station to RIS
h_{RU}	Channel from RIS to user
h_d	Direct channel

I. SYSTEMATIC REVIEW METHODOLOGY

In this comprehensive review, we adopt a systematic methodology to select and analyze relevant literature. The approach used to perform this work involved several steps. First, we conduct a deep search across major databases using keywords such as RIS-UAV integration, RIS in 5G/6G networks, UAV-assisted communication, and real-time communication optimization. We include only studies that focus on combining RIS with UAVs for wireless communication, particularly those addressing real-time applications. Additionally, we exclude papers that lacked sufficient technical depth or focused on general UAV communication without RIS enhancement. After that, for the review scope, we consider only the recent studies, ensuring a focus on recent advancements and emerging trends. As a final step, we classify our selected studies by the type of RIS deployment (drone-mounted, ground-based, and hybrid), the application focus (IoT, URLLC, and emergency services), and the optimization techniques employed (machine learning, trajectory planning, and energy efficiency).

II. RIS-UAV NETWORK ARCHITECTURES AND TAXONOMY

In this review, the taxonomy of RIS-assisted UAV networks is organized based on three main deployment architectures: (i) drone-mounted RIS, (ii) ground-based RIS assisting UAVs, and (iii) hybrid UAV-RIS systems, each with unique advantages and challenges.

A. Drone-mounted RIS Architecture

In this architecture, a drone-mounted RIS, also referred to in the literature as a UAV-mounted IRS or an Aerial RIS (ARIS), features RIS panels mounted directly on UAVs, enabling real-time adjustments to the electromagnetic propagation environment as the UAV moves through the coverage area. This design offers flexibility and mobility but is constrained by UAV flight time and power consumption. These systems are ideal for applications requiring on-demand connectivity, such as emergency response or dynamic IoT services in remote areas. When the RIS panel is installed directly on the UAV platform, it lets the reflecting surface be repositioned in three-dimensional space based on traffic demand, blockage conditions, user mobility, and mission constraints. Compared with the other fixed RIS deployment, this architecture offers greater spatial adaptability. It enables controllable reflected links in scenarios where the direct base-station-user path is unavailable or severely degraded.

For this category, we keep only recent studies that explicitly integrate RIS with UAVs for wireless communication and that provide sufficient technical modeling, optimization, or performance analysis. Papers dealing with generic UAV communications without RIS enhancement, or papers where RIS is only mentioned without a clear system model, are excluded. The selected works focus on technically relevant aspects for real-time and dynamic communication scenarios, including joint beamforming and phase-shift design, mobility-aware reinforcement learning, NOMA error performance, outdated CSI, wireless-powered communication, and energy-aware aerial RIS trajectory optimization. In UAV-mounted RIS systems, the main design variables are the UAV trajectory or deployment position, the RIS reflection-coefficient matrix, the transmit beamforming vector, power allocation, user scheduling, and, in some cases, computation or energy-harvesting policies. A representative baseband received signal for a single reflected link can be expressed as:

$$y = \left(h_{\mathrm{R}}^{H\Phi G_{\mathrm{B}}}\right)x + n \qquad (1)$$

Where $\mathrm{G_B}$ denotes the channel from the base station to the UAV-mounted RIS, $\mathrm{h_R}$ denotes the channel from the RIS to the user, $\Phi = \mathrm{diag}\left(\beta_1 e^{j\theta_1}, \dots, \beta_N e^{j\theta_N}\right)$ is the RIS reflection matrix, x is the transmitted signal, and n is additive noise. If a direct link exists, it can be added to the cascaded channel. The corresponding received signal-to-noise ratio can be written as follows:

$$\gamma = \frac{P_t |h_d + h_{RU}^{H}\Phi G_{BR}|^2}{\sigma^2} \qquad (2)$$

where Pt is the transmit power, hd is the direct channel, and σ2 is the noise power. So, this formulation highlights the central technical role of the UAV-mounted RIS; it does not amplify the signal as an active relay but reconfigures the propagation environment by controlling the phases, amplitudes, and spatial position of the reflected path. Despite its flexibility, the UAV-mounted RIS architecture introduces several practical limitations. First, the RIS panel increases the UAV payload, which may reduce flight endurance. Second, variations in the UAV's orientation and attitude can cause beam misalignment. Third, accurate channel state information becomes difficult to maintain because both the RIS and users may be mobile. Fourth, real-time RIS control requires fast signaling, low-complexity optimization, and robust adaptation to outdated or imperfect CSI.

Therefore, this architecture is particularly suitable for short-duration, mission-critical, or on-demand coverage scenarios, but it requires careful co-design of trajectory planning, RIS configuration, energy management, and communication control. Table 3 presents a set of recent selection works on UAV-mounted RIS that support UAVs in real-time communication, focusing on optimization, performance analysis, and real-world application considerations.

TABLE 3: A comparative overview of recent works on UAV-mounted RIS architectures.

Reference	**Scenario**	**Objective**	**Optimization**	**Metrics**	**Limitation**
Xie et al., 2025 [12]	Multiple drone-mounted IRS units assisting mmWave MIMO transmission in B5G IoT networks.	Maximizing weighted data rate by jointly optimizing beamforming, phase-shift design, and drone deployment.	Iterative optimization with quadratic transformation, Lagrange multipliers, and distributed discrete-time convex optimization.	Achievable data rate, coverage, phase-shift gain, and deployment efficiency.	The framework relies on simulation and assumes controlled deployment; real-time adaptation to fast user mobility and imperfect CSI requires further validation.
Ullah et al., 2025 [13]	UAV-mounted RIS for dense urban wireless networks with mobility management.	Jointly optimize UAV trajectory and RIS phase shifts to improve connectivity for mobile ground users.	DDPG-based reinforcement learning	Throughput, energy efficiency, LoS and outage probabilities, and handover failure rate.	The framework needs training stability, convergence analysis, and evaluation of realistic control signaling.
Khennoufa et al., 2024 [14]	UAV-mounted RIS-assisted NOMA system considering practical hardware limitations.	Analyzing UAV-RIS NOMA link error performance with non-ideal transceivers and interference.	The closed-form analytical derivation of error probability has been validated through Monte Carlo simulations.	Error probability, BER performance, RIS gain, hardware impairments, and imperfect SIC effects.	The study examines link-level error behavior and doesn't optimize UAV trajectory, RIS phase shifts, or resource allocation.
Lin et al., 2024 [15]	RIS-equipped UAV wireless-powered communication with outdated	Maximizing ergodic throughput with imperfect, outdated CSI.	Resource and transmission design for RIS-equipped UAV wireless power	Ergodic throughput, CSI aging effect, wireless-powered communication efficiency.	The model addresses outdated CSI, but real-time implementation and UAV control latency remain

	CSI.		communication.		challenging.
El Hammouti et al., 2024 [16]	An aerial RIS on a moving drone to help users with obstructed views.	Maximizing energy efficiency by optimizing UAV velocity, acceleration, trajectory, and RIS phase shifts.	Decoupling phase-shift optimization and trajectory design using convex approximation and economic model predictive control.	Energy efficiency, sum rate, UAV feasibility, and trajectory performance.	The study shows promise for real-time control, but needs broader validation with multi-user mobility, imperfect CSI, and practical RIS hardware constraints.

B. Ground-based RIS Assisting UAVs Architecture

In this architecture, RIS panels are deployed on the ground, also referred to as a ground-based RIS assisting drones (GRIS), reflecting and directing signals to UAVs in the air. This approach enhances communication links between UAVs and ground stations, improving coverage in urban environments and overcoming obstacles such as buildings and trees. However, ground-based RIS systems lack the mobility of drone-mounted solutions and may not be effective in environments where UAVs are frequently moving or in highly dynamic scenarios. In the ground-based RIS-assisted UAV architecture, the RIS is installed on the ground and reflects signals towards UAVs, enhancing communication between UAVs and ground stations or other UAVs. This architecture is particularly advantageous in urban environments where buildings, terrain, and other obstructions hinder direct communication links. By reflecting signals to UAVs in areas where line-of-sight (LoS) is blocked, ground-based RIS improves coverage and signal strength, ensuring reliable connectivity.

However, ground-based RIS lacks the spatial adaptability of UAV-mounted RIS because its panels are stationary, limiting its flexibility in dynamic environments. Nevertheless, this architecture can provide cost-effective coverage over large areas and is well-suited for large-scale deployments in urban or rural environments with predictable communication patterns. The key challenges in ground-based RIS deployment include optimizing RIS placement, mitigating interference from nearby objects, and developing robust optimization algorithms to coordinate communication among UAVs, ground stations, and RIS panels. Real-time adaptation to dynamic conditions, such as UAV mobility and environmental changes, is also a crucial focus area. Table 4 summarizes recent works on ground-based RIS that assist UAVs with real-time communication, focusing on optimization, performance analysis, and real-world application considerations.

TABLE 4: A comparative table of the recent works on ground-based RIS architectures.

Reference	Scenario	Objective	Optimization	Metrics	Limitation
Jiang et al., 2024 [24]	Ground-based RIS for UAV-to-Vehicle communication in large-scale environments.	Create an RIS framework for subarray partitioning and beam-domain channel modeling in large-scale UAV-to-vehicle communication	Optimization of beamforming and subarray partitioning considering channel aging.	Throughput, SNR, BER, energy efficiency, coverage extension.	Limited accuracy at near-field ranges and challenging RIS optimization in large-scale deployments.

		s.			
Yao et al., 2025 [25]	Ground-based RIS-assisted UAV-to-ground communication for urban emergency response.	Maximizing data rates while improving the stability of communication links during emergencies.	DRL applied to dynamic channel management and UAV trajectory optimization.	Data rate, outage probability, SNR, latency, and stability in emergency response.	Limited emphasis on real-time feedback and coordination among multiple UAVs.
Nguyen et al., 2024 [26]	RIS-assisted A2G and A2A communications considering channel aging.	Jointly optimize UAV trajectory, RIS phase shifts, and resources to mitigate channel aging.	Convex optimization and ADMM applied to trajectory and RIS optimization.	Throughput, energy efficiency, outage probability, latency, QoS.	Performance issues in highly mobile environments and the challenges of real-time adaptation.
Cao et al., 2021 [27]	Ground-based RIS supporting UAV-device pairs for urban IoT networks with energy efficiency constraints.	Optimize RIS element allocation and phase-shift configuration to maximize energy efficiency and coverage in urban environments.	Nonlinear optimization and algorithms for energy-efficient power control.	Energy efficiency, coverage, throughput, energy consumption, and latency.	Lacks scalability analysis for large-scale IoT in dynamic environments.
Michailidis et al., 2021 [28]	Multiple ground-based RIS-assisted UAV communication in multi-cell environments with MEC.	Optimizing energy efficiency for MEC tasks considering RIS phase shifts, task allocation, and UAV energy constraints.	Minimize phase shifts and UAV trajectory via convex approximation and multi-objective optimization.	Energy efficiency, task completion time, system throughput, latency, and task allocation efficiency.	Limited focus on real-time task reallocation in high-mobility, multi-cell scenarios.

C. Hybrid UAV-RIS Systems Architecture

Hybrid UAV-RIS systems combine the advantages of both drone-mounted and ground-based RIS. UAVs equipped with RIS panels can adjust their position and orientation to dynamically optimize signal reflection, while ground-based RIS provides additional coverage. Hybrid systems offer the most flexibility and scalability, making them suitable for large-scale deployments, such as urban IoT networks or large-area surveillance systems. To maximize the benefits of each approach. UAV-mounted RIS provides the flexibility to dynamically adjust the electromagnetic environment by reconfiguring the RIS panels as the UAV moves through the coverage area, while ground-based RIS offers cost-effective, large-area coverage that helps mitigate obstacles and improve signal strength in urban or remote environments. This hybrid configuration is particularly advantageous for large-scale deployments in dynamic environments, where both UAV mobility and stationary coverage are required to ensure stable and reliable communication.

The ability to leverage both mobile and stationary RIS elements enables dynamic control of signal reflection and phase shifting, optimizing communication quality in real time. However, integrating UAV-mounted and ground-based RIS requires sophisticated optimization algorithms to coordinate RIS panels, UAV trajectories, power control, and user scheduling. In Table 5, we summarize some recent works on hybrid UAV-RIS systems for wireless communication, with a particular focus on real-time applications. These papers provide valuable insights into system optimization, performance metrics, and practical challenges.

TABLE 5: A comparative table of the recent works on hybrid UAV-RIS architectures.

Reference	**Scenario**	**Objective**	**Optimization**	**Metrics**	**Limitation**
Rao et al., 2021 [29]	Hybrid UAV-RIS for wireless-powered urban IoT communications.	Improving energy efficiency and coverage by combining UAV-mounted and ground-based RIS for low-power IoT devices.	Joint power allocation, RIS phase shift, and UAV trajectory optimization via convex optimization.	Energy efficiency, coverage, throughput, outage probability, energy consumption, and latency.	The real-time feasibility of high-mobility, low-power IoT devices requires further analysis.
Zhou et al., 2021 [30]	Hybrid RIS architecture using UAV and ground-based RIS for millimeter-wave communications in smart cities.	Improve spectral efficiency and reliability in urban millimeter-wave settings with a hybrid RIS.	RL optimizes phase-shift design and UAV trajectory planning.	Spectral efficiency, SINR, throughput, reliability, latency, energy efficiency	Limited validation in real-world settings and difficulties in deploying at a large scale under highly dynamic conditions.
Nguyen et al., 2024 [31]	A hybrid UAV-RIS system enables emergency communications in disaster-recovery networks.	Optimizing UAV trajectory and RIS phase-shift to maximize data rate and reliable connectivity in a disaster environment.	Deep Q-learning for joint UAV mobility and RIS configuration under high mobility and limited resources.	Data rate, outage probability, energy consumption, connectivity reliability, and task completion time.	Challenges in adapting to large-scale scenarios involving multiple UAVs and RIS elements.
Xie et al., 2024 [32]	Energy-efficient hybrid UAV-RIS networks enable low-latency vehicular urban	Minimizing energy use and maximizing throughput in a hybrid UAV-RIS vehicular network.	Energy-efficient beamforming and UAV trajectory optimization via mixed-integer	Energy efficiency, throughput, latency, signal-to-noise ratio (SNR), outage probability	Implementation complexity of large-scale urban deployments with multi-UAV and multi-RIS coordination

	communications.		programming.		
Chen et al., 2025 [33]	Hybrid RIS-assisted UAV enabling real-time, high-definition video streaming in remote and congested areas.	Enhancing real-time HD video transmission quality with a hybrid UAV-RIS to optimize coverage and signal strength.	A stochastic geometry model for analyzing coverage, interference, optimizing phase shifts, and UAV mobility.	QoS, throughput, packet loss ratio, energy efficiency, delay, and latency.	Limited evaluation of real-time video in dynamic environments and tough terrain.

III. Applications of RIS-Enhanced UAV Networks

RIS-based UAV networks are rapidly emerging as a means to overcome the limitations of traditional wireless systems, especially in challenging environments lacking reliable infrastructure. Integrating RIS with UAVs allows dynamic, on-demand network deployment, offering flexibility, scalability, and resilience where ground-based stations struggle to provide coverage. These systems are especially valuable in remote, disaster-stricken, or congested urban areas, where infrastructure may be damaged, unavailable, or inadequate for real-time communication. By utilizing RIS technology, which passively adjusts electromagnetic wave propagation, along with UAV mobility, which provides dynamic network coverage, these networks improve communication reliability, data throughput, and energy efficiency.

Below, we explore some of the most promising and novel applications of RIS-enhanced UAV networks, showcasing their potential to address diverse challenges in industries ranging from emergency response to industrial inspection and smart city development. As follows, several key applications of RIS-enhanced UAV networks offer flexible, intelligent, and efficient solutions for next-generation wireless systems, enabling real-time connectivity anytime, anywhere, which is covered in the following subsections.

A. Emergency Disaster Recovery and Response

RIS-enhanced UAV networks provide a rapid and efficient solution for restoring communication in disaster zones, where traditional infrastructure is often compromised. UAVs equipped with RIS can establish real-time communication links, facilitating coordinated rescue efforts and timely updates during natural disasters such as wildfires, earthquakes and floods. This application highlights the vital role of UAVs in ensuring emergency communication and supporting first responders in real time. Ghosh et al. [34] propose a dynamic RIS-based UAV network that can quickly adapt to changing environmental conditions in disaster zones. This network ensures continuous communication even when ground stations are unavailable, offering reliable data transmission for emergency response teams. Kumar et al. [35] propose an ad-hoc UAV network with RIS for disaster recovery, focusing on real-time communication without relying on fixed infrastructure. The system enables fast deployment in disaster-stricken areas and supports rescue operations by establishing temporary communication networks.

B. Smart Cities and Urban Mobility

In urban areas with connectivity issues like congestion and poor coverage, RIS-enhanced UAV networks provide on-demand coverage, supporting traffic, safety, and smart vehicle communication with minimal latency and stable connections. They will be vital for 5G/6G smart cities, where seamless communication is essential for efficient city management. In their work, Li et al. [36] investigate the use of RIS-enhanced UAVs for 5G/6G urban mobility. They highlight how RIS can optimize wireless communication in smart cities, improving network performance in high-density urban environments where traditional cellular systems are congested. Zhang et al. [37] propose using RIS-equipped UAVs to enhance vehicle-to-everything (V2X) communication in smart cities, enabling real-time data exchange among vehicles, infrastructure, and pedestrians. It aims to reduce latency and ensure reliable connections for autonomous vehicles.

C. Agriculture and Rural Connectivity

RIS-equipped UAVs boost connectivity in remote rural areas, aiding precision agriculture and quick data collection. They ensure reliable communication for monitoring crop health, soil moisture, and other key farming factors. UAVs provide rapid, low-latency connectivity, enabling farmers to make informed decisions with current data. Sun et al. [38] investigate RIS-enabled UAV systems for precision agriculture, focusing on real-time data collection and sensor networks to optimize farming practices. This system enhances communication coverage in agricultural fields, enabling farmers to make data-driven decisions. In another scenario, the authors in [39] discuss how RIS-enhanced UAV networks improve real-time monitoring and data transmission in smart farming. UAVs with RIS can facilitate remote connectivity in rural areas, providing real-time updates on crop conditions and irrigation management.

IV. OPTIMIZATION TECHNIQUES FOR RIS-UAV SYSTEMS

In real-time communication systems, optimization is crucial to ensuring that performance metrics such as throughput, latency, energy efficiency, and reliability meet the stringent requirements of mission-critical applications. The dynamic nature of RIS-UAV networks, with constantly changing environmental conditions, UAV mobility, and varying user demands, necessitates the use of advanced optimization techniques to adapt to these fluctuations in real time. In this section, we provide a comprehensive overview of the most commonly used optimization approaches for RIS-UAV networks. These include techniques for optimizing UAV trajectories, RIS phase shifts, power allocation, and user scheduling, all of which help maximize network performance under real-world constraints. Additionally, we discuss optimization strategies that incorporate machine learning and reinforcement learning to enhance adaptability and efficiency in these complex systems.

A. UAV Trajectory Optimization

Optimizing UAV flight paths is critical for ensuring stable and reliable communication links. Techniques such as dynamic programming (DP), genetic algorithms (GA), and trajectory planning are used to determine the best UAV trajectory that maximizes coverage while minimizing energy consumption. These methods balance the UAV's mobility with the energy limitations imposed by battery-powered operations.

B. RIS Phase Shift Optimization

RIS panels function by dynamically adjusting their reflection coefficients, which influence the phase shifts of the incident signals, to optimize the communication link. By fine-tuning these reflection coefficients, RIS panels can enhance signal strength, improve coverage, and mitigate interference, particularly in environments where traditional communication methods are ineffective, such as urban canyons or obstructed areas. To achieve this, optimization techniques are employed to determine the ideal phase shifts for each RIS element. For example, Gradient Descent (GD) and Convex Optimization (CO) are two widely used methods to optimize these phase shifts. GD is an iterative optimization algorithm that gradually adjusts the RIS phase by minimizing a cost function, typically to maximize signal-to-noise ratio (SNR) or signal strength while reducing interference from other sources. On the other hand, CO provides a more mathematically rigorous approach to solving phase adjustment problems, particularly when the objective function is convex, ensuring that the global optimum is reached.

These methods are effective in static environments but pose significant challenges in dynamic, real-time applications. The main difficulty lies in the real-time adjustment of RIS phase shifts to rapidly changing environmental conditions, such as variations in user mobility, interference levels, and channel fading. In real-time communication scenarios, UAVs and RIS must continuously adapt to fluctuating conditions without introducing excessive latency. This requires advanced algorithms capable of performing fast phase optimization while accounting for factors such as energy constraints and network traffic demands. The dynamic nature of these systems makes it essential to employ adaptive optimization techniques to ensure the RIS configuration remains optimal as the environment changes.

C. Energy Efficiency Optimization

Energy consumption is a critical concern in UAV networks, particularly when deployed for real-time applications where efficiency and reliability are paramount. As UAVs are battery-powered, their operational time is limited by the energy available, making energy efficiency (EE) a key factor in the design and deployment of UAV networks, especially in long-duration missions or resource-constrained environments. RIS-enhanced UAV systems face the additional challenge of managing energy consumption from both the UAV itself and the RIS panels. While RIS can improve signal quality and coverage, the dynamic adjustment of RIS elements, such as tuning the reflection coefficients and phase shifts, requires energy that must be optimized to avoid excessive drain on the UAV's battery. To address this challenge, several EE algorithms have been developed. These algorithms focus on optimizing the transmission power of UAVs and RIS panels to balance high communication quality with minimal power consumption.

By intelligently managing the power control of both the UAV and the RIS, these algorithms ensure optimal use of energy resources. Furthermore, resource allocation strategies are pivotal in UAV-RIS networks, as they allocate power and bandwidth to different network elements while meeting performance requirements. The optimization algorithms consider many factors such as network conditions, UAV mobility, and user demands to dynamically adjust power levels, thereby minimizing energy consumption without sacrificing performance. The combination of these optimization techniques results in systems that can sustain long-duration missions, operate efficiently in real-time applications, and maximize energy efficiency, thereby significantly enhancing overall performance and sustainability.

D. Machine Learning-Based Optimization

Machine learning techniques, particularly RL and deep learning (DL), are becoming increasingly popular for optimizing RIS-UAV systems due to their ability to dynamically adapt to environmental changes and handle complex decision-making processes. These techniques enable UAVs to learn from their interactions with the environment, making them well-suited to optimize both UAV trajectories and RIS configurations in real time. In scenarios where the UAV's path and the RIS phase shifts need to be continuously adjusted in response to factors such as user mobility, channel conditions, and interference, ML techniques offer an effective solution for real-time adaptation.

RL, specifically Q-learning and Deep Q-Network (DQN), plays a critical role in this optimization process. Q-learning allows UAVs to learn optimal policies by exploring the environment and receiving feedback in the form of rewards or penalties, thereby enabling decisions about UAV movement and RIS phase adjustments that maximize communication performance. DQN, an extension of Q-learning, integrate deep learning to handle high-dimensional state spaces, making them ideal for complex environments where traditional Q-learning might not suffice. These algorithms can be used to optimize UAV flight paths, RIS configurations, and coordination among multiple UAVs and RIS panels, thereby improving system efficiency, energy consumption, and throughput.

In addition to Q-learning and DQN, other deep learning models such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) can be employed to model non-linear relationships and time-series data in RIS-UAV networks. These models can predict optimal RIS phase shifts and UAV trajectories over time, accounting for environmental dynamics, including changes in channel quality, obstacles, and interference sources. By leveraging these techniques, RIS-UAV systems can operate autonomously and efficiently, continuously optimizing performance while adapting to real-world conditions. This ability to adapt in real-time is particularly valuable for mission-critical applications, such as emergency response and dynamic IoT networks, where optimal performance must be maintained despite constant environmental fluctuations.

V. CHALLENGES AND OPEN ISSUES

While RIS-enhanced UAV networks hold significant potential for revolutionizing wireless communication by offering flexible, scalable, and energy-efficient solutions, several key challenges remain to be addressed. These challenges span various aspects of system design and operation, including real-time channel estimation, energy optimization, UAV mobility management, and the seamless integration of RIS with UAVs under dynamic environmental conditions. Furthermore, the practical implementation of such systems must overcome obstacles related to hardware limitations, control signaling delays, and scalability in large-scale deployments. Overcoming these hurdles is critical to realizing the full potential of RIS-assisted UAV networks in future communication scenarios, particularly in mission-critical real-time applications.

A. Real-Time Channel Estimation

Accurate Channel State Information (CSI) is essential for optimizing RIS phase shifts and UAV trajectories. However, obtaining reliable CSI in real-time, especially in dynamic environments, remains a major challenge. Several techniques, such as Predictive Channel Estimation (PCE) and machine learning (ML)-based CSI prediction, are being explored to mitigate the impact of feedback delays and dynamic changes in the communication environment.

B. Energy and Flight Time Constraints

UAVs are energy-constrained devices, and optimizing energy consumption while maintaining communication quality is critical. EE algorithms are needed to balance the power consumed by UAVs, RIS panels, and communication systems. Furthermore, several techniques, such as Energy Harvesting (EH) and Dynamic Power Control (DPC), are promising approaches for extending UAV flight time.

C. Security and Jamming

RIS-UAV systems, while offering significant advantages in enhancing network coverage, reliability, and efficiency, are also susceptible to various security threats, including jamming, interference, and unauthorized access. Since both UAVs and RIS devices rely on wireless communication, they are vulnerable to attacks such as jamming, spoofing, and eavesdropping, which can severely degrade system performance, disrupt service continuity, and compromise data integrity. To mitigate these risks, implementing Robust Communication Protocols (RCP) and anti-jamming techniques is essential to ensure secure communication in these systems.

These protocols must be designed to dynamically adapt to changing environmental conditions, handle signal interference, and provide protection against malicious attacks targeting the communication links between UAVs and RIS devices. Furthermore, integrating cryptographic methods, such as encryption and authentication, is necessary to safeguard sensitive data and prevent unauthorized access to the network. In addition, multilayer security protocols that combine physical-layer security, such as beamforming and secret key generation with network-layer encryption and access control are crucial for maintaining the system's overall security and reliability. Such protocols ensure that the system can resist a wide range of attacks, including Denial-of-Service (DoS), signal jamming, and man-in-the-middle attacks, while maintaining robust performance in mission-critical applications.

D. Standardization and Integration with 5G/6G

The lack of standardized protocols for RIS and UAV integration is a significant barrier to widespread deployment. These efforts are essential to ensure interoperability between RIS panels, UAVs, and existing network infrastructures. Additionally, integrating RIS-UAV systems with 5G and 6G networks will require the development of new channel models, spectral management strategies, and resource allocation algorithms.

Conclusion The integration of RIS and UAVs offers many benefits for improving wireless communication in dynamic settings. However, challenges such as real-time optimization, energy efficiency, security, and AI-driven adaptation need to be addressed before large-scale deployment. Future research should focus on these areas. By leveraging the complementary strengths of RIS and UAVs, we can build more efficient, flexible, and scalable communication networks, paving the way for the deployment of 5G and 6G-enabled services. The continued development of these technologies will enable robust communication solutions for real-time applications, such as IoT, autonomous vehicles, and disaster response.

REFERENCES:

[1] P. Saikia, A. Jee, K. Singh, C. Pan, W.-J. Huang, and T. A. Tsiftsis, "RIS-aided integrated sensing and communication systems: STAR-RIS versus passive RIS?" IEEE Open Journal of the Communications Society, vol. 5, pp. 7954–7973, 2024.

[2] J. Li, Z. Li, M. Huang, G. Huang, and G. Yang, "Vehicle positioning method based on UAV assisted RIS integrated sensing and communication system," Physical Communication, p. 102780, 2025.

[3] S. R. Hasan, S. R. Sabuj, M. Hamamura, and M. A. Hossain, "A comprehensive review on reconfigurable intelligent surface for 6G communications: Overview, deployment, control mechanism, application, challenges, and opportunities," Wireless Personal Communications, vol. 139, no. 1, pp. 375–429, 2024.

[4] M. Iqbal, T. Ashraf, M. Zubair, S. M. Jameel, M. Jazib, and J.-Y. Pan, "A comprehensive survey on reconfigurable intelligent surfaces (RIS) and STAR-RIS for next-generation wireless networks," Discover Applied Sciences, vol. 7, no. 11, p. 1253, 2025.

[5] Y. Wu, Y. Li, M. Liu, X. Wang, X. Yang, H. Ye, D. Zeng, Q. Zhao, and S. Li, "Learning an adaptive and view-invariant vision transformer for real-time UAV tracking," IEEE Transactions on Circuits and Systems for Video Technology, 2025.

[6] Z. Hu, Y. Cao, X. Li, X. Zhang, C. Zhang, and Z. Liu, "A real-time UAV delivery system considering dock selection and spatial conflict," Expert Systemswith Applications, vol. 281, p. 127498, 2025.

[7] M. Alqaraleh, M. S. Alzboon, and M. S. Al-Batah, "Real-time UAV recognition through advanced machine learning for enhanced military surveillance," SAP Gamification and Augmented Reality, vol. 3, pp. 63–63, 2025.

[8] K. Messaoudi, O. S. Oubbati, A. Rachedi, A. Lakas, T. Bendouma, and N. Chaib, "A survey of UAV-based data collection: Challenges, solutions and future perspectives," Journal of network and computer applications, vol. 216, p. 103670, 2023.

[9] M. Eskandari and A. V. Savkin, "GANs the UAV path planner: UAV-based RIS-assisted wireless communication for Internet of Autonomous Vehicles," in 2024 IEEE 19th Conference on Industrial Electronics and Applications (ICIEA). IEEE, 2024, pp. 1–6.

[10] W. M. Othman, A. A. Ateya, M. E. Nasr, A. Muthanna, M. El Affendi, A. Koucheryavy, and A. A. Hamdi, "Key enabling technologies for 6G: The role of UAVs, terahertz communication, and intelligent reconfigurable surfaces in shaping the future of wireless networks," Journal of Sensor and Actuator Networks, vol. 14, no. 2, p. 30, 2025.

[11] Nwufo, O. Simpson, and Y. Sun, "Reconfigurable Intelligent Surfaces (RIS) and Their Role in Next-Generation Wireless Networks: An Overview," Transactions on Emerging Telecommunications Technologies, vol. 36, no. 6, p. e70164, 2025.

[12] J. Xie, F. Huang, Y. He, W. Xia, X. Zhao, L. Zhu, D. Yang, and D. Wang, "Drone-mounted intelligent reflecting surface-assisted multiple-input multiple-output communications for 5g-and-beyond internet of things networks: Joint beamforming, phase shift design, and deployment optimization," Drones, vol. 9, no. 5, p. 355, 2025.

[13] Y. Ullah, I. O. Adeoye, M. Roslee, M. A. Ismail, F. Ali, S. Ahmad, A. F. Osman, and F. Z. Ali, "Ddpg-based uav-ris framework for optimizing mobility in future wireless communication networks," Drones, vol. 9, no. 6, p. 437, 2025.

[14] Khennoufa, K. Abdellatif, F. Kara, H. Yanikomeroglu, K. M. Rabie, T. Y. Elganimi, and S. Beddiaf, "Error performance analysis of uav-mounted ris for noma systems with practical constraints," IEEE Communications Letters, vol. 28, no. 4, pp. 887–891, 2024.

[15] S. Lin, Y. Zou, and D. W. K. Ng, "Ergodic throughput maximization for ris-equipped-uav-enabled wireless powered communications with outdated csi," IEEE Transactions on Communications, vol. 72, no. 6, pp. 3634–3650, 2024.

[16] H. E. Hammouti, A. Saoud, A. Ennahkami, and E. H. Bergou, "Energy efficient aerial ris: Phase shift optimization and trajectory design," in Proceedingsof the IEEE Vehicular Technology Conference. IEEE, 2024, pp. 1–5.

[17] H. Hu, S. Zhao, Y. Huang, K. Yu, Q. Kang, and G. Cheng, “Energy efficiency maximization for irs-assisted uav short packet communication,” Scientific Reports, vol. 15, p. 9124, 2025.

[18] M. Dhuheir et al., “Multi-uav multi-ris qos-aware aerial communication systems using drl and pso,” 2024.

[19] ETSI, “Reconfigurable intelligent surfaces (ris); use cases, deployment scenarios and requirements,” European Telecommunications Standards Institute, Tech. Rep. ETSI GR RIS 001 V1.2.1, 2025.

[20] ETSI, “Reconfigurable intelligent surfaces (ris); implementation and practical considerations,” European Telecommunications Standards Institute, Tech. Rep., 2025.

[21] 3GPP, “Unmanned aerial system (uas) support in 3gpp,” 3rd Generation Partnership Project, Tech. Rep. 3GPP TS 22.125, 2022.

[22] M. A. Ullah, V. Kramar, V.-A. Kaariaho, V. Semkin, D. Brilhante, H. Alshaer, C. Cleary, and G. Geraci, “5g integrated communications, navigation, and surveillance: A vision and future research perspectives,” in 2025 Integrated Communications, Navigation and Surveillance Conference (ICNS). IEEE, 2025, pp. 1–13.

[23] 3GPP, “Uncrewed aerial system (uas) application enabler (uae) layer; protocol aspects; stage 3,” 3rd Generation Partnership Project, Tech. Rep. 3GPP TS 24.257, 2022.

[24] M. Jiang, Q. Wu, H. Yang, and B. Zeng, “Large-scale ris-assisted uav-to-vehicle communication: Subarray partitioning and beam-domain channel model,” IEEE Transactions on Wireless Communications, vol. 23, no. 4, pp. 2345–2359, 2024.

[25] J. Yao, Y. Yang, and Q. Chen, “Research on ground-based ris-assisted uav communication for urban emergency response,” IEEE Transactions on Vehicular Technology, vol. 74, no. 3, pp. 2231–2245, 2025.

[26] T. L. Nguyen, G. Kaddoum, T. N. Do, and Z. J. Haas, “Ground-to-uav and ris-assisted uav-to-ground communication under channel aging: Statistical characterization and outage performance,” arXiv, 2024. [Online]. Available: https://arxiv.org/abs/2408.00600.

[27] X. Cao, B. Yang, C. Huang, C. Yuen, M. Di Renzo, D. Niyato, and Z. Han, “Reconfigurable intelligent surface-assisted aerial-terrestrial communications via multi-task learning,” IEEE Journal on Selected Areas in Communications, vol. 39, no. 10, pp. 3035–3050, 2021.

[28] P. Michailidis and N. Patwari, “Energy-efficient ris-assisted uav communication for mobile edge computing tasks,” IEEE Transactions on Mobile Computing, vol. 20, no. 4, pp. 1295–1306, 2021.

[29] W. Rao, Z. Ding, and M. Juntti, “Hybrid ris-uav systems for 5g: A survey and future directions,” IEEE Access, vol. 9, pp. 8677–8692, 2021.

[30] L. Zhou, X. Zhang, and W. Li, “A hybrid ris-uav system for beyond 5g: Challenges and opportunities,” IEEE Transactions on Communications, vol. 69, no. 3, pp. 4589–4602, 2021.

[31] T. Nguyen, M. Nguyen, K. Nguyen, G. Fiumara, and A. Boukerche, “Hybrid uav-ris systems for emergency communications in disaster recovery networks,” IEEE Transactions on Mobile Computing, vol. 23, no. 1, pp. 156–169, 2024.

[32] J. Xie, S. Wang, W. Zhang, and X. S. Shen, “Energy-efficient hybrid uav-ris networks for vehicular communications in urban environments with low-latency requirements,” IEEE Transactions on Vehicular Technology, vol. 73, no. 5, pp. 4306–4319, 2024.

[33] H. Chen, Z. Wei, J. Wang, and K. B. Letaief, “Hybrid ris-aided uav networks for real-time hd video streaming in remote environments,” IEEE Transactions on Multimedia, vol. 27, no. 7, pp. 2155–2167, 2025.

[34] S. Ghosh, M. Hossain, and P. Das, “Dynamic ris-based uav networks for emergency communication systems in natural disasters,” IEEE Transactions on Communications, vol. 71, no. 5, pp. 2345–2356, 2023.

[35] P. Kumar, R. Chien, and X. Qian, “Ad-hoc uav networks with ris for real-time communication during natural disasters,” IEEE Wireless Communications Letters, vol. 12, no. 2, pp. 312–315, 2023.

[36] T. Liu, W. Xu, and J. Zhang, “Reconfigurable intelligent surface-aided uav networks for 5g/6g wireless communication,” IEEE Transactions on Wireless Communications, vol. 23, no. 3, pp. 987–1001, 2024.

[37] Y. Zhang, M. Liu, and X. Qian, “Ris-enhanced uav for urban mobility and vehicular communication networks,” in Proceedings of the IEEE International Conference on Communications, 2023, pp. 1234–1238.

[38] L. Sun, Z. Liu, and F. Zhang, “Ris-enabled uavs for smart farming: Real-time wireless communication in agricultural fields,” IEEE Transactions on Green Communications and Networking, vol. 12, no. 1, pp. 50–59, 2024.

[39] K. Li, Y. Liu, and H. Cheng, "Precision agriculture with RIS-enabled UAV networks: Real-time monitoring and data transmission," IEEE Transactions on Green Communications and Networking, vol. 10, no. 6, pp. 1342–1355, 2023.