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SURVEY

Intelligent Reflecting Surface–UAV Systems in the Internet of Things Network: A Survey

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ABSTRACT Intelligent reflecting surfaces (IRSs) and unmanned aerial vehicles (UAVs) are used in Internet of Things (IoT) networks to reduce costs, maximize energy efficiency, and provide a large coverage area through a flexible base station. IRS can reduce the power consumption in the UAV's system, as well as increase the line-of-sight probability. This paper highlights the importance of the IRS in improving the UAV system's performance. It also discusses the UAV components, how they work with the IRS hardware, and their working principles when they are separated or integrated. Then, we discuss several IoT system models using IRS and UAV to enhance the system's performance by maximizing energy efficiency, the achievable rate, and the signal received by the user equipment at ground level. Finally, the IRS-UAV system's open issues are explored, which include some system model scenarios, 3D-IRS-UAV systems, and new proposed solutions. This paper is the first study summarizing the types of IRS-UAV in cellular networks and the main open problems with new proposed solutions. This paper is important for researchers to understand the open issues in various IRS-UAV system scenarios and to develop their own IRS-UAV systems for various 5G network applications.

INDEX TERMS Aerial intelligent reflecting surface (AIRSs), energy efficiency, intelligent reflecting surfaces (IRSs), Internet of Things (IoT), wireless communication, 5G technology.

I. INTRODUCTION

With the introduction and implementation of the fifth generation (5G) network over the last decade, the world of telecommunications has seen tremendous development, resulting in the introduction of many new services and facilities. This network is designed to support an ever-increasing number of connected devices and their applications, contributing huge user convenience.

Several terms, including "cyber-physical systems" (CPSs), the "Internet of Things" (IoT), and "machine-to-machine" (M2M), have been used in recent years to describe a key focus area for the information and communication technology (ICT) sector [1]. Each of these terms is used with a specific emphasis; for example, the IoT is also broadly referred to as the "Internet of Everything," referring to the connection of all articles (i.e., people and machines) to the Internet over a wire or wirelessly through a communication network. IoT networks are classified into four types: low power wide area networks (LPWAN), personal and local area networks (PAN/LAN) [2], mesh networks [3], and cellular networks [4]. Intelligent reflecting surfaces (IRSs) and unmanned aerial vehicles (UAVs) are two examples of the IoT cellular networks.

With the rapid advancement of manufacturing technology and the continual reduction of costs, UAVs stand out enough

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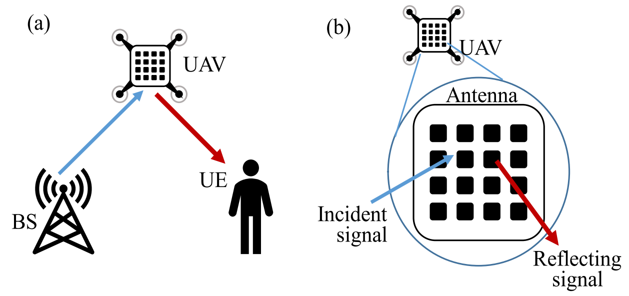

FIGURE 1. UAV communication system: (a) the working principle of a UAV; (b) UAV components.

TABLE 1. Summary of recent reviews for the IRS-UAV integrated system.

Authors	Description
Anas *et al.* (2022) [8]	- The IRS's benefits in the communication system - IRS-aided simultaneous wireless information and power transfer (SWIPT) system - Challenges and open problems in the IRS-UAV systems
Ki-Won *et al.* (2022) [9]	- IRS-UAV communication scenarios - Primary performance criteria - Optimization algorithm - Challenges and open problems
Khan *et al.* (2022) [10]	- Benefits of IRS-UAV in communication networks - Primary performance criteria - Open issues
Cao *et al.* (2022) [11]	- IRS-UAV application in IoT network - Challenges and open problems - IRS-UAV system designs and working principles - Primary performance criteria - Open issues and proposed solution

to be noticed for potential use in the communication network. Compared to traditional terrestrial communications, UAVs can serve as aerial base stations (BSs) to provide remote communication administrations in a variety of situations [5]. The air-to-ground (A2G) channel is likely to be dominated by a line-of-sight (LoS) link, which aids in the establishment of high information rates and reliable transmissions [6], [7]. Additionally, UAV mobility is controllable and can improve communication performance [12]. For example, to achieve better channel conditions, a UAV can fly close to its intended ground user equipment (UE). However, UAVs face a few challenges in some situations, such as energy limits and non-LoS. To overcome these challenges, the IRS can be implemented in the UAV system.

IRS has recently emerged as a promising new approach for developing dynamic and adaptive wireless channels and radio propagation environments for 5G wireless communication systems [13]. IRS is comprised of a planar surface with a vast number of passive reflecting elements, each capable of inducing a controllable amplitude and/or phase change in the incident signal. These reflecting elements enable the flexible reconfiguration of wireless channels and signal propagation between transmitters and receivers [14]. By strategically deploying IRSs throughout the wireless network and intelligently coordinating their reflections, it is possible to overcome wireless channel fading impairments and interference issues, potentially resulting in significant improvements in wireless communication capacity and reliability.

Previous work on IRS-UAV review is summarized in Table 1. More specifically, Anas et al. [8] discuss IRS-UAV applications and the role of IRS and next-generation wireless technology. However, the discussion of the open problem in [9] regarding the IRS-UAV system and the proposed solution can be further expanded by discussing the proposed solution for potential open issues in the IRS-UAV network. Park et al. [9] discuss the optimization algorithm used for IRS-UAV communication and the primary performance criteria. While Cao et al. [11] discuss the application of IRS-UAV in vehicle-to-anything (V2X) communication. However, the IRS and UAV working principles and designs in [10] and [12] can be added to give an overall picture to the reader. Khan et al. [10] discuss the different use cases of physical layer security for IRS-UAV communications. However, discussion on the IRS-UAV system's design and the proposed solution about the open problem and IRS-UAV system can be added in [11].

Thus, in this work, we present a theoretical and component study of the IRS-UAV, a comprehensive overview of the IRS-UAV system types, as well as an up-to-date review of IRS-UAV technology papers. We go into greater detail about the IRS-UAV system designs and operating principles, as well as the major performance criteria, which include energy efficiency, energy consumption, capacity, achievable rate, sum rate, and signal-to-noise ratio (SNR). This paper also highlights open issues and various recommended solutions for IRS-UAV systems.

To the best of our knowledge, this is the first study summarizing the types of IRS-UAV in cellular networks and discussing the proposed solutions for most open problems in this system. The contributions of this work are as follows:

1) We elaborate on the UAV and IRS working principles, provide a comparison of their stand-alone and combined uses, and discuss their components in detail.
2) We discuss the effects of IRS in terms of energy efficiency, power, and data transmission, as well as the comparison between UAV systems with and without IRS in the IoT network.

The remainder of this paper is organized as follows. In Section II, a summary of current review papers on IRS and UAV technologies is presented. In Section III, we focus on the IRS-UAV system components and the basic working principle of IRS and UAV. Section IV discusses the IRS-UAV communication network system's ability to enhance the system's performance by maximizing energy efficiency and improving data transmission. Finally, the open issues and future work are discussed in Section V, with the conclusion provided in Section VI. Additionally, the nomenclature is provided in Table 2.

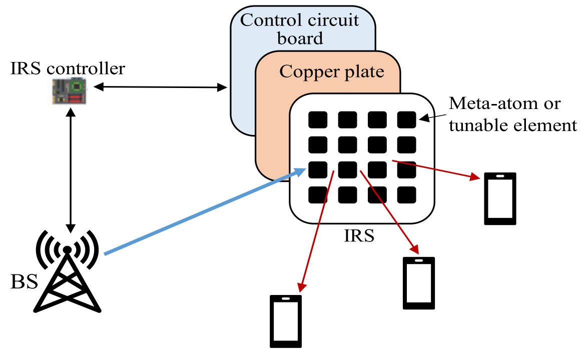

FIGURE 2. IRS architecture.

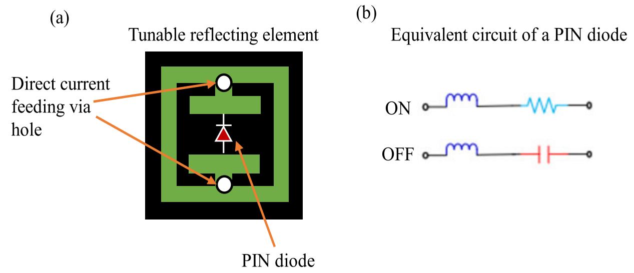

FIGURE 3. (a) the design of the reflecting element; and (b) the PIN diode's equivalent circuit.

TABLE 2. Nomenclature.

AIRS	Aerial intelligent reflecting surface
AP	Access point
BER	Bit error rate
BS	Base station
DL	Downlink
GIRS	Ground intelligent reflecting surface
GN	Ground node
HD	Half-duplex
IoT	Internet of Things
IRS	Intelligent reflecting surface
LEO	Low earth orbit
LoS	Line-of-sight
MIMO	Multiple-input multiple-output
NOMA	Non-orthogonal multiple access
PIN	Positive intrinsic-negative
RF	Radiofrequency
SAT	Satellite
SINR	Signal-to-interference plus noise ratio
SNR	Signal-to-noise ratio
UAV	Unmanned aerial vehicle
UE	User equipment

II. RECENT REVIEWS ON IRS AND UAV TECHNOLOGIES

It has been proved that using IRS in 5G systems is not only cost-effective, but also environmentally friendly and energy efficient [15]. Thus, the UAV and IRS are often used to gather data on the 5G network to improve network performance. The IRS offers a variety of practical benefits for implementation. Firstly, IRS can passively reflect incident signals without necessitating any transmit radiofrequency (RF) connections, resulting in lower hardware and energy requirements when compared to conventional active antenna arrays or recently proposed active surfaces [16]. Moreover, IRS can operate in full-duplex (FD) mode and is devoid of any antenna noise amplification or self-interference, providing a competitive edge over conventional active relays like half-duplex (HD) relays, which have low spectral efficiency, and FD relays, which require self-interference cancellation techniques. Additionally, IRS has a lightweight and conformal design, making it easy to integrate into wireless networks.

IRS can be easily integrated into wireless systems as an auxiliary device. Its high degree of flexibility and compatibility with wireless networks, such as cellular or WiFi, allows for mass deployment to enhance spectral efficiency, energy efficiency, and cost-effectiveness, making it an ideal solution for improving wireless networks. As a result, it is expected that the IRS will prompt major perspective changes in wireless system and network designs. To elaborate further, the transition can be made from the current massive Multiple-Input Multiple-Output (MIMO) system without IRS to a new small or moderate MIMO system aided by IRS, and from the existing heterogeneous wireless network to a new hybrid network aided by IRS. Employing an IRS-assisted MIMO system can reduce the number of antennas required by the BS while preserving the quality of service (QoS) using fine-grained reflect beams generated by smart passive reflection via the IRS [13]. This can lead to a substantial reduction in equipment costs and energy consumption, particularly for future wireless systems that operate at high frequency bands.

There are numerous papers in the literature that discuss IRS and UAV technologies. Pérez-Adán et al. [17] and Gong et al. [18] focus on the physical characterization of the IRS and its electromagnetic properties, as well as the techniques used in the IRS system design in [17]. Holloway et al. [19] and Chen et al. [20] primarily concentrate on the theoretical fundamentals and physics characterization of IRS meta-surfaces as well as their application at various operating frequencies. While Chen et al. [21] discuss UAV swarm communication architectures and appropriate application scenarios. Alladi et al. [22] investigate the various applications of blockchain technology in UAV systems and how blockchain can improve UAV utility in various scenarios. Table 3 summarizes the recent reviews for both IRS and UAV technologies.

III. THEORY AND DESIGN OF IRS-UAV

A UAV is a type of drone with an array antenna that can receive and transmit signals, as illustrated in Fig. 1. UAVs are frequently used as relay BSs. When compared to a traditional BS, a relay BS is used to cover greater areas at a reduced cost.

UAVs work by amplifying and forwarding the input signal. During the signal forwarding process, the amplified power is added to the signal power and the noise power [31]. Thus, the signal power at UAVs can be written as (1):

$$P_{UAV} = P_R + P_A + P_N \tag{1}$$

TABLE 3. Summary of recent reviews for IRS and UAV technologies.

Authors	Field	Description
Alghamdi *et al.*, 2020 [14]	IRS	The optimization and performance analysis technique of intelligent surfaces
Gong *et al.*, 2020 [18]	IRS	Focus on physical characterization of the IRS
Pérez-Adán *et al.*, 2021 [17]	IRS	IRS application, approached issues and open problems
Sur *et al.*, 2022 [23]	IRS	IRS opportunities and challenges
Naeem *et al.*, 2022 [24]	IRS	Discuss the different deployment strategies for IRS in 6G
Zheng *et al.*, 2022 [25]	IRS	Channel estimation and passive beamforming design for IRS
Okogbaa *et al.*, 2022 [26]	IRS	Focus on design and application of IRS
Samaras *et al.*, 2019 [27]	UAV	Complete overview of deep learning technologies applied to counter UAV
Xiao *et al.*, 2021 [28]	UAV	mmWave beamforming enable UAV communication network
Mohsan, 2022 [29]	UAV	The emerging charging techniques for UAV, and the classification and type of UAV
Alsamhi *et al.*, 2022 [30]	UAV	Intelligent UAV computing technology at 6G network

where,P_{UAV} is the UAV's forward signal power, P_R is the UAV received signal power, P_A is the additional UAV power amplifier, and P_N is the noise power.

As illustrated in Fig. 2, the IRS is composed of a smart IRS controller and three physical layers. The meta-surface, located on the first or outer layer, is made up of a vast number of tunable and reconfigurable metallic patches printed on a dielectric substrate, which enable direct control of the incident signals [32]. For the second layer, a copper backplane plate is typically used to reduce energy dissipation when reflecting signals. The third or inner layer includes a control circuit board that drives the reflecting elements, enabling real-time tuning of their reflection amplitudes and/or phase shifts. A smart controller, connected to each IRS, determines the reflection angle, and can be accomplished through various means such as a field-programmable gate array (FPGA) [33], a microcontroller [34], or a direct current source [35]. The IRS controller also functions as a gateway, allowing communication with other network components such as BS and user terminals via wired or wireless backhaul/control links.

The meta-surface consists of an array of numerous meta-atoms with a sub-wavelength electrical thickness, arranged in a planar manner. These meta-atoms can be metals or dielectrics that can alter the direction of incident electromagnetic waves [36]. The alterations in the incident waves are determined by the properties of these elements and the structural arrangement of the array. The electromagnetic properties of the meta-surface are dependent on its physical structure and, as a result, on the frequency it is designed to work with. The meta-atoms, which are the reflective elements or tunable chips embedded in the meta-surface, interact with the scattering elements and use various methods such as positive intrinsic-negative (PIN) diodes [37], varactor-tuned resonators [38], liquid crystal, and microelectromechanical system switches [39]. There are a variety of switching technologies available for controlling the electromagnetic reflection from the smart surface.

Placing PIN diodes as switch elements is one way to control the reflection effect in meta-surfaces [40]. The smart surface operates with two distinct states that are generated by an external bias on the PIN diodes, allowing the surface to control the incoming energy. When the PIN diode is turned off, most of the incoming energy is absorbed. When the PIN diode is turned on, however, a significant portion of the incident energy is reflected. Fig. 3 shows the reflecting element's design and the PIN equivalent circuit. By applying various biasing voltages to the PIN diode via a direct-current feeding line, the element can switch between "ON" and "OFF" states, resulting in a phase-shift contrast of π in the incident signal [41]. The PIN diode's switching frequency can be increased up to a maximum of 5 MHz, which is proportional to the switching time of 0.2 μs [39]. This switching time is significantly less than the typical millisecond channel coherence time. The smart surface enhances the adaptability of the reflected signal by providing additional control over the reflection amplitude of each IRS element.

Fig. 4 demonstrates that signal propagation can be regulated using varactor-tuned resonators. By applying a bias voltage to the varactor, a tunable phase shift is obtained [14]. The phase shift of reflected signals can also be controlled using liquid crystals [42]. The effective dielectric constant of each unit can be adjusted by varying the direct current voltages applied to the patches of liquid crystal-loaded unit cells. Hence, the incident signal's phase shifts can be regulated at various positions on the meta-surface.

Meta-surfaces are created based on Snell's law, where the strongest reflected signal is obtained in the angular direction R and the most dissipated scattered signal is obtained in the specular direction I, which equals the incident wave angle, as illustrated in Fig. 5. However, the reflection and incident angles on the meta-surface are not always the same [43]. As a result, the received power P_d at the destination for the i-th reconfigurable meta-surface can be expressed as (2) and illustrated in Fig. 6.

$$P_d = P_s \left(\frac{\lambda}{4\pi}\right)^2 \left| \frac{1}{z} + \sum\nolimits_{i=1}^{N} \frac{R_i \times e^{-j\Delta\varphi_i}}{r_{s,i} + r_{d,i}} \right|^2 \tag{2}$$

Referring to (2), P_d is the UE received power, P_s is the transmitted power from the BS to IRS, λ is the wavelength, d is the ground distance between the BS and UE, z is the distance between the BS's antenna and the UE, r_s is the distance between the source and the reflection point at IRS, r_d is the distance between the reflection point at IRS and the destination, R_i is the reflection coefficient, and ϕ represents

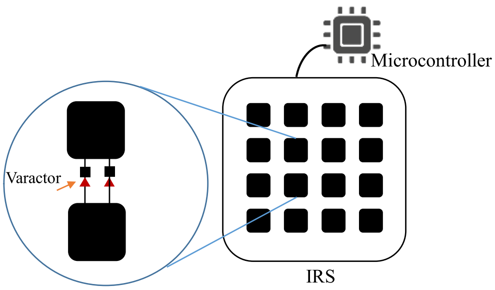

FIGURE 4. Varactor-tuned resonators.

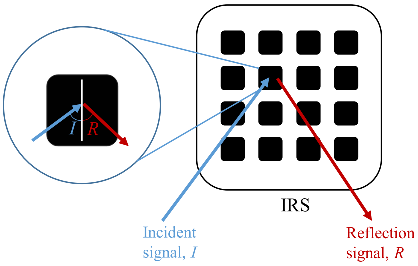

FIGURE 5. The IRS working principle by using Snell's Law.

the phase difference between the two paths, calculated using (3):

$$\Delta\varphi = \frac{2\pi\,(r_s + r_d - z)}{\lambda} \quad (3)$$

The optimization of each R_i is performed to synchronize the received signal's phase with the LoS path, based on certain assumptions like the presence of perfect IRS phase knowledge and the absence of reflection losses. Consequently, the received power at the destination can be represented as (4):

$$P_d \approx (N-1)^2\, P_s \left(\frac{\lambda}{4\pi d}\right)^2 \quad (4)$$

The IRS system is illustrated in Fig. 6, with N reflecting elements-surfaces laid on the ground to act as a reflecting surface to aid in correspondence between the BS and the UE. The independent tuning of the reflection angles and phase of the reflected beam for each meta-surface is governed by Snell's law, unlike antenna arrays where the incidence and reflection angles are identical [44].

IV. IRS-UAV WIRELESS COMMUNICATION NETWORKS

The most common standardizations in a 5G communication network are focused on energy efficiency and capacity maximization, and data transmission. Thus, numerous techniques, such as UAV and IRS, are used on the 5G network to improve energy efficiency and capacity. Indeed, we can employ UAVs and IRS in a variety of architectures within a 5G system.

This section discusses the scenario of combining both UAV and IRS data collection into the same system. We discuss two scenarios: the first occurs when the IRS and UAV are integrated into the same device, which is referred as AIRS from this point forward. The second scenario is one in which the IRS detaches itself from the UAV, which is referred to as GIRS (ground IRS-UAV) from this point onwards.

A. ENERGY EFFICIENCY AND CAPACITY

The authors in [45], [46], [47], and [48] work to maximize the energy efficiency of many IRS-UAV system models. Shafique et al. [45] concentrate on an integrated IRS-UAV communication system that consists of one IRS with N reflective elements and two BSs. To facilitate communication between ground nodes, the IRS combines an additional degree of freedom with the adaptability of a FD UAV deployment. A non-convex energy efficiency problem is formulated to maximize energy efficiency and ergodic capacity by optimizing both the UAV's altitude and the IRS's reflecting elements number. The problem is formulated using fractional programming. The optimization algorithms are then applied to various transmission modes (IRS only, UAV only, and integrated UAV-IRS). Yao et al. [46], discuss an IRS-assisted UAV communication system for emergency wireless networks that includes a multiple IRS with Npassive reflecting elements, multiple UAVs, and multiple UEs. In this system, the IRS is integrated with the 5G-UAV, which utilizes K sub-channels in its bandwidth. To address complex channel conditions with a novel heterogeneous Fisher-Snedecor F composite fading channel model, a joint power problem is formulated to maximize both energy efficiency and capacity. The proposed power allocation with the simple closed-form expression and joint bandwidth power optimization schemes differs from those used in traditional fading channels to achieve this goal. Mohamed and Aïssa [47] focus on a downlink (DL) communication between a UAV and an IRS using one IRS with N elements, one UAV, one BS with multi antenna, and K single antenna cell edge UEs. A joint BS beamforming problem is formulated in order to maximize the system's total energy efficiency. By optimizing the beamforming vector at the BS in conjunction with the phase shift matrix of the UAVs' passive reflecting element. To maximize the energy efficiency of the system, iterative algorithms and alternation optimization techniques are proposed; then, the Difference of Convex-functions (DC) programming is proposed to solve highly non-convex problems. Mohamed and Aïssa [48] discuss an aerial IRS in a multi-cell uplink communication model with M cells and each cell having a single BS with M antennas and Ksingle antenna UEs. The beamforming problem is formulated in such a way that energy efficiency is maximized. In particular, the authors optimize the active and passive beamforming and the UE's transmit power in concert to maximize the energy efficiency. Alternative techniques for active iterative solution generation are proposed. To begin, a minimum mean square error was proposed to achieve transmit beamforming. The phase shift matrix was then obtained using semidefinite relaxation techniques.

Mamaghani and Hong [49] discuss how an IRS-UAV-mounted cooperative jammer aided THz covert communications in beyond 5G (B5G)-IoT networks. The authors used one UAV, one UAV-mounted cooperative jammer (UCJ) and multi single antenna UEs, and optimized the IRS beamforming, UCJs trajectory and velocity to enhance the minimum average energy efficiency. An algorithm that is computationally efficient is proposed to solve a sequence of approximated convex optimization subproblems. The proposed low-complexity overall algorithm is intended to improve system performance.

The energy efficiency increased by 4%, 32%, 12%, and 66% when using IRS compared to cases that involved no IRS as presented in [45], [46], [47], and [48]. The authors in [47] and [48], study HD, with a focus on uplink (UL) in [48] and DL in [47]. The FD system was studied by [45] and [49] but the energy, efficiency enhancement is low in [45] and the system is complex in [49] because the authors used two UAVs in the system model. Fig. 7 shows the effect of the number of reflecting elements on the energy efficiency in the AIRS and UAV-only modes, as presented by [48]. Energy efficiency does not depend on the number of reflecting elements in the UAV-only modes. But in the AIRS mode, when the IRS's reflecting element number is increased, the energy efficiency increases due to the increase in the total power, which includes the received signal power (illustrated in Fig. 8) [46]. The increase in reflecting element's numbers led to the increase in array gain because the reflecting element is affecting both the channel between the BS and UAV-IRS and between the UAV-IRS and the UEs.

The authors in [50], [51], [52], [53], and [54] work to minimize the power consumption in the IRS-UAV system. Cho and Choi [50] discuss a single UAV-DL system in multiple UE MIMO scenarios using a single UAV antenna and M passive elements at each IRS. The authors divided the channel into small-scale and large-scale fading channels in this system. An optimization problem is formulated to minimize UAV energy consumption by jointly optimizing the UAV flight speed, trajectory, and communication time with the assistance of multiple IRS. An approach called successive convex approximation (SCA) is suggested to tackle optimization problems, and a low-complexity algorithm is employed to select the best IRS for transmission. Zhou et al. [51] concentrate on AIRS-enhanced cell-free massive MIMO system scenario using multi access points (APs) and using central processing unit (CPU) to control. The energy consumption and total transmission power can be minimized by solving an energy problem through joint design of the AIRS Doppler compensation vector, beamforming vector, and power allocation vector at each AP, along with the AIRS reflecting vector. The angle-sensing mothed is proposed to solve the energy problem. Yang [52] concentrate on a UAV-assisted IRS system that consists of two UAVs and one IRS with an N-element. To minimize the system's energy consumption, a high non-convex problem is formulated, by creating the UE's transmission power and task allocation ratio using the UAV's trajectory and transmission power, as well as the IRS's phase shift matrix. To solve the high non-convex problem, an alternative optimization strategy based on the block coordinate descent method is also proposed. Cai et al. [53] discuss an IRS-assisted UAV DL time division multiple access communication system in which there is one IRS with N elements, one UAV with M antennas, and one UE with K elements. A non-convex optimization problem is formulated to minimize the system's average total power consumption by optimizing the UAV trajectory and velocity simultaneously with the minimum data rate requirement for each user. Additionally, phase control is performed at the IRS. To obtain an effective suboptimal solution, the alternating optimization algorithm is proposed.

The authors in [54] and [55] work to improve the power in the IRS-UAV system. Zhou et al. [54] discuss an AIRS-aided cell-free massive MIMO based wireless sensor network system in which there is one IRS with N reflective elements, multiple AP and multi single antenna UE. A problem of optimizing transmission power is defined, aiming to minimize the total transmission power of all access points while meeting a given signal-to-interference plus noise ratio (SINR) through the optimization of beamforming vectors and AIRS reflection coefficients. An iterative optimization algorithm is suggested to solve the transmission power optimization problem by designing a passive beamforming mechanism at the AIRS and an active beamforming mechanism at each AP. Ge et al. [55] focus on a DL communication between a UAV and an IRS using K IRS with N reflective element, and one UAV with K single antenna UE. An optimization problem is created to increase the power received by the ground user, involving the optimization of passive beamforming at the IRSs, active beamforming at the UAV, and trajectory of the UAV during a specified flight time. To solve the joint optimization problem, the efficient algorithm and SCA technique are proposed.

The total power in the system was reduced when using IRS, compared to cases with no IRS, as presented in [46], [51], and [54], When the IRS's reflecting element number doubles, the power consumption is reduced by 44%, 14%, and 27%, as presented in [50], [52], and [53], respectively. Fig. 9 and Fig. 10 show the effect of the reflecting element number on the transmission power and the power consumption, as presented by Yang [52] and Zhou et al. [54], respectively. The UAV-IRS system utilizes a PIN diode to control each reflector, resulting in lower power consumption compared to the MIMO-UAV system that requires power amplifiers, as the power consumption in PIN diodes is significantly lower. Consequently, the total power in UAV-IRS is smaller than in UAV only because the total power depends on power consumption and power transmission, and both are smaller in the UAV-IRS. In addition, when the IRS's reflecting elements number increased, the transmission became stronger [56]. The authors in [50] and [55] focus their study on the power in DL, while the other authors do not discuss the effect of distance between UAV-IRS and BS, and the distance between UAV-IRS and the UEs on the total power.

The authors in [57], [58], [59], and [60] work to maximize the SNR. In particular, Lee et al. [57] discuss a low earth orbit (LEO) satellite (SAT) communication system that consists of

IRS, single source LEO SAT (Sat-S), and multi single antenna terrestrial user. A constrained optimization problem is created to maximize the SNR at the receiver, while meeting a power transmission constraint at the Sat-S. By optimizing the reflect beamforming and transmit beamforming. The IRS assisted LEO SAT communication system is proposed to provide high quality communication service and achieve better energy efficiency. Lu et al. [58] concentrate on an AIRS-enabled wireless relay system that consists of one IRS on an aerial platform with N reflective element and one BS. An optimization problem with high non-convexity is defined to maximize the worst-case SNR over all possible locations by optimizing the placement of AIRS, the 3D passive beamforming, and the transmit beamforming at the source node. The objective of maximizing the SNR was achieved by decoupling the design of passive beamforming for the AIRS, which involved balancing the resulting angular span and cascaded path loss. Next, the Bram broadening and flattening techniques were applied to form a flattened beam pattern with a broadened and adjustable beamwidth suitable for the size of the target coverage area. Lu et al. [59] concentrate on an AIRS-enabled wireless relay system that consists of an IRS on an aerial platform with N reflective elements and a BS. An optimization problem is formulated to maximize the worst-case SNR across all locations, which is a non-convex problem with high dimensions. The optimization involves the placement, transmit beamforming of the source node, and the phase shift of the AIRS. The proposed schemes present an efficient suboptimal solution based on sub-array design to address a non-convex problem, and this solution is compared with the benchmark scheme. Conversely, Hashida et al. [60] added the IRS to the UAV communication system to prevent interference signals from spreading to a wide area and to maximize the system's performance by maximizing the SINR.

The SNR enhancement in the wireless-powered communication network when IRS is implemented compared to cases without IRS is illustrated in Fig. 11 [13]. The increase in SNR is because the reflecting elements in IRS provide additional signal reflection power [61]. Note that the authors in [57], [58], and [59] did not discuss the effect of the distance between UAV-IRS and BS or the distance between UAV-IRS and UEs on the SNR when using IRS compared to cases without IRS.

In [45], [49], [54], [57], and [59] the authors integrate IRS and UAV into a single AIRS device, which reduces energy consumption by eliminating the need for an additional power amplifier. At the UAV, the PIN power consumption is less than the AF power consumption. The IRS also does not require any energy source for RF processing, decoding, encoding and transmission [62]. Thus, the AIRS is more energy efficient than the IRS and UAV separately [50], [53], [55], [60]. Note that the authors used a variety of fading models, including Rayleigh fading [47], [49], [52], [54], Rician fading [45], [50], [53], [55], a novel heterogeneous F composite fading channel model [46], multi-path fading channel [51],

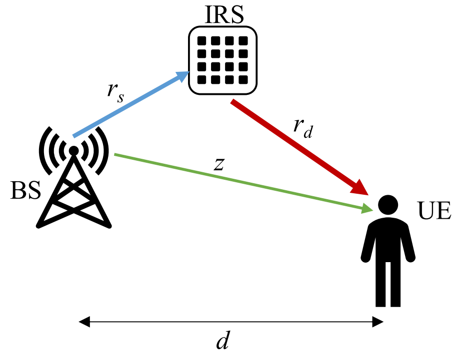

FIGURE 6. The visualization of (2).

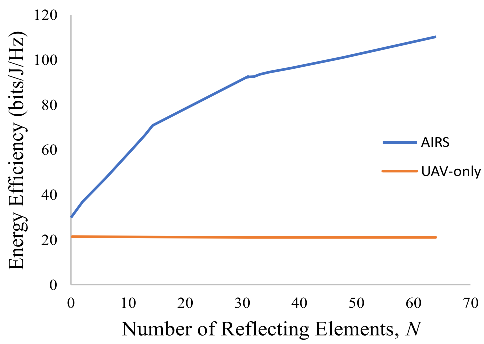

FIGURE 7. Energy efficiency vs. the number of reflecting elements [48].

and block fading [48]. Table 4 summarizes the recent research in energy efficiency and capacity maximization in IRS-UAV systems.

B. THE ACHIEVABLE RATE AND SUM RATE

The achievable rate and the sum rate are used to represent the system's data transmission efficiency. The achievable rate suggests the maximum number of bits that are transmitted in the channel per one second. While the sum rate is used to represent the summation of the achievable rate of multiple concurrent retransmissions. Zheng et al. [63] discuss a LEO SAT communication system with a two-sided cooperative IRS. A beamforming optimization problem is formulated to maximize the overall channel gain from the high mobility SAT to each ground node (GN) by optimizing the active transmit and receive beamforming at the SAT/GN as well as the cooperative passive beamforming (CPB) at the two-sided IRS. To solve the beamforming optimization problem, an efficient transmission protocol is proposed. Zhou et al. [64] discuss an aerial IRS in a cell-free DL communication model with multi-access points and K single antenna users when the AIRS and AP are controlled by a CPU. To maximize the achievable user transmission rate, the rate optimization problem is formulated by designing the power allocation vector of each AP, the phase shift matrix at the AIRS, and the beamforming vector at each AP. To solve the rate optimization problem, an iterative optimization strategy and optimization algorithm are proposed Pan et al. [65] focus on

TABLE 4. Summary of existing literature on energy efficiency and capacity.

Author	Type of System	Goal	Description	Method
Shafique *et al.* [45]	UAV-IRS relaying system	Maximize energy efficiency and ergodic capacity	Solve a non-convex energy efficiency problem by optimizing the UAV's altitude and the reflecting element's number.	Optimization algorithm
Yao *et al.* [46]	Multi-IRS multiple UE system	Maximize the energy efficiency and ergodic capacity	Using proposed mothed to solve the power problem under complex channel condition	Power allocation; Bandwidth power optimization schemes and algorithm
Mohamed *et al.* [47]	Multi antenna BS with associated single antenna UE assisted UAV-IRS	Maximize the energy efficiency and ergodic capacity	Solve beamforming problem by optimizing the beamforming vector	Iterative algorithm; alternating optimization techniques; DC programming
Mohamed *et al.* [48]	Multi-cell uplink at cellular network with NOMA aerial IRS	Maximize the energy efficiency	Optimize the passive and active beamforming to solve beamforming problem	Optimization algorithm; semidefinite relaxation; minimum mean square error
Tatar Mamaghani *et al.* [49]	IRS-UAV-mounted cooperative jammer aided THz communication system	Maximize the energy efficiency	Solve the optimization problem by optimizing the IRS beamforming, and UCJs trajectory and velocity	Block successive convex approximation approach; a low-complex algorithm
Cho *et al.*[50]	Single UAV DL with multi-IRS and multiple UE	Minimize the energy consumption	The optimization problem is solved by optimizing the UAV trajectory, flight speed, and communication time	SCA; Minimize energy consumption algorithm
Zhou *et al.* [51]	AIRS-enhanced CF massive MIMO system	Minimize the energy consumption	Design the AIRS Doppler compensation vector to solve the energy problem	Angle sensing algorithm; angle information-aided transmission strategy
Yang [52]	UAV assisted mobile edge computing system with IRS	Minimize the power consumption	A high non-convex problem is solved by optimizing the transmission power and UAVs flight trajectory	Block coordinate descent method; alternating optimization algorithm
Cai *et al.*[53]	IRS-UAV enabled narrowband DL TDMA system	Minimize the power consumption	Optimize the UAV trajectory and velocity to solve the non-convex optimization problem	Iterative algorithm
Zhou *et al.* [54]	AIRS enhanced cell free massive MIMO-based WSN	Minimize the total transmit power of all applications	A transmission power optimization problem is solved by optimizing the beamforming vectors and AIRS reflection coefficient	Iterative optimization algorithm
Ge *et al.* [55]	IRSs-assisted UAV system	Maximize the received power	The optimization problem is solved by optimizing the passive and active beamforming and UAVs trajectory	SCA
Lee *et al.* [57]	IRS-LEO satellite system	Maximize the receive signal-to-noise ratio (SNR)	Optimize the reflect and transmit beamforming to solve the optimization problem	Added IRS
Lu *et al.* [58]	5D-AIRS enable system	Maximize the worst-case SNR	A high non-convex optimization problem is solved by optimizing the AIRS placement and passive beamforming	Novel Bram broadening and flattening techniques
Lu *et al.* [59]	AIRS assisted system	Maximize the worst-case SNR	A high non-convex optimization problem is solved by optimizing the transmit beamforming	Efficient suboptimal solution
Hashida *et al.* [60]	IRS-aided UAV system	Maximize the SINR	Optimization problem is solved by using reflecting element	Added IRS

DL communication between a UAV and an IRS using one IRS with N reflective elements, a UAV, and multi single antenna UE. The non-convex optimization problem is formulated to maximize the minimum average achievable rate for all users by optimizing the phase shift of IRS, the power control, the UAVs trajectory, and the allocation of THz sub-bands. To maximize the minimum average achievable rate, the iteration algorithm band on SCA is proposed. Guo et al. [66] discuss a UAV-borne IRS-aided system with multi-UAV-IRS, and multi single antenna UE. The non-convex optimization problem is formulated to maximize the minimum rate of multiple user clusters by optimizing the passive beamforming at the UAV-borne IRSs, the placement of UAVs, and beamforming at the BS. The simulated annealing-based hybrid particle swarm optimization algorithm is proposed to design the deployment of UAVs for maximize the average minimum achievable rate, then, the penalty-based block coordinate descent (BCD) algorithm is proposed to design the passive and active beamforming for maximizing the instantaneous minimum rate.

Huang et al. [67] discuss a multi-IRS aided communication system in which there is a multi-IRS with N reflective elements, multi single antenna UE, and single antenna AP. The optimization problem is formulated to maximize the average achievable data rate by optimizing the location number and phase shift coefficient of IRS. To solve the optimization problem, the differential evaluation algorithm was proposed. Ji et al. [68] discuss an IRS-assisted UAV communication system in the presence of a jammer. A non-convex problem is formulated to maximize the average rate of the UAV communication by optimizing the UAV's trajectory, the GNs' transmit power and the IRS' passive beamforming. The SCA, semidefinite relaxation techniques, and alternating optimization-based algorithm are proposed to solve a non-convex problem.

The achievable rate enhancement when using IRS compared to cases without IRS is illustrated in in Fig. 12 [69]. The increase in the achievable rate is because of the increase in signal reflection power when reflecting elements are used. The authors in [63], [64], [65], [66], [67], and [68] discuss the achievable rate when using IRS and UAV-IRS, and the effects of changing the number of IRS's reflecting elements. However, the authors did not discuss the relationship between the achievable rate and the distance between UAV-IRS and the BS or between the UAV-IRS and UEs. More specifically, it is expected that the achievable rate decreases with increasing distance, which is due to the decrease in the signal power [70]. The ratio between the power and the achievable rate can be represented as in (5), with the equation for SINR is represented in (6):

$$R_A = \frac{W}{j} \log_2 (1 + SINR) \tag{5}$$

$$SINR = \frac{|H|^2 P}{I^{intra} + I^{inter} + \sigma^2} \tag{6}$$

where R_A is the achievable rate, W is the bandwidth, j is the sub-channel, H is the channel gain, P is the power allocation,I^{intra} is the intra-cell interference and, I^{inter} is the inter-cell interference.

Nguyen et al. [71] focus on DL communication between the UAV and UE by using an IRS-assisted wireless network. A mixed-integer non-linear optimization problem is formulated to maximize the sum rate achieved by the UEs by optimizing the IRS phase shifts, UAV placement, and sub-channel assignments, considering the wireless backhaul capacity constraint. To optimize the UAV placement and sub-channel assignment, the alternating optimization method and SCA are proposed. Then, the iterative sub-channel assignment method is proposed to efficiently utilize the bandwidth and balance bandwidth allocation for backhaul links and wireless access. Zhang et al. [72] focus on DL communication between a UAV and an IRS using one IRS and multi single antenna UEs. A joint optimization problem is formulated to maximize the sum-rate of all users by optimizing the UAV trajectory and designing the reflecting IRS. The BCD method is proposed to decompose the joint optimization problem. To begin, an approximation linear algorithm was proposed to optimize the UAV's transmit power. Then, the phase shift was optimized by using the IRM method. Finally, the UAV trajectory was optimized using an enhanced reinforcement Learning algorithm. The UE sum rate is enhanced by 15% and 85% in IRS cases compared to cases without IRS in [71] and [72], respectively (illustrated in Fig. 13). The UE sum rate number increases because of the high passive beamforming gain from the large reflecting elements number [73].

Xu et al. [74] focus on DL communication between a master UAV (MUAV) and an auxiliary UAV (AUAV), which carries an IRS. The authors used one MUAV with multi antenna, one IRS-AUAV with N reflective elements and multi single antenna UE. The high complexity optimization problem is formulated to maximize the throughput under the battery capacity, same-side distance power, and UAV's trajectories. To maximize the throughput of the system, the pre-activation penalty multi-agent Deep Deterministic Policy Gradient (PP-MADDPG) method is proposed. As a result, the throughput increased by 94% and 15%, respectively, when ε-greedy method and the Deep Deterministic Policy Gradient (DDPG) were used. Lyu et al. [75] focus on DL communication between a UAV-IRS and BS using one UAV-IRS with N reflective elements, one BS, and multi single antenna UE. The iterative alternating optimization problem is formulated to minimize the system's weighted sum age of information (AoI) by optimizing the UAV's trajectory and the active and passive beamforming. To solve the non-convex problem, the SCA algorithm is proposed. As a result, the system weighted sum AoI was reduced by 67% when the SCA algorithm was used compared to the fixed location cases.

Shao et al. [76] concentrate on an IRS self-sensing system that consists of an IRS with N reflective elements and M sensors, as well as one UAV. The authors study the performance effects of adding sensors on the IRS, and the multiple signal classification algorithm is proposed to sense the direction of nearby target from IRS. The average received signal at the IRS sensor was then maximized by optimizing the IRS passive reflective matrix, which led to a minimization of the mean square error. As a result, the root mean square error was reduced by 15 times in the self-sensing IRS model compared to the model without a sensor. Hua and Wu [77] discuss a UAV-assisted IRS communication system with a single antenna UAV, single antenna BS, and multi-IRS with N reflective elements. A non-convex fairness bit error rate (BER) problem is formulated to minimize the maximization of BER by optimizing the IRS phase shift, IRS scheduling and the UAV trajectory. To solve the fairness problem in BER, the binary constraint was transformed into a series of equivalent equality constraints. Then, to obtain a suboptimal solution, the penalty-based algorithm was proposed. As a result, the fairness utility value increases with time, and the performance gain increases as IRS's reflecting elements number increases when using the proposed scheme. The increase is because the reflecting elements help to achieve high passive beamforming gain.

In [63], [64], [66], [67], [74], and [75] the authors integrate the IRS and UAV into a single AIRS device, which results in better performance than UAV with ground IRS (GIRS) presented in [11], [65], [68], [71], [72], and [76]. AIRS have good propagation path without obstacles to maximize the single power reaching at UEs via a reflecting path [60]. Additionally, AIRS provide a larger coverage area than GIRS and is more flexible; the UAV need to spend more flying time around GIRSs to improve the received signal strength, because the large number of IRSs increases the performance [55]. The large number of IRSs reflective elements also improves the achievable rate performance in the system, which means we can transmit power by using large number of IRS reflective elements [64].

The number of reflecting elements required for IRS on a UAV depends on several factors, including the size and shape of the IRS, the operating frequency, and the desired communication performance. To guarantee optimal relaying performance, the number of reflecting elements in the IRS should be carefully designed to achieve the desired signal strength and coverage while minimizing interference and power consumption. Generally, a larger number of reflecting elements can provide better performance, but it also increases the complexity and cost of the IRS.

Several methods can be used to determine the optimal number of reflecting elements in the IRS, including:

1) Channel measurements: The wireless channel between the UAV and the ground users can be measured to determine the optimal number of reflecting elements required for the IRS to achieve the desired signal strength and coverage [78].
2) Optimization algorithms: Optimization algorithms can be used to design the optimal IRS configuration, including the number of reflecting elements, to minimize interference and power consumption while maximizing the signal strength and coverage [79].
3) Simulation and modeling: Simulation and modeling tools can be used to evaluate the performance of different IRS configurations with varying numbers of reflecting elements, and the optimal number can be determined based on the results [80].

In general, the optimal number of reflecting elements in the IRS depends on the specific communication requirements and operating conditions. For example, a larger IRS with more reflecting elements may be required for long-range communications or in environments with significant signal attenuation, while a smaller IRS with fewer elements may be sufficient for shorter-range communications or in less challenging environments.

In conclusion, the number of reflecting elements required for an IRS on a UAV to guarantee optimal relaying performance depends on several factors and can be determined through channel measurements, optimization algorithms, or simulation and modeling tools. The optimal number of reflecting elements should be carefully designed to achieve the desired signal strength and coverage while minimizing interference and power consumption.

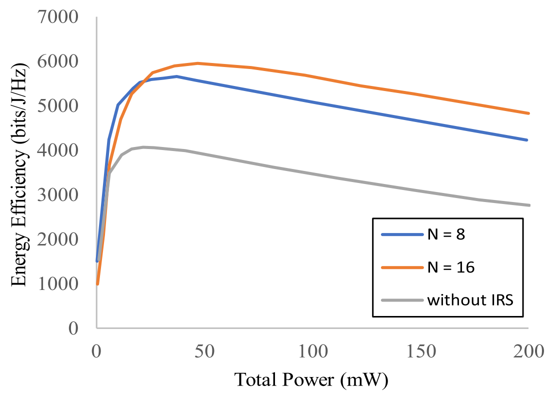

FIGURE 8. Energy efficiency vs. versus the total power for 5G-UAVs system with and without IRS [46].

Table 5 summarizes the existing literature on achievable rate and sum-rate in the IRS-UAV systems, while Table 6 summarizes the available simulation parameters.

V. OPEN ISSUES AND FUTURE WORK

The IRS-UAV system in the 5G wireless communication network has several unresolved issues and needs additional research, which are discussed as follows:

A. IRS-UAV CHANNEL MODEL

Because the IRS and the UAV are connected, the system has a quick, dynamic movement pattern. Real-time channel estimation and reconfiguration are necessary for this mobile operation, taking into consideration the effects of fading and shadowing, in addition to the smart controller functions as a dynamic information conduit between the terrestrial BS and AIRS. Based on this, the issue arises on how real-time reconfigurability under mobile situations can be enabled while requiring the least amount of computing under IRS's hardware constraints. Research on channel design and estimation for AIRS-Non-Orthogonal Multiple Access (NOMA) is required due to the dynamic channel state information (CSI)-dependence of its passive AIRS elements to set the reflecting elements, combined with the multi-user nature of NOMA. Developing reliable aerial channel models necessitates accounting for several factors such as IRS reflection coefficients, fluctuations, mutual coupling between elements, reflection loss, and misaligned signal beams resulting from UAV mobility. In contrast to conventional technologies, the passive elements of the IRS's metamaterial architecture reflect the signal in the intended direction, eliminating the need for a transceiver chain.

The usual scenario in communication systems involves a considerable separation between the transmitting and receiving antennas and the users, which is commonly referred to as

TABLE 5. Summary of existing literature on achievable rate and sum-rate.

Authors	Type of System	Goal	Description	Method
Zheng *et al.* [63]	LEO satellite system	Maximize the achievable rate	Optimize the passive and active beamforming to solve beamforming problem	Efficient transmission protocol
Zhou *et al.* [64]	AIRS aided cell-free massive MIMO system	Maximize the achievable rate	The rate optimization problem is solved by design the power allocation vector the beamforming vector of each AP	Iterative optimization strategy; Optimization algorithm
Pan *et al.* 62 [65]	IRS-UAV THz communication system	Maximize the achievable rate	Optimize the phase shift of IRS and power control to solve a non-convex optimization problem	Iteration algorithm
Guo *et al.* [66]	UAV-borne IRS aided system	Maximize the achievable rate	Optimize the active and passive beamforming to solve a non-convex optimization problem,	simulated annealing-based hybrid particle swarm optimization algorithm; BCD algorithm
Huang *et al.* [67]	Multi IRS- aided system	Maximize the AADR	The optimization problem is solved by optimizing the phase shift coefficient of IRS	DE algorithm
Ji *et al.* [68]	IRS assisted UAV system	Maximize the average rate	Optimize the passive beamforming and UAVs trajectory to solve a non-convex problem	SCA; semidefinite relaxation; alternating optimization algorithm
Nguyen et al.[71]	IRS assisted UAV system	Maximize the sum rate	The mixed integer non-linear optimization problem is solved by optimizing the IRS phase shift and UAV placement	SCA; alternating optimization method
Zhang *et al.* [72]	IRS assisted UAV system	Maximize the sum rate	Optimize the UAVs trajectory and design the IRS reflecting to solve the optimization problem	BCD method
Xu *et al.* [74]	MUAV and AUAV with IRS system	Maximize the throughput	A high complex optimization problem is solved by optimizing the UAVs trajectory	PP-MADDPG method
Lyu *et al.* [75]	AIRS aided system	Minimize the weighted sum AoI	The iterative alternating optimization problem is solved by optimizing the active and passive beamforming, and UAVs trajectory	SCA
Shao *et al.* [76]	IRS self-sensing system	Minimize the minimum square error	The IRS passive reflective matrix is optimized to solve the optimization problem	Added sensor
Hua *et al.* [77]	IRS assisted UAV system	Minimize the maximum BER	Optimize the IRS phase shift and UAVs trajectory to solve a non-convex fairness BER problem	Penalty based algorithm

the "far-field" regime. However, in the case of UAV mobility, it is difficult to maintain a consistent distance between users and their serving IRS that would allow for the near-field or far-field regime to be implemented in an AIRS- NOMA network. Therefore, the system needs to be dynamically adjusted to determine the appropriate regime to operate under. Furthermore, to optimize channel estimation techniques in the fast-changing wireless environment and meet the dynamic QoS requirements of users, the AIRS control layer must furnish environment data and measurements to the ground controller. Achieving this goal necessitates the use of sensing components with receiver chains to facilitate data sharing with the BS. The development of efficient algorithms is crucial to reduce complexity and minimize energy consumption.

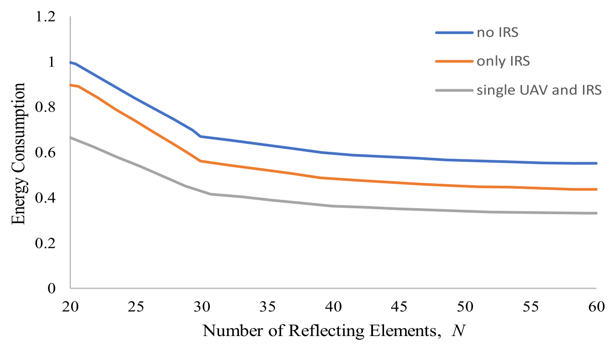

FIGURE 9. Energy consumption versus the number of IRS elements [52].

B. IRS-UAV THZ COMMUNICATION

Compared to microwave and millimeter wave-based communication, THz communication offers significantly narrow frequency bands and can achieve transmission rates of several hundred gigabits per second, making it a promising technology for high-speed communication [81]. This characteristic causes a substantially narrower signal beam to form, which can result in excessive attenuation and consequently cause damage to performance. It is particularly challenging to regulate these beams. The use of IRS allows for the creation and management of impinging waves to address the problem at hand by designing the signal beam. The AIRS-NOMA architecture can offer remarkable performance improvements over the GIRS-NOMA approach in terms of energy efficiency, coverage area, and data rate. Some studies have investigated incorporating THz communication with AIRS by considering aerial conditions [65], [82]. However, integrating AIRS-NOMA and THz communication presents additional challenges due to high attenuation in THz channels. To model

TABLE 6. Summary of available simulation parameters on achievable rate and sum-rate in the IRS-UAV systems.

Reference	Specified simulation parameter	Value
Mohamed *et al.* [48]	Number of UE	2
	Path loss exponent	4
	Rician factor	5
	The power dissipated by the circuity of the UE	17 dBm
	The power consumption of each element of the IRS	-20 dBm
	The flight consumption power	20 dBm
Yao *et al.* [46]	Total available bandwidth	200 MHz
	Path loss exponent	0~1
	The fading parameter	1~20
	The shadowing parameter	1~20
	The transmit power from the on-site command center	0~1W
Zhou *et al.* [54]	The bandwidth	1 MHz.
	Number of AIRS element	30
	Noise power	-110 dBm
	Rice factor	10
Wu *et al.* [13]	The variance in the additive white Gaussian noise	-80 dBm
	The maximum transmit power	5 dBm
	Number of reflecting elements	5
Yang *et al.* [69]	The bandwidth	10MHz
	Fixed amplitude reflection coefficient	1
	Number of reflecting elements	25-150
	Variance	-94 dBm
	Power amplifier efficiency	0.5
	Circuit power at source	100 mW
	Circuit power at UE	100 mW
	Circuit power at IRS	5 mW
	Circuit power at UAV	100 mW
	Minimum distance between source and IRS	80 m
	Minimum distance between IRS and UE	10 m
Zhang *et al.* [72]	Referenced channel power gain	-50 dB
	Noise power	-80 dB
	Path loss index (UAV-UE link)	2.5
	Corresponding Rician factor (UAV-UE link) (IRS-UE link)	10 dB
	Path loss index (IRS-UE link)	2.2
	Maximum transmission power	10 dB
	UAV's height	30 m
	Number of UE	4
	Number of reflecting elements	10, 20

THz waves and accurately measure the channel, appropriate path-loss models (near-field and far-field), practical phase-shift models, and beamforming control methods must be carefully selected to account for the propagation peculiarities of AIRS-NOMA. The decoding complexity of NOMA systems is a major hurdle in THz communication. While the THz band has the potential to link a large number of devices, the decoding complexity required for NOMA communication to support them can be prohibitively high. However, the IRS has emerged as a promising solution since it can intelligently adjust the reflecting elements to match the user's channel conditions, as noted in [83]. Leveraging the AIRS framework can improve spectrum efficiency and coverage capacity, enabling more users to connect to the network, even at greater distances from the base station. Furthermore, the significant directivity of LoS THz waves makes them susceptible to obstruction by obstacles, making the AIRS framework critical for THz communication, as it can enhance the LoS path.

C. IRS-UAV 5G STANDARDIZATION

Numerous authors have worked to improve the IRS-UAV system's energy efficiency, capacity, and sum rate [39], [45]. However, these studies do not address the issue of energy efficiency or reach the required capacity and sum-rate for a 5G wireless network. Additionally, the IRS-UAV system supports a variety of system configurations in terms of IRS-UAVs, users, and BS, including multi-IRS-UAV multi-user [42], multi IRS-UAV single user [48], single IRS-UAV multi-user [45], single IRS-UAV single user [46], and using a single BS (single cell) [50] or a multi BS (multi-cell) [39].

These scenarios have received insufficient attention. Conversely, the channel model has numerous unexplored aspects, including several fading channel models, such as the correlation fading channel model, the frequency selective channel model, and a practical THz channel model. In addition, there are many open issues in the high mobility aspects of the IRS-UAV system, such as the effect of IRS-UAV mobility on the achievable ergodic capacity and the number of IRSs required to support high user mobility. Besides, it is unclear whether IRS-assisted communications support UAVs under high speed. Additionally, the effects of IRS hardware impairment on the IRS-UAV system performance need more study, such as the number of IRS reflective elements, which cause a large channel estimation overhead. Further study should also be directed to the IRS phase shift in the IoT system. IRS has the potential to significantly improve both coverage and signal strength in indoor and outdoor IoT deployments, ensuring seamless connectivity and smooth communication between IoT devices and gateways. Through the optimization of signal paths and the reduction of signal losses, IRS plays a crucial role in conserving energy and extending the battery life of IoT devices, resulting in longer-lasting and more sustainable deployments. Moreover, IRS's ability to control signal reflections and propagation enables the efficient use of the spectrum, making it adaptable to a wide range of IoT applications with varying data rates. Notably, only a few studies focus on the 3D IRS-UAV network system; most studies discuss the 2D IRS-UAV network system (the 2D plane includes only UAV distance to IRS or UEs and UAV height). However, the IRS-UAV system is a 3D plane, so we need to focus more on the 3D-IRS-UAV system [58], [84], [85]. Additionally, numerous authors discuss the HD communication [46], [47] in a variety of contexts. However, only a few studies discuss the IRS-UAV system in FD model [39], which highlights the research potential of FD to enhance the IRS-UAV system parameters.

D. THE UAV TRAJECTORY AND THE PHASE SHIFT OF THE IRS

UAVs have the potential to revolutionize wireless networks by serving as flying base stations. The use of UAVs as base stations can increase the coverage and capacity of wireless networks in areas with limited or no existing infrastructure, such as disaster zones, remote locations, or events.

One advantage of using UAVs as base stations is that they can be deployed quickly and easily and can be moved to different locations as needed. This flexibility allows wireless network operators to provide coverage in areas that are difficult or expensive to reach with traditional infrastructure.

To further improve the performance of wireless networks using UAVs as base stations, smart design of the position or trajectory of the UAV and the phase shift of the IRS can be utilized.

An IRS is a two-dimensional array of passive elements that reflects wireless signals in a desired direction. By controlling the phase shift of the individual elements in the IRS, the reflected signals can be manipulated to enhance the signal strength and quality at the receiver. By integrating an IRS with a UAV base station, it is possible to optimize the reflected signals and further increase the coverage and capacity of the wireless network. The position and trajectory of the UAV can be designed to provide targeted coverage to specific areas or to follow a moving target, such as a vehicle or a person.

Using UAVs and IRSs in wireless networks can provide increased coverage, capacity, and reliability. However, optimizing the position or trajectory of the UAV and the phase shift of the IRS is crucial to maximizing the performance of the system. Here are some open issues related to the trajectory of the UAV and the phase shift of the IRS, along with some potential solutions:

- Trajectory planning: As mentioned earlier, UAVs need to follow a specific trajectory to provide optimal coverage and capacity. Designing an efficient trajectory can be challenging, especially in dynamic environments. One solution is to use machine learning algorithms to optimize the UAV's trajectory based on network conditions and environmental factors [86], [87]. Another solution is to use collaborative algorithms that take into account the trajectories of other UAVs in the network to avoid collisions and optimize overall network performance [88], [89].
- Path loss and signal attenuation: The signal strength of wireless transmissions from the UAV to ground-based devices can be affected by the distance between the UAV and the device, as well as obstacles such as buildings and other structures. The phase shift of the IRS can help mitigate this issue, but further research is needed to optimize the design and placement of the IRS to achieve maximum signal strength. One solution is to use algorithms that can dynamically adjust the phase shift of the IRS based on the location of the UAV and the ground-based device, to maximize signal strength and reduce path loss [90].
- Interference management: UAVs can cause interference with other wireless networks, especially if they are flying close to other base stations. One solution is to use algorithms that can dynamically adjust the position and trajectory of the UAV to avoid interference with other networks [91]. Another solution is to use frequency hopping techniques, where the UAV and ground-based devices can dynamically switch frequencies to avoid interference with other networks [92].
- Power consumption: The amount of power required to operate the UAV and the IRS can limit the duration of the UAV's flight and the amount of time it can provide connectivity. One solution is to use energy-efficient systems and algorithms that can minimize power consumption while still providing optimal network performance. Another solution is to use renewable energy sources such as solar panels to power the UAV and the IRS, which can help extend the operating time of the system [93].
- Cost: The cost of deploying and maintaining a fleet of UAVs and IRSs can be significant, especially if they need to be used for extended periods of time. One solution is to use autonomous systems that can perform maintenance tasks such as battery replacement and sensor calibration, reducing the need for human intervention [94]. Another solution is to use low-cost materials and manufacturing processes to reduce the overall cost of the system [95].

E. THE UAV ALTITUDE AND THE REFLECTING ELEMENT PARAMETERS

When IRS is deployed on a UAV, the reflecting parameters of the IRS may need to be changed as the UAV moves along its trajectory. This is because the wireless channel conditions between the UAV and the ground stations may change as the UAV moves, leading to variations in the optimal phase shift and amplitude of the IRS.

To improve the performance of the UAV-IRS system, it is important to model the IRS deployment with a UAV trajectory. This can be done by modeling the wireless channel between the UAV and the ground stations as a function of the UAV's position and orientation. This model can then be used to optimize the phase shift and amplitude of the IRS in real-time as the UAV moves along its trajectory [96].

One approach is to use a Kalman filter to estimate the UAV's position and orientation based on sensor measurements such as GPS, accelerometers, and gyroscopes. The estimated position and orientation can then be used to update the model of the wireless channel and optimize the reflecting parameters of the IRS in real-time [97].

Another approach is to use machine learning techniques to predict the optimal reflecting parameters of the IRS based on the UAV's trajectory and other relevant factors such as weather conditions and user locations. This approach can provide real-time optimization of the IRS's parameters and lead to improved overall system performance [98].

F. THE UAV ALTITUDE AND THE PATH LOSS

The use of UAVs as base stations in wireless communication systems can lead to additional path loss due to the higher altitude of the UAV. One way to compensate for this degradation is by employing an active IRS that can amplify the incident signal in multiuser communication systems.

An active IRS consists of not only passive elements that reflect the incident signal, but also active elements that can amplify the signal. By properly designing the active elements' phase shift and amplitude, the active IRS can enhance the incident signal's strength and quality, compensating for the additional path loss [13].

One of the key advantages of an active IRS is that it can serve multiple users simultaneously, which is especially useful in crowded areas with high user density. The active IRS can dynamically adjust its phase shift and amplitude to provide optimal signal quality for each user, leading to improved overall system performance [99].

To design an active IRS-assisted multiuser system, several factors need to be considered, including the number of users, the position of the active IRS, the frequency of the communication signal, and the system bandwidth.

One approach is to use a resource allocation algorithm to allocate power and bandwidth to each user while considering the active IRS's channel gain and phase shift. The algorithm can optimize the system's performance by maximizing the sum rate of all users or minimizing the total power consumption of the system [100].

Another approach is to use machine learning techniques to predict the optimal phase shift and amplitude of the active IRS based on the wireless channel conditions, user locations, and other relevant factors [101]. This approach can provide real-time optimization of the active IRS's parameters and lead to improved overall system performance.

G. THE UAV BODY JITTERING AND NO-FLY ZONES

Body jittering can have a significant impact on the performance of UAV communication systems. For example, if a UAV is transmitting a video feed to a ground station, body jittering can cause the video to become unstable and difficult to interpret. Similarly, if a UAV is transmitting telemetry data, body jittering can cause errors and inaccuracies in the data [102]. To mitigate the effects of body jittering on UAV communication systems, it is important to use high-quality communication equipment that is capable of handling rapid changes in signal strength and quality. In addition, the UAV should be equipped with stabilizing systems, such as gyroscopes, that can help reduce the impact of body jittering on the communication system [28].

No-fly zones are areas where UAVs are prohibited from flying due to safety, security, or privacy concerns. These zones can include airports, military installations, and other sensitive locations. No-fly zones are established by governments and regulatory bodies, and it is important for UAV operators to be aware of them to avoid violating laws and regulations. When designing UAV communication systems, it is important to consider the presence of no-fly zones and ensure that the system can detect and avoid these areas. This may involve using geofencing technology [103], which uses GPS coordinates to establish virtual boundaries around no-fly zones and prevent the UAV from entering these areas.

Overall, both body jittering and no-fly zones should be carefully considered when designing and operating UAV communication systems to ensure safety, reliability, and compliance with regulations.

H. THE REAL-TIME ONLINE DESIGN FOR IRS-ASSISTED COMMUNICATIONS

IRS has shown great potential in enhancing the performance of wireless communication systems. However, the use of large-scale IRS, which typically consists of hundreds or even thousands of elements, presents a significant challenge in terms of real-time online design and optimization.

One of the main bottlenecks in employing large-scale IRS in practice is the computational complexity associated with optimizing the phase shift of each individual element. As the number of elements increases, the optimization problem becomes increasingly complex, making real-time online design unaffordable for IRS-assisted communications.

To address this challenge, researchers have proposed several solutions for exploiting the potential of large-scale IRS in a more efficient way and developing corresponding scalable optimization frameworks, which are listed as follows:

1) Low-complexity optimization algorithms: One approach is to develop low-complexity optimization algorithms that can efficiently optimize the phase shift of large-scale IRS. For example, the Alternating Direction Method of Multipliers algorithm can be used to decompose the optimization problem into smaller sub-problems, reducing the overall computational complexity [104].
2) Grouping of IRS elements: Another approach is to group the IRS elements into clusters and optimize the phase shift of each cluster, rather than optimizing the phase shift of each individual element. This reduces the complexity of the optimization problem while still allowing for effective use of the IRS [105].

I. THE WEIGHT OF THE IRS IN THE AIRS NETWORK

The weight of an IRS depends on its size, material, and complexity. Generally, an IRS is composed of a large number of individual reflecting elements that are arranged in a specific pattern. The size and number of these elements determine the weight of the IRS. Since the weight of the UAV is a critical factor that affects its flight time and stability, the IRS deployed on the UAV should be lightweight and compact. Several techniques can be used to achieve this:

1) Using lightweight materials: The reflecting elements of the IRS can be made of lightweight materials such as

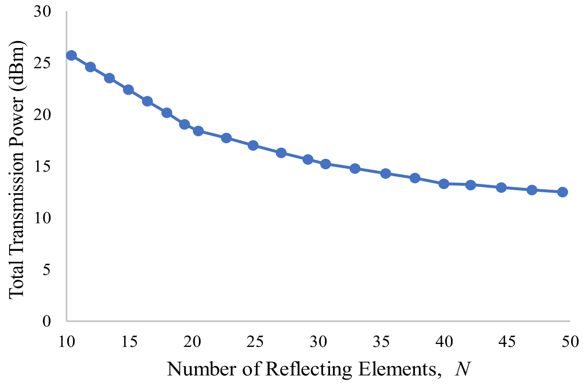

FIGURE 10. Impact of the number of IRS elements on the total transmission power [54].

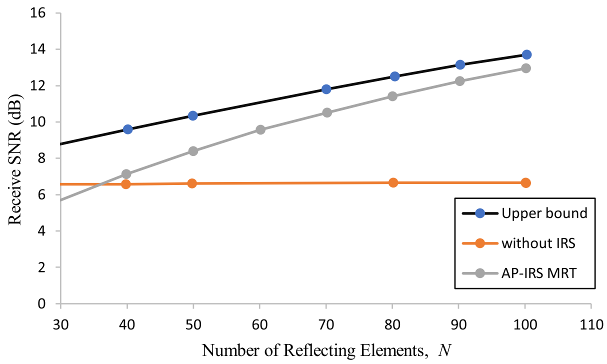

FIGURE 11. Receive SNR versus the number of reflecting elements [61].

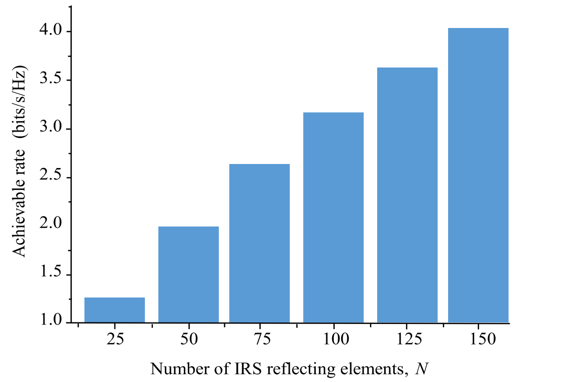

FIGURE 12. Achievable rate of an IRS-assisted network with the number of IRS reflecting elements, N [70].

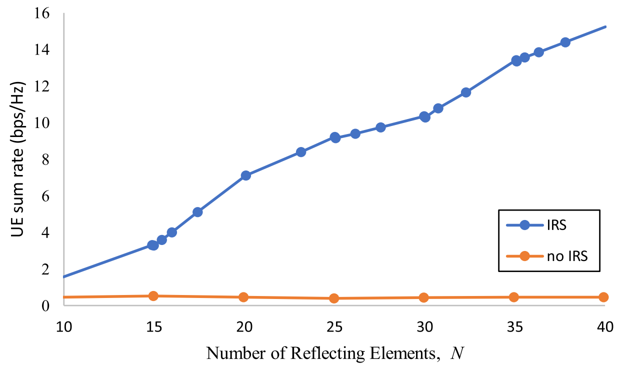

FIGURE 13. The relationship of different methods (IRS and no IRS) versus the number of reflecting elements on the UE sum rate [73].

polymers or thin metal films, which can significantly reduce the weight of the IRS [106].
2) Miniaturization: The size of the reflecting elements can be miniaturized to reduce the weight of the IRS while still maintaining its reflecting properties [107].
3) Integration: The reflecting elements can be integrated into the UAV structure, such as the wings or fuselage, to reduce the weight of the IRS.

The size and shape of the IRS should also be optimized to fit the specific UAV platform. For example, the IRS can be designed to be modular, allowing for easy assembly and disassembly, and to fit within the payload capacity of the UAV.

J. THE INTERFERENCE TO THE UE

IRSs deployed on UAVs have the potential to significantly enhance wireless communication performance. However, they may also introduce interference to ground users, especially when the UAV is operating in densely populated areas.

To avoid interference from the UAV IRS to ground users, several techniques can be employed:

1) Spatially restrict the IRS: The IRS can be designed to only reflect the signal in certain directions, avoiding interference to ground users in other directions. This can be achieved by using directional antennas for the IRS or by limiting the range of the reflected signal.
2) Frequency division: By dividing the frequency band used by the UAV and ground users, the UAV IRS can operate in a frequency band that does not interfere with the ground users.
3) Power control: The UAV IRS can adjust its power level to avoid interfering with ground users. For example, the IRS can reduce its power level when it is close to ground users or when ground users are detected nearby [7].
4) Dynamic configuration: The UAV IRS can dynamically adjust its reflecting parameters based on the location and signal strength of the ground users. This can be achieved by using real-time optimization algorithms or machine learning techniques to adjust the IRS reflecting parameters based on the wireless channel conditions.
5) Coordinated operation: The UAV IRS can be coordinated with ground base stations to avoid interference. For example, the ground base station can adjust its transmission power or frequency to avoid interference with the UAV IRS [60].

VI. CONCLUSION

UAVs and IRS are several of the various technologies that can be found in IoT networks. These two technologies can be combined in the same system to maximize energy efficiency and data transmission in two scenarios. The first scenario is when using the IRS and UAV together on the same AIRS device. The second scenario is when using either the IRS or UAV as stand-alone, as represented by the GIRS-UAV. In this paper, the difference between UAV and IRS working principles for the retransmission of data has been discussed. In the UAV system, the retransmission of data depends on the RF processing and the antenna array to transmit the received signal. Conversely, in the IRS system, the retransmission of data depends on the reflecting elements to reflect the incident signal. From the energy efficiency comparison between the AIRS and GIRS-UAV scenarios, AIRS has been shown to have greater reduction on the power consumption compared to GIRS-UAV. This reduction can be attributed to several reasons. Firstly, the AIRS system in UAVs does not need to use an antenna array to retransmit the incident signal. Secondly, the AIRS system does not require any power source for RF processing, decoding, encoding, or transmission due to its working principle, which is dependent on reflecting the incident signal by using multi-small reflective elements. Thirdly, due to the high-flying speed of the UAVs, they need more flying time close to the GIRS to enhance the received signal strength.

This paper has also successfully discussed the effects of adding the IRS to the UAV on energy efficiency, power, and data transmission. The energy efficiency increases when using IRS due to enhancing the total power in the system because the power consumption and power transmission in the IRS-UAV system are smaller than the UAV only. The data transmission also increases when using IRS because of the high passive beamforming gain from the usage of the reflecting elements of IRS.

We also discussed the open issues and the future research direction of IRS-UAV systems, such as the IRS phase shift affected by the movement of the UAV, real-time online design and optimization, and the interference of the user. In recent years, many researchers have focused on the IRS-UAV system to improve energy efficiency and data transmission. However, there are many scenarios and system models that can be further investigated, such as the 3D IRS-UAV system and the FD mode. Thus, there is a need to focus on these areas in the near future for a better understanding of the IRS UAV system.

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