Flying Reconfigurable Intelligent Surfaces for 6G: Enhancing Physical Layer Security in Low-Altitude Wireless Networks

Shanza Shakoor, *Student Member, IEEE,* Quang Nhat Le, *Member, IEEE,* Minh-Hien T. Nguyen, *Member, IEEE,* Vishal Sharma, *Senior Member, IEEE,* Mehmet Özdem, *Member, IEEE,* Berk Canberk, *Senior Member, IEEE,* and Trung Q. Duong, *Fellow, IEEE*

***Abstract*—Low-altitude wireless networks (LAWNs) are expected to play a pivotal role in sixth-generation (6G) systems by enabling flexible, on-demand, and infrastructure-light connectivity for communication, sensing, and security-critical applications. However, the highly dynamic propagation conditions, frequent blockages, and evolving security threats inherent to LAWNs pose fundamental challenges to conventional static network architectures. In this article, we investigate flying reconfigurable intelligent surfaces (FRIS) as a transformative enabler for cell-free integrated sensing and communication (CF-ISAC) in LAWNs. By jointly exploiting aerial mobility and programmable electromagnetic reflections, FRIS introduces a new degree of freedom for three-dimensional and environment-aware control of wireless propagation. We present a comprehensive overview of enabling technologies, highlight physical layer security benefits, and provide a representative case study demonstrating the performance gains and sensing–communication trade-offs of FRIS-assisted CF-ISAC systems. Finally, we discuss key research challenges and future directions toward practical and secure 6G low-altitude deployments.**

***Index Terms*—Cell-free (CF), flying reconfigurable intelligent surfaces (FRIS), integrated sensing and communication (ISAC), low-altitude wireless networks (LAWNs), physical layer security (PLS).**

I. Introduction

Sixth-generation (6G) wireless networks are envisioned to support a diverse set of applications that require extreme data rates, ultra-low latency, massive connectivity, high reliability, and strong security guarantees [1]. Representative examples include autonomous aerial and ground mobility, immersive extended reality, massive internet of things, digital twins, and mission-critical public safety services [2], [3]. Meeting these ambitious requirements demands a fundamental shift away from traditional infrastructure-centric network designs toward intelligent, adaptive, and environment-aware wireless systems [4], [5].

In this context, low-altitude wireless networks (LAWNs) have emerged as a key architectural component of future 6G systems. By leveraging aerial platforms operating at low-altitudes, LAWNs enable flexible, rapidly deployable, and infrastructure-light connectivity in scenarios where terrestrial networks are unavailable, overloaded, or unreliable [6], [7]. Despite these advantages, LAWNs are inherently characterized by high mobility, rapidly changing geometry, frequent line-of-sight (LoS) blockages, and strong sensitivity to time-varying conditions [8]. These characteristics severely challenge conventional static network architectures, which are typically designed for quasi-stationary propagation conditions and predictable interference patterns.

Reconfigurable intelligent surfaces (RISs) have recently gained significant attention as a promising solution for enhancing wireless performance by transforming the propagation environment into a programmable entity [9], [10]. By intelligently controlling the phase and amplitude of reflected electromagnetic waves, RISs can improve coverage, mitigate blockages, and suppress interference with low energy consumption [11]. However, most existing RIS deployments are static and terrestrially mounted, which fundamentally limits their effectiveness in LAWNs. In highly dynamic low-altitude environments, a fixed RIS may quickly become misaligned with user locations, obstacles, or dominant propagation paths, resulting in suboptimal or even negligible performance gains.

To overcome these limitations, flying RIS (FRIS), where RISs are mounted on aerial platforms such as uncrewed aerial vehicles (UAVs), have emerged as an extension of conventional RIS technology [12]. By leveraging three-dimensional (3D) mobility and programmable reflections, FRIS enables controllable LoS and non-LoS propagation while mitigating blockages, offering energy-efficient 3D control of wireless propagation in LAWNs through predominantly passive reflection [13].

The mobility of FRIS is particularly attractive in LAWNs, where communication links are highly sensitive to geometry, blockage, and user motion. By dynamically adjusting their position and reflection coefficients, FRIS can create favorable propagation paths, bypass obstacles, and adapt to rapidly changing network conditions [14]. This capability allows the

S. Shakoor and Q. N. Le are with the Dept. of Electrical and Computer Engineering, Memorial University, St. John's, NL A1B 3X9, Canada (e-mail: {sshakoor, qnle}@mun.ca).

M.-H. T. Nguyen and V. Sharma are with with the School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, Belfast, U.K (e-mails: {h.nguyen, v.sharma}@qub.ac.uk).

M. Özdem is with Turk Telekom, 06090 Ankara, Turkey (e-mail: mehmet.ozdem@turktelekom.com.tr).

B. Canberk is with the School of Computing, Engineering and Built Environment, Edinburgh Napier University, Edinburgh EH10 5DT, U.K. (Email: b.canberk@napier.ac.uk).

T. Q. Duong is with the Faculty of Engineering and Applied Science, Memorial University, St. John's, NL A1C 5S7, Canada, and is also with the School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, Belfast, U.K. (e-mail: tduong@mun.ca).

wireless environment itself to become an active participant in network operation, rather than a passive and uncontrollable medium. As a result, FRIS enables proactive rather than reactive adaptation, significantly improving robustness and reliability in low-altitude deployments.

Beyond performance enhancement, security represents a critical challenge for LAWNs, which often operate in open and potentially adversarial environments. Static infrastructure and purely cryptographic solutions may be insufficient to counter mobile eavesdroppers, jammers, or spoofing attacks. In this regard, FRIS provides new opportunities for strengthening security at the physical layer by spatially shaping electromagnetic propagation [14], [15]. Through intelligent reflection control and mobility-aware positioning, FRIS can enhance legitimate links while degrading unauthorized or malicious receivers, thereby complementing higher-layer security mechanisms.

Motivated by these considerations, this article investigates FRIS as a key architectural enabler for next-generation LAWNs. By focusing on the fundamental principles, enabling technologies, and representative performance insights of FRIS-assisted LAWNs, this work aims to clarify the role of FRIS in future 6G deployments and to identify the major research challenges that must be addressed for practical realization.

The main contributions of this article are summarized as follows:

- We present a unified architectural vision for FRIS-assisted cell-free integrated sensing and communication (CF-ISAC) in LAWNs, highlighting advantages over static RIS and conventional UAV-based solutions.
- We discuss key enabling technologies, including CF, ISAC, physical layer security (PLS), and millimeter-wave/terahertz (mmWave/THz) communication, tailored to FRIS-assisted LAWNs.
- We provide representative use cases that demonstrate the practical relevance of FRIS-assisted systems in 6G scenarios such as disaster recovery, dense crowds, and smart cities.
- We present a case study that quantifies the benefits of FRIS mobility and intelligent reflection control, illustrating performance gains and sensing–communication trade-offs.
- We outline practical deployment considerations and identify open research challenges to guide future work toward real-world adoption.

Unlike existing surveys on RIS, UAV-assisted communications, or ISAC systems, this article focuses specifically on the unique interplay between UAV and RIS in LAWNs. While prior works typically treat RIS as static or UAVs as active relays, this work highlights FRIS as a fundamentally different paradigm, where mobility and passive beam manipulation are jointly exploited. Moreover, we emphasize the integration of CF architectures, ISAC, and PLS under a unified FRIS-assisted framework tailored for highly dynamic LAWNs. This perspective enables new insights into environment-aware network control, which are not captured in conventional RIS or UAV surveys.

The remainder of the article is organized as follows. Section II presents the architecture of FRIS-aided LAWNs, providing the foundation for subsequent discussions. Building on this, Section III introduces the key enabling technologies for FRIS-assisted LAWNs. Section IV then highlights representative use cases, followed by Section V, which provides a case study along with performance insights. Next, Section VI discusses practical deployment considerations, while Section VII outlines open research challenges and future directions. Finally, Section VIII concludes the paper.

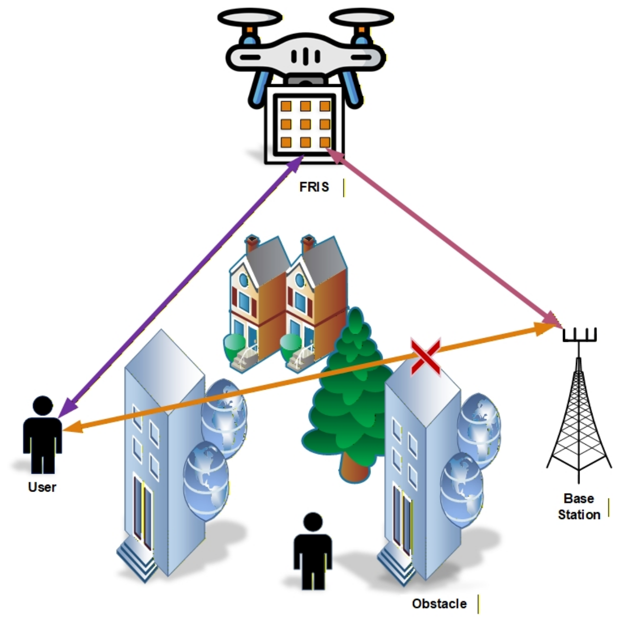

Fig. 1. System architecture of FRIS-assisted LAWN.

II. FRIS-Assisted LAWNs Architecture

This section presents the architecture of FRIS-assisted LAWNs, highlighting their differences from static infrastructures and the role of FRIS as a mobile and programmable propagation controller.

A. System Overview

A representative FRIS-assisted LAWNs architecture is illustrated in Fig. 1. In this architecture, multiple distributed access points (APs) cooperatively serve ground users, while a FRIS dynamically reconfigures the wireless propagation environment. The FRIS adjusts both its spatial position and reflection coefficients to establish favorable propagation paths, mitigate blockages, and adapt to user mobility and environmental changes.

Unlike conventional networks where the wireless channel is treated as an uncontrollable medium, FRIS-assisted architectures enable active manipulation of the propagation environment. By repositioning in 3D space and shaping reflected signals, the FRIS can create controllable LoS and non-LoS links between network entities and users. This capability is particularly valuable in low-altitude environments, where propagation conditions vary rapidly due to mobility, obstacles, and terrain irregularities.

B. FRIS versus Static RIS and UAV Relays

Table I compares FRIS-aided networks with architectures employing static RIS and those without RIS support. Static RIS deployments can reduce blockage. However, their fixed locations limit their effectiveness in highly dynamic low-altitude scenarios. Once user locations or dominant propagation paths change, the performance gains of static RIS may degrade significantly.

In contrast, FRIS introduces controlled mobility, enabling continuous alignment with dominant propagation paths and dynamic user distributions. This mobility allows FRIS to maintain favorable channel conditions even under rapid topology changes, significantly enhancing robustness and reliability. Moreover, FRIS differs fundamentally from UAV-based relays. While UAV relays rely on active transmission and decoding, FRIS primarily operates in a passive or semi-passive manner by reflecting incident signals. As a result, FRIS consumes less energy, generates minimal additional interference, and scales more effectively in dense deployments.

TABLE I
COMPARISON OF RIS-ENABLED ARCHITECTURES FOR LAWNS

Feature	No RIS	Static RIS	FRIS
Mobility	✗	✗	✓
3D Propagation Control	Limited	Partial	Full
Blockage Mitigation	✗	Partial	Strong
ISAC Capability	Limited	Partial	Integrated
PLS Support	Low	Medium	High
LAWNs Suitability	Low	Medium	High

C. Integration with CF Network Operation

The distributed nature of LAWNs naturally aligns with a CF networking paradigm, where multiple APs cooperatively serve users without fixed cell boundaries. In FRIS-enabled CF architectures, the FRIS acts as a shared propagation resource that enhances macro-diversity and coverage continuity across the network. By dynamically repositioning toward users experiencing poor channel conditions or coverage gaps, the FRIS complements cooperative transmission and improves overall network performance.

From an architectural perspective, the FRIS can be coordinated by a central processing unit (CPU) or operate using decentralized control mechanisms, depending on network scale and latency constraints. The CPU is responsible for collecting channel state information (CSI), coordinating distributed APs, and jointly optimizing transmit beamforming and FRIS phase shifts, while managing signaling overhead across the network. Importantly, the architectural abstraction of FRIS-assisted networks is independent of specific waveform designs or optimization algorithms, making it compatible with a wide range of 6G transmission and coordination strategies.

D. Architectural Advantages for LAWNs

By combining aerial mobility with programmable electromagnetic control, FRIS-assisted architectures offer several key advantages for LAWNs. These include enhanced coverage in obstructed environments, improved adaptability to user mobility, reduced reliance on fixed infrastructure, and increased resilience to environmental dynamics. As summarized in Table I, these advantages position FRIS as a promising architectural building block for next-generation low-altitude 6G networks.

FRIS is particularly suitable for LAWNs due to its ability to jointly exploit altitude, spatial positioning, and programmable reflections. Unlike static RIS, FRIS can dynamically maintain favorable channel geometry under rapid topology variations. Compared to UAV relays, FRIS avoids active transmission overhead while still enabling strong channel manipulation, making it more energy-efficient and scalable for dense low-altitude deployments.

III. ENABLING TECHNOLOGIES FOR FRIS-ASSISTED LAWNS

Building on the architectural framework discussed in the previous section, this section presents key enabling technologies for 6G-enabled LAWNs, with FRIS serving as a unifying platform. A summary of these enabling technologies and their primary benefits is provided in Table II.

A. FRIS-Assisted ISAC

ISAC enables wireless networks to perform data transmission and environmental sensing using shared radio hardware and spectrum resources. This capability is particularly valuable in low-altitude environments, where rapid mobility and dynamic obstacles require continuous situational awareness.

FRIS-assisted ISAC exploits reflected signals not only to enhance communication links but also to support sensing tasks such as user localization, obstacle detection, and target tracking. By dynamically adjusting its position and reflection coefficients, the FRIS can improve sensing coverage and accuracy while simultaneously shaping the communication channel. This dual functionality enables real-time adaptation of the wireless environment without excessive signaling overhead, which is essential for scalable low-altitude deployments.

Moreover, sensing information can be fed back to guide FRIS repositioning and reflection control, creating a closed-loop interaction between sensing and communication. This tight coupling allows FRIS-aided networks to proactively respond to environmental changes, improving robustness and reliability in highly dynamic scenarios.

B. FRIS-Assisted CF Networking

CF networking eliminates fixed cell boundaries by allowing multiple distributed APs to cooperatively serve users. This paradigm is well suited to LAWNs, where user mobility and irregular coverage patterns make traditional cell-based designs inefficient.

When combined with FRIS, CF operation benefits from enhanced macro-diversity and improved channel conditions. The FRIS acts as a shared propagation resource that can be repositioned to assist users experiencing poor connectivity or severe blockage. By shaping reflected signals toward specific regions, the FRIS complements cooperative transmission

TABLE II
KEY ENABLING TECHNOLOGIES IN FRIS-ASSISTED LAWNS

Technology	**Role in FRIS-assisted LAWNs**	**Key Benefits**
RIS	Programmable reflection of radio waves	Flexible coverage, blockage mitigation, improved signal quality
PLS	Enhances secrecy and privacy	Protects sensitive data, supports resilience against eavesdropping and jamming
ISAC	Combines wireless communication and sensing	Obstacle detection, user tracking, adaptive deployment
mmWave/THz Communication	High-frequency communication links	Ultra-high throughput, low latency, directional transmission
CF / Swarm Deployment	Collaborative UAV-RIS operation	Redundancy, dynamic coverage, network robustness

among APs and improves coverage continuity across the network.

C. FRIS-Assisted mmWave/THz Communications

High-frequency communication, including mmWave/THz bands, is a key enabler for achieving the ultra-high data rates envisioned for 6G systems. However, signals at these frequencies are highly sensitive to blockage, misalignment, and path loss, which are exacerbated in low-altitude environments.

FRIS provides an effective solution by establishing controllable reflected paths that bypass obstacles and maintain reliable connectivity. By dynamically repositioning to preserve favorable reflection geometry, FRIS can compensate for intermittent LoS loss and support stable high-frequency links. In addition, the highly directional nature of mmWave transmission, when combined with intelligent reflection control, improves spatial selectivity and reduces unintended signal leakage.

These capabilities make FRIS particularly well suited for enabling high-throughput communication in dynamic low-altitude scenarios, where static infrastructure alone may be insufficient.

D. FRIS-Assisted PLS

PLS has emerged as an important complement to conventional cryptographic techniques, especially in open and adversarial wireless environments. LAWNs are particularly vulnerable to eavesdropping and jamming due to their exposure and dynamic topology.

FRIS enhances PLS by enabling spatial control of electromagnetic propagation. Through intelligent reflection configuration and mobility-aware positioning, the FRIS can strengthen legitimate links while suppressing signal leakage toward unauthorized receivers. This spatial selectivity improves secrecy performance without increasing transmit power or relying on complex encryption schemes.

Furthermore, the integration of FRIS with sensing functionality enables adaptive security strategies that respond to environmental changes or potential threats. As highlighted in Table II, FRIS-assisted PLS provides an additional layer of protection that is well aligned with the distributed and dynamic nature of LAWNs. To illustrate the practical relevance of the aforementioned enabling technologies, the next section presents representative use cases of FRIS-assisted LAWNs.

IV. REPRESENTATIVE USE CASES

FRIS-assisted LAWNs combine mobility, programmable propagation control, and integrated sensing, enabling a wide range of emerging 6G applications. The following representative use cases illustrate how FRIS can support flexible coverage, environment awareness, and enhanced security in dynamic and infrastructure-limited scenarios.

A. Disaster Recovery and Emergency Communications

In post-disaster scenarios, terrestrial infrastructure is often damaged or unavailable, making rapid restoration of connectivity critical for rescue and relief operations. FRIS can be quickly deployed to establish temporary communication coverage, while simultaneously sensing the environment for obstacles and survivors. The ability to adaptively shape the wireless propagation environment and bypass blockages provides robust connectivity for first responders, even in complex terrain and unpredictable conditions.

B. Temporary Events and Dense Crowds

Large public gatherings such as concerts, festivals, or sport events create highly dynamic traffic hotspots that are difficult to support using static infrastructure. FRIS-assisted networks can provide on-demand capacity enhancement by dynamically redirecting signal energy toward high-density user clusters. Integrated sensing enables crowd monitoring and mobility prediction, allowing the FRIS to adapt its position and reflection coefficients in real time. This capability supports reliable service delivery while improving safety and situational awareness.

C. Border Surveillance and Critical Infrastructure Protection

The combination of communication, sensing, and PLS makes FRIS particularly attractive for border monitoring and protection of critical facilities. FRIS-assisted ISAC can detect unauthorized targets and adapt coverage to challenging terrain, while secure propagation control protects sensitive communication links. The mobility of FRIS also enables rapid repositioning in response to detected threats or changing environmental conditions.

D. Urban Air Mobility and Smart City Applications

Future smart cities will feature dense aerial and ground-level communication demands driven by urban air mobility, autonomous vehicles, and digital twins. FRIS-assisted networks can support these applications by enabling adaptive 3D coverage, real-time environmental sensing, and secure data exchange in complex urban environments. By continuously reshaping the propagation environment, FRIS can improve reliability and reduce service disruptions caused by blockages and interference.

E. Military and Mission-Critical Operations

In tactical and mission-critical scenarios, communication reliability, sensing accuracy, and security are paramount. FRIS-assisted CF-ISAC systems provide a resilient and rapidly reconfigurable solution capable of operating in contested and adversarial environments, where conventional infrastructure-centric networks may be ineffective or vulnerable. The ability to dynamically shape propagation paths and suppress unintended signal leakage enhances both operational effectiveness and security.

V. Case Study: Secure FRIS-Assisted CF-ISAC LAWNs

To demonstrate the practical applicability of FRIS-assisted CF-ISAC systems in LAWNs, we present a detailed case study evaluating system performance under realistic operational conditions. The focus is on a FRIS that dynamically adjusts its position and phase shifts to enhance communication reliability, optimize coverage, and maintain sensing accuracy simultaneously. This case study investigates the impact of key design parameters and highlights the trade-offs between sensing and communication objectives. The results provide valuable insights into the effectiveness of FRIS mobility and intelligent reflection control for future 6G low-altitude deployments.

A. Scenario Description

As illustrated in Fig. 2, we consider a LAWN deployed over an area of $100\,\text{m} \times 100\,\text{m}$, where $L = 4$ geographically distributed APs serve $K = 3$ legitimate users (LUs) while simultaneously sensing a potential target acting as an eavesdropper (Eve). Both the LUs and the target are equipped with single antennas. Each AP is equipped with a uniform linear array of $M = 4$ antennas with half-wavelength spacing $\lambda/2$. A single FRIS is deployed at a fixed altitude of $H = 50$ m and consists of $N = 10$ passive reflecting elements. The FRIS can dynamically adjust its horizontal position $\mathbf{q}[t] = (x[t], y[t], H)$ over $T = 10$ time slots, subject to a maximum horizontal displacement of $v_{\max}\varrho_t = 20\,\text{m/s} \times$ time duration per slot.

The system operates at a carrier frequency $f_c = 2.7$ GHz with bandwidth $B = 10$ MHz. Path-loss exponents for ground and air-to-ground links are $\alpha_1 = 4$ and $\alpha_2 = 2$, respectively, with a Rician factor $\kappa = 3$ for small-scale fading. A CPU coordinates the APs and FRIS to optimize transmit beamforming vectors $\mathbf{w}_{l,k}$ and FRIS phase shifts θ_n, ensuring

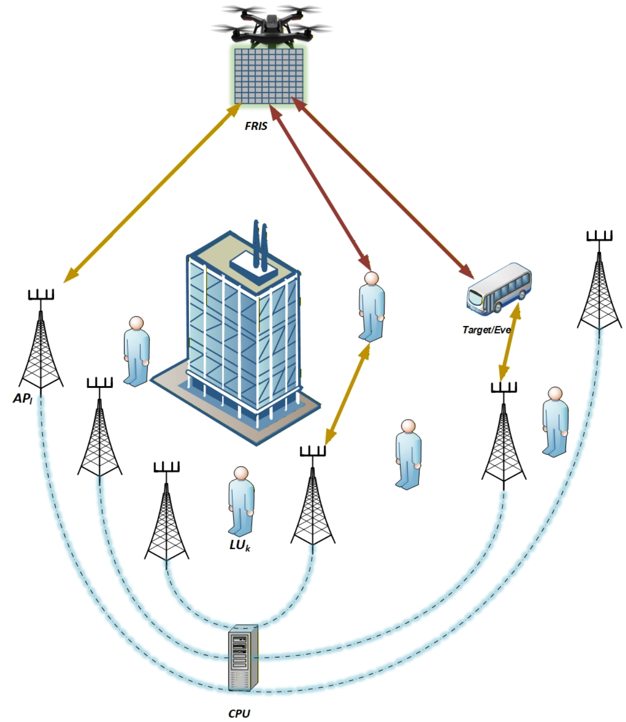

Fig. 2. System architecture of FRIS-assisted CF-ISAC LAWN.

high signal quality for LUs while maintaining a minimum sensing threshold $\gamma_s^{\min} = 1$ dB for target detection. Here, $\gamma_s^{\min}$ represents the minimum sensing signal-to-noise ratio required to ensure reliable detection of the target (Eve). Unlike static RIS deployments, the FRIS mobility enables adaptation to time-varying user distributions and environmental blockages, creating controllable reflection paths that improve signal reach and communication reliability.

B. Performance Insights

The performance of the FRIS-assisted CF-ISAC system is evaluated in terms of the sum secrecy rate (SSR) of LUs under variations in the number of FRIS elements and the minimum sensing threshold. These results highlight the system's ability to exploit spatial and environmental degrees of freedom for simultaneous communication and sensing.

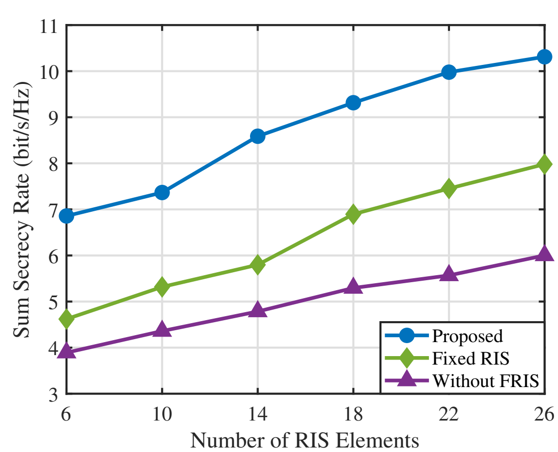

Fig. 3. Impact of the number of RIS elements on the LUs' SSR.

Fig. 3 shows that the SSR increases monotonically with the number of FRIS elements N. Each additional element introduces an extra degree of control over the propagation environment, effectively increasing the rank of the equivalent channel between the APs and LUs. This enables the system to better focus energy toward the LUs while reducing unintended leakage, resulting in higher spectral efficiency. The dynamic positioning of the FRIS further enhances these gains by exploiting favorable LoS and non-LoS paths, adapting to user locations and environmental blockages in real time.

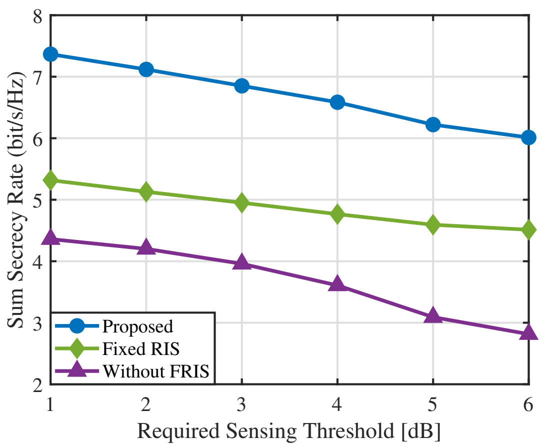

Fig. 4. Impact of sensing threshold requirement on the SSR of the LUs.

The trade-off between sensing and communication performance is illustrated in Fig. 4. Increasing the minimum sensing threshold $\gamma_s^{\min}$ requires more transmit power to maintain radar detection accuracy, which reduces the power available for data transmission to the LUs. Nevertheless, the FRIS-assisted system compensates for this constraint by dynamically controlling phase shifts and adjusting its horizontal position to reinforce constructive signal components at the LUs while minimally affecting the sensing performance. This real-time environment shaping ensures robust communication even under stringent sensing requirements, demonstrating the capability of FRIS to jointly optimize multi-criteria objectives in low-altitude 6G networks.

C. Key Observations

Several key insights emerge from this case study:

- **FRIS mobility is critical:** Dynamic repositioning allows the network to circumvent obstacles and optimize reflection paths, improving coverage and throughput.
- **Performance improves with FRIS size:** Larger FRIS size increases spatial degrees of freedom, boosting coverage and SSR.
- **Sensing-communication trade-offs exist:** Higher sensing thresholds improve target detection but reduce power available for communication, highlighting the need for joint optimization of FRIS trajectory and reflection control.
- **Mobility-aware environment control is essential:** The performance gains shown in Figs. 3 and 4 are strongly influenced by FRIS mobility, underscoring only intelligent reflection is insufficient in dynamic low-altitude environments.
- **Practical constraints matter:** The performance gains of FRIS must be balanced against mobility cost, UAV energy limitations, and control signaling overhead, which may impact real-time deployment feasibility.

VI. Practical Deployment Considerations

Deploying FRIS-assisted CF-ISAC systems in real-world LAWNs requires careful consideration of operational constraints, hardware limitations, and regulatory requirements. In this section, we highlight key practical factors that influence system design and deployment.

A. FRIS Hardware and Control Architecture

FRIS platforms combine UAV mobility with programmable electromagnetic surfaces, creating a tightly coupled hardware system. The FRIS must support rapid phase shift updates, precise attitude control, and robust communication with the CPU. Lightweight and low-power designs are essential to extend flight endurance, while reliable control links are needed to maintain synchronization between the FRIS and the distributed APs. In practice, the FRIS control architecture should be resilient to intermittent connectivity and support fallback modes in case of control link failures.

B. Flight Regulations and Airspace Management

Operating FRIS in urban and suburban environments involves compliance with aviation regulations and airspace restrictions. Regulatory constraints may limit flight altitude, speed, and permissible flight zones, affecting the optimal deployment of FRIS. In addition, coordination with air traffic management systems is required for safe operation in shared airspace. Practical deployment therefore requires integration of communication objectives with flight planning and regulatory constraints, ensuring both safe and effective operation.

C. Environmental Factors and Weather Conditions

Weather conditions such as wind, rain, and turbulence can significantly impact UAV stability and FRIS performance. High winds may force the FRIS to deviate from its planned trajectory, leading to misalignment of reflection paths and degraded communication performance. Rain and humidity can also affect the propagation environment and reduce the effectiveness of high-frequency mmWave links. Robust deployment strategies must account for these uncertainties by incorporating weather-aware trajectory planning and adaptive reflection control.

D. Security and Privacy in Control Links

The control and configuration links between the FRIS, APs, and the CPU are critical for system operation. These links are susceptible to jamming, spoofing, or eavesdropping attacks, which can compromise FRIS performance or enable unauthorized manipulation. Secure control protocols, authentication mechanisms, and encrypted communication are necessary to protect these links. Additionally, privacy concerns arise when FRIS sensing is used to track users or targets, requiring careful handling of collected data and adherence to privacy regulations.

E. Integration with Existing Networks

FRIS-assisted CF-ISAC systems are likely to coexist with legacy cellular networks and other aerial communication platforms. Practical deployment requires seamless integration with existing infrastructure, including coordination with base stations, spectrum sharing, and interference management. Hybrid operation modes, where FRIS complements terrestrial networks during peak demand or emergency events, may be more feasible than fully replacing existing systems. Therefore, network-level planning and compatibility with existing protocols are essential for realistic adoption.

VII. Research Challenges and Future Directions

While FRIS-assisted CF-ISAC offers promising performance improvements for LAWNs, several open challenges must be addressed before practical deployment.

A. Channel Modeling and Estimation for Mobile FRIS

Reliable operation of FRIS-assisted LAWNs depends on accurate and timely CSI. However, channel acquisition is significantly more challenging than in conventional networks due to the mobility of the FRIS and the cascaded nature of the AP–FRIS–user links. Rapid geometry changes, Doppler effects, and time-varying propagation conditions can make CSI outdated within a few milliseconds. Furthermore, ISAC introduces additional complexity because sensing echoes and communication signals share the same propagation paths. Designing robust channel estimation and tracking techniques that scale to large FRIS sizes and operate with limited training overhead remains a key research challenge.

B. Energy-Efficient FRIS Operation and Endurance

FRIS platforms are constrained by limited onboard energy, which must be shared between propulsion, hovering, sensing, and communication functions. Aggressive mobility and frequent reconfiguration can improve performance but reduce operational time. Energy-aware control mechanisms are needed to jointly optimize FRIS trajectory, reflection behavior, and communication performance over long time horizons. This requires balancing the trade-off between mobility gains and energy consumption, especially in mission-critical or long-duration deployments.

C. Scalability and Real-Time Coordination in CF LAWNs

As the number of APs, users, and FRIS elements increases, centralized coordination becomes increasingly complex and latency-sensitive. Real-time operation requires fast information exchange between distributed APs, the CPU, and the FRIS, which may strain fronthaul capacity and computational resources. Scalable coordination architectures, potentially leveraging distributed optimization or learning-based control, are needed to enable practical deployment of large-scale FRIS-assisted CF-ISAC systems.

D. Balancing Sensing, Communication, and Security Objectives

FRIS-assisted LAWNs must simultaneously support reliable communication, accurate sensing, and strong PLS using shared radio resources. Improving sensing performance often requires increased transmit power or specific waveform structures, which can reduce achievable data rates or secrecy margins. Security requirements may also conflict with sensing objectives when the sensed target is a potential eavesdropper. Developing adaptive strategies that dynamically balance these competing objectives based on mission requirements and environmental conditions is a major research challenge.

E. Security Against Intelligent and Mobile Adversaries

Although FRIS enhances PLS, adversaries can also be mobile, adaptive, and sensing-aware. Intelligent eavesdroppers may exploit knowledge of FRIS mobility and reflection patterns to intercept communication or perform spoofing attacks. Robust FRIS strategies that remain effective against smart adversaries, including adversarial machine learning attacks, are largely unexplored. Addressing these threats requires new secure design principles, such as adaptive reflection randomization, secure trajectory planning, and resilient sensing methods.

VIII. Conclusion

This article introduced FRISs as a promising enabler for secure and adaptive LAWNs. By combining aerial mobility with programmable reflection, FRIS can improve communication coverage, support ISAC, and enhance PLS. The case study demonstrates that mobility-aware reflection control significantly improves secrecy performance while effectively balancing sensing and communication trade-offs, highlighting the benefit of FRIS mobility in dynamic environments. Future work should address practical deployment challenges such as channel estimation, energy-efficient operation, scalable coordination, and security against intelligent adversaries. Overall, FRIS-assisted architectures offer a flexible and resilient solution for 6G LAWNs.

Acknowledgment

This work was supported in part by the Canada Excellence Research Chair (CERC) Program CERC-2022-00109 and in part by the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant Program RGPIN-2025-04941. The work of M.-H. T. Nguyen and V. Sharma was supported by UKRI in the UKRI-Horizon Europe program with the UKRI reference number 10061165 under MISO project "Autonomous Multi-Format In-Situ Observation Platform for Atmospheric Carbon Dioxide and Methane

Monitoring in Permafrost & Wetlands" and partly funded by the US-Ireland R&D Partnership Programme, supported by Northern Ireland's Department for the Economy (DfE), for the project, MAARS: Multi-Bessel Antenna with Liquid Crystal Reconfiguration for Angle-Range Secure Communication (grant number: USI 278). The work of B. Canberk is partially supported by The Scientific and Technological Research Council of Türkiye (TÜBİTAK) 1515 Frontier R&D Laboratories Support Program for Türk Telekom 6G R&D Lab under project number 5249902.

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Shanza Shakoor is currently working toward the PhD degree with the Department of Electrical and Computer Engineering, Memorial University, Canada.

Quang Nhat Le is currently a Postdoctoral Fellow with the Department of Electrical and Computer Engineering, Memorial University, Canada.

Minh-Hien T. Nguyen is currently a Postdoctoral Fellow with School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, UK.

Vishal Sharma is currently a Reader with School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, UK.

Mehmet Ozdem is currently the Director of Innovation and Product and Service Development at Turk Telekom, Turkey, and the Vice President of the International Telecommunication Union SG12 and Quality of Service Development Group organizations.

Berk Canberk is currently a Full Professor and the Head of Subject (Department Chair) for Cybersecurity and System Engineering at Edinburgh Napier University, UK.

Trung Q. Duong is a Canada Excellence Research Chair (CERC) and Full Professor at Memorial University, Canada. He is also an adjunct professor at Queen's University Belfast, UK, a visiting professor at Kyung Hee University, South Korea and Edinburgh Napier University, UK.