ARTICLE IN PRESS

The Korean Institute of Communications and Information Sciences

Available online at www.sciencedirect.com

ScienceDirect

ICT Express xxx (xxxx) xxx

www.elsevier.com/locate/icte

RIS-carried UAV communication: Current research, challenges, and future trends

Nematullo Rahmatov, Hoki Baek*

School of Computer Science and Engineering, Kyungpook National University, Daegu, Republic of Korea

Received 15 December 2022; received in revised form 8 February 2023; accepted 18 March 2023
Available online xxxx

Abstract

Enhanced quality of service (QoS) and resource allocation are important measurements in a mobile communication system. Compared to traditional mobile networks, 6G uses spectrum from 0.3 to 3 terahertz (THz) and millimeter wave (mmWave) from 30 to 300 GHz (GHz), making QoS and proper resource allocation difficult. Unmanned aerial vehicles (UAVs) have garnered attention in academia and industry because of their high mobility, elastic placement, cost-efficiency, and easy combination with other communication systems. Similarly, reconfigurable intelligent surfaces (RISs) also gain the attention of the wireless research community owing to their precise signal reflection, spectrum, and energy efficiency, as well as their capability of regulating waveforms such as amplitude, frequency, polarization, and phase using passive reflections. The UAV has several weaknesses and is plagued by eavesdroppers, blockage, etc. Likewise, deploying RIS also is ineffective in standalone scenarios due to the user's mobility. Thus, we comprehensively review recent studies on UAV and RIS technologies. Furthermore, we have discussed the challenges of future communication technologies evolving RIS-assisted UAVs and future trends. We aim to provide sufficient information for the research on UAV and RIS's revolutionized phases, problems, and research trends.

Keywords: Unmanned aerial vehicles; Reconfigurable intelligent surface; QoS; RIS-carried UAV

1. Introduction

Even with 5G/6G networks, there is still a necessity for clear wireless communication between users. The rapid deployment of the 5G network is economically difficult for all countries. For instance, the cost of hardware components such as base stations (BSs) in the BS subsystem and cloud technology in the core network part of 5G mobile networks is considerably higher compared with that of traditional mobile networks. Therefore, it will take time to deploy 5G mobile networks globally. However, there are cost-effective solutions to deploying 5G networks through UAVs. Because UAVs are more cost-effective than 5G ground BSs [1] . Research on 5G networks has been conducted since 2015. The International Telecommunication Union (ITU) authorized that 5G must include three features [2]. Enhanced mobile broadband (eMBB), Massive machine-type communication (mMTC), and Ultra-reliable low latency communications (URLLC). eMBB is a modern technology that can support high data rates and volumes, including a 20-Gbps speed for downlink and a 10-Gbps speed for uplink services.

An mMTC is a new service type which is capable of supporting at least 1 million machine connections per square kilometer. URLLC is a 5G network service type that reduces latency by up to 90% and increases connection reliability by 9.9999%. Owing to the qualities listed above, modern 5G communication technology has attracted the attention of academic and industrial researchers worldwide. Despite the aforementioned outstanding qualities of 5G networks, their limitations are as follows: Coverage: To deploy modern mobile networks, additional 5G towers, and transmitters must be regularly installed; however, the coverage of a 5G network is limited compared with that of the traditional 4G mobile network. Spectrum and bandwidth deficiency: A 5G network can support a high data rate with a high data volume, including a 20-Gbps speed for downlink and a 10-Gbps speed for uplink services; however, when the number of users increases within a specific cell, a single antenna cannot allocate its resources to more users using a single antenna. Rural and remote locations: From the economic perspective, developing countries cannot

* Corresponding author.
E-mail addresses: nematullo.9006@knu.ac.kr (N. Rahmatov), neloyou@knu.ac.kr (H. Baek).

Peer review under responsibility of The Korean Institute of Communications and Information Sciences (KICS).

https://doi.org/10.1016/j.icte.2023.03.004

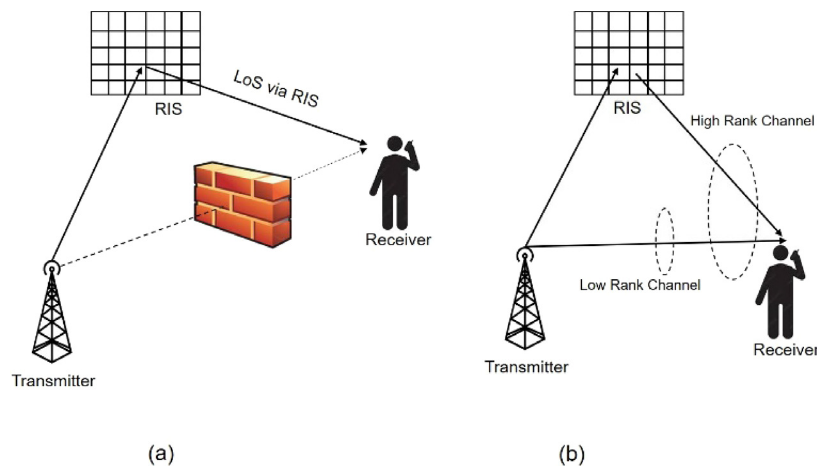

Fig. 1. Essential services of RIS for adjusting wireless communication. (a) RIS for coverage analysis; (b) RIS to enhance the channel level state.

rapidly deploy 5G networks owing to their high equipment costs. The majority of people in developing countries live in rural areas. Some edge users suffer from spectrum cutoff and cochannel interference due to a lack of BSs. Therefore, the 6G technology of the next generation of mobile communication is assumed to be a problem-solving approach to tackle the limitations of the current 5G network.

According to Tataria et al. [3], a 6G network can provide better services than a 5G, such as High coverage extension, Massive connectivity, Higher data rates, and Low latency. One of the recent techniques for 6G mobile networks to deploy enhanced communication services is the implementation of reconfigurable intelligent surface (RIS)-assisted UAVs. UAVs have played a crucial role in the rapid deployment of 5G and beyond 5G (B5G) in the last decade, owing to their high mobility, ease of deployment, and cost-effectiveness. The most important advantages of UAVs in the modern era of communication are their efficiency in scenarios such as air-to-ground channel modeling, optimum as flying BSs, trajectory optimization, cellular network planning, resource management, and energy efficiency [4,5]. Extensive research has been conducted regarding UAV groups, categories, sorting, charging, and adjustment. From current research trends, UAV-use cases and issues, as well as UAV security issues, are identified. Specifically, the review addresses machine/deep learning (ML/DL) methods, energy harvesting methods, sensing methods, navigation and localization algorithms, offloading algorithms, mobility models, aerial blockchain technology, and novel antenna design methods for UAV applications [6]. The 5G network can provide high capacity and excellent performance to its users only by combining several technologies such as wireless power transfer (WPT), non-orthogonal multiple access (NOMA), visible-light communication (VLC), machine learning (ML), and millimeter-wave (mmWave) communication. Numerous studies have mentioned the importance of UAVs in providing maximum throughput, achievable data rate, good capacity, security, and coverage for B5G networks [7,8]. The UAV technology is an effective source to cope with mission-critical services, such as alarm transmission during a natural disaster. Spectrum-sharing cognitive radio networks (CRN) enable UAVs to serve as flying BSs and provide extended coverage within affected zones. UAV relays can provide a real-time optimization framework for resource allocation if a natural disaster destroys a network [9]. A UAV integrated with a low Earth-orbit satellite can be used in disaster areas lacking ground services. Thus, nowadays, a UAV-BS system is suggested for various downlink users with the diverse numerical delay-bound quality of service (QoS) requirements. The main objective of this system is to maximize network capacity during emergencies [10]. RIS is a new paradigm for intelligently sharing wireless signals in the 6G technology. RIS is usually cost-effective and equipped with a microcontroller for installation in high communication towers, buildings, and UAVs through an accurate hovering position. RIS comprises numerous low-cost 64-antenna TDD active arrays that can independently reflect the occasional signal using an adaptable phase shift keying scheme [11,12]. Security is a crucial demand of many types of communication. A RIS-integrated multiple input single output (MISO) systems is used for physical layer security to assure secure communication, where legitimate users can hide from eavesdroppers. Similarly, a RIS-integrated MISO system is used for resolving the energy maximization problem while performing cooperative jamming under perfect and imperfect channel state information (CSI) [13,14]. RIS is an efficient technique for channel gain when the optimal distance and altitude from BS are considered. Some UAVs are weak and cannot provide a signal for mobile users owing to the downward tilt of the ground BSs. Therefore, the optimal solution for RIS installation, such as on building walls and UAVs, must be considered in the first stage. RIS is generally a non-standalone but efficient technology for power enhancement of the received signal [15]. Furthermore, RIS can demonstrate the benefits of integrating with recent radio communication systems. Some benefits and examples of using RIS to organize wireless services are shown in Fig. 1. Fig. 1(a) shows RIS for coverage extension, whereas Fig. 1(b) shows RIS for channel rank improvement.

Reflection, refraction, diffraction, and scattering are a few benefits of RIS carried by a UAV BSc for better communications. A RIS-carrying UAV can suggestively minimize its

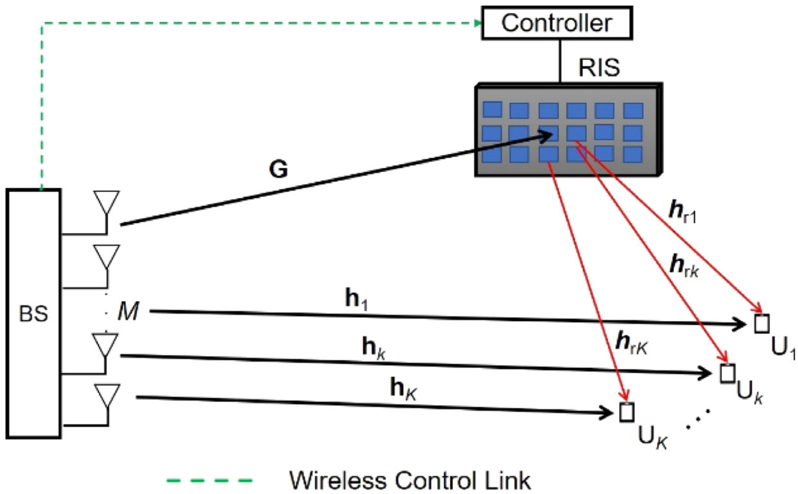

Fig. 2. RIS-improved MU-MISO system [24].

Table 1
Summary of some papers on combined UAV and RIS.

Papers	Objective	Optimization variables	Advantages	Disadvantages
[15]	To maximize the average achievable rate	UAV trajectory, RIS passive beamforming	Simple, low price of equipment	Vulnerable to interference
[17]	Maximization of transmission capacity	Optimizing reflection and location parameters of RIS-carried UAV	Accessibility in rural areas	Susceptible to terrestrial jamming
[18]	To maximize the rate of strong user	Optimizing location, phase shift of RIS-UAV	Low algorithm complexity	Limited/Feeble to (EE) energy efficiency
[19]	To maximize the secrecy rate	UAV power control, trajectory and RIS phase shift	Efficient for security of PHY layer	Vulnerable to intermittent connectivity
[20]	Maximization of users received power	Passive beamforming of RIS, active beamforming and trajectory optimization of UAV	Efficient for downlink transmission	Too oversimplified for urban users
[22]	Optimization of weighted bit error rate (BER)	UAV trajectory optimization, RIS phase shift and scheduling	Energy efficient, transceiver optimization	Poor phase shift due to fixed RISs

battery usage by enhancing the UAV's trajectory and resource-sharing ability. Finally, some studies used RIS-carried UAVs to solve nonconvex power minimization problems to upswing UAV's trajectory design and resource allocation [16]. Numerous studies have been conducted on RIS-carried UAV communication networks [17–23]. An effective gradient-projection (GPA)-based algorithm was used to design the symbol-level precoding (SLP), and a Riemannian conjugate gradient (RCG)-based algorithm was used to tackle the mirroring design. The primary objective of the presented model was to implement the RIS-aided improved multiuser (MU) MISO system. The proposed algorithms demonstrated superior energy efficiency and a reduced symbol error rate (SER) [24]. Fig. 2 indicates RIS-aided MU MISO systems.

Another study has been conducted on the performance analysis of RIS-carried UAVs, considering aerial and ground RISs [25]. Most existing papers have focused on a fixed RIS confined to the closest wireless users. However, few studies focus on several RISs to bypass any blockage in high path attenuation [26,27]. To resolve all the challenges mentioned above, the best and most straightforward solution is to deploy a RIS-carried UAV communication system. Table 1 summarizes some papers on RIS-carried UAV communication.

1.1. Advantages of RIS-carried UAV for 6G

When LoS links are blocked due to obstacles between UAV BSs and ground users (GUs), the RIS technology can provide a virtual LoS, allowing wireless network coverage to be prolonged and expanded. RIS is attached to a UAV that has the function of agility. A novel rank of autonomy can be attained for RIS as the UAV's agility and RIS's location can be effectively arranged. Likewise, RIS can be installed on a UAV with a function of mobility, and a straight LoS link can be considered between the sender and recipient. By deploying the RIS technology on a UAV, total internal reflection can be attained for further expansion of network coverage. RIS-carried UAV systems can enhance the attainable signal-to-noise ratio (SNR) at a given data throughput. No research has been conducted on terrane-based RIS to enhance

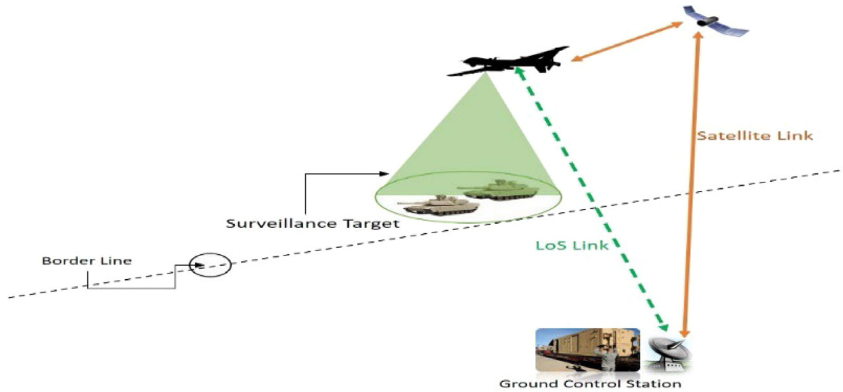

Fig. 3. An illustration of the hunter-killer surveillance UAV.

the ground-air UAV network [28]. UAVs and RISs can be operated on mmWave and the terahertz (THz) frequency. The links between mmWave and THz are effective against environmental obstructions and high path attenuation. Due to NOMA and free-space optics (FSO) mechanisms, a RIS-carried UAV can enhance communication quality and data rate. However, UAV-based links are susceptible to cochannel interference from the perspective of eavesdroppers. Therefore, RIS technology and UAV can reduce this challenge combinedly. It can reduce average energy consumption by combining UAV with RIS and providing joint enhancement for UAV direction, power sharing, and RIS BPSK [29,30]. RIS-carried UAV is an efficient technique for two applications, including (a) maximizing the attainable data rate for regular users and (b) minimizing the secrecy rate to protect eavesdropping [16,31]. In such a situation, it is easy for an eavesdropper to snip a user's data out of legitimacy, which can be a reason for security alarms. Through RIS submissive transmission, it is conceivable to support the replicated waves for the authorized wireless subscriber and minimize the accepted SNR at the eavesdropper site. Directional antenna-combined RIS-carried UAVs efficiently reduce power consumption when UAVs move in the air for a prolonged duration [32]. Similarly, implementing RIS-carried UAVs can be an effective method for maximizing the probabilistic LoS model and revealing the potential of RIS-carried UAV communication services [33,34]. Table 2 lists the most recent and available literature on RIS-carried UAVs.

1.2. Contributions of this review

This review explains RIS and UAV technologies for B5G/6G communication. Our primary focus was on 6G technological trends. Our main contributions are as follows:

- We have comprehensively analyzed the advantages of UAVs and RISs while implementing modern communication technologies such as B5G and 6G.
- Our extensive review shows the emerging B5G and 6G communication technologies for integrating several application scenarios.
- Finally, we have provided various trials and guidelines for future research regarding an efficient combination of RISs and UAVs for 6G communication.

1.3. Paper organization

This review is organized as follows. Section 2 summarizes the research contributions regarding UAVs and RISs. Section 3 discusses future technologies and use cases that can advance B5G and 6G communication networks. Section 4 examines crucial challenges and future research directions on 6G. Section 5 concludes this review.

2. General review on UAVs and RISs

In this section, we have surveyed some papers that provide helpful information on UAV and RIS technologies. For UAVs, we have outlined existing research and materials. Similarly, we have discussed the elementary architecture and operation of RISs. In general, we focus on joint architecture existing in different RIS studies.

2.1. UAV technology

A UAV is one of the de facto modern technologies of the 21st century and is effective in various areas, including wireless communication, military services, natural disasters, and agriculture. UAVs are typically operated by humans from remote areas to protect themselves from other harms and hazards. For example, during a war between two countries, an economically powerful country can deploy different types of hunter-killer surveillance UAVs to attack its enemies. Different types of UAVs and their applications are presented in several recent studies [36–39]. Shin et al. presented a charge schedule for multi-drones [36] using DL algorithms. In addition, several studies have been conducted regarding various features of UAVs, e.g., mobile-charging features [37], adaptive drone placement [38] and UAV collaboration [39]. Fig. 3 illustrates a predator UAV system during a war between two countries. In such a scenario, typically, the country operating a predator UAV will suffer minimal loss or no loss compared to the country that is deploying an artillery system because even if a predator UAV is destroyed, the operation teams of the UAV remain alive.

Table 2
RIS-carried UAV communication scenarios.

Papers	Number of UAV & RIS	Channel model	Pros & Cons	Main finding
[30]	One UAV, Multiple RISs	3GPP	Useful for theoretical analysis; further experiential validation is required	Energy consumption minimization is presented
[31]	Multiple UAVs, Multiple RISs	mmWave channel	Useful for practical analysis; too complicated for simulation	Coverage maximization, data privacy methods are presented
[32]	One UAV, One RIS	LoS, NLoS	Useful for theoretical analysis; too oversimplified for urban and rural environment	Link budget analysis have been performed to analyze SNR
[33]	One UAV, Multiple RISs	mmWave channel	Useful for simulation studies; further implementation verification required	Several energy consumption minimization methods are presented
[34]	One UAV, Multiple RISs	Multipath channel	Useful for theoretical analysis; further experiential validation is required	Sum rate is maximized through optimizing various parameters
[35]	One UAV, One RIS	LoS	Useful for theoretical analysis; oversimplified in real time scenarios for urban environment	Received signal strength increases as optimal UAV and RIS parameters are analyzed

2.2. RIS technology

RIS is a type of antenna that is proficient in modifying its electromagnetic waves and radiation assets dynamically in a controllable and reversible manner. It is a new and modernized paradigm to spread B5G and 6G communication technology signals to the desired location for better communication quality. Typically, RIS design contains liquid crystals, varicap-tuned resonating systems, microelectromechanical systems (MEMS), grouped silicon, and electromagnetic switches. Although diverse methods of RIS exist in available papers, and most of these works are attentive for designing three layers: (a) a metalenses layer, including a passive conductor; (b) a regulation layer, which is utilized to change the breadth or phase of meta-atom elements; and (c) a gateway layer, which can interconnect the regulation layer with an aerial or ground BS. RIS can support data rates below 10 GHz. Organizing the wavefronts to gain beam direction, attenuation, filtration, localization, parallelization, sensing, diffraction, and filtering is feasible. Two elementary approaches to achieving concentration and direction-finding are traditional antenna arrays and nanoantennas. By combining hybrid beamforming with RIS, an accurate and efficient solution for identifying user-vehicle localization issues can be found. Furthermore, RIS can adjust the wireless propagation environment for communication better than MIMO.

It can be implemented with less power than MIMO, and other coverage densification technologies, such as bright reflect arrays and software-defined surfaces [40–42]. An efficient energy utilization approach is one of the mandatory requirements in combined UAV and RIS-based 6G communication infrastructure. Maria Diamanti et al. presented an efficient energy utilization approach in [43] for multiuser-communication scenarios. The authors of the study ameliorated the uplink signal strength using the Stackelberg game strategy between a UAV and multi-users to attain energy efficiency for every user in distributed conditions. In general, for the spectrum placement of 5G, the ITU allocated three frequency bands, including mmWave, c-band, and Sub-3 GHz. The 5G spectrum bands are listed in the following order: mmWave: primarily for adding additional capacity at traffic hot spots, i.e., airports and stadiums, among other locations; c-band: primarily for covering large urban areas; and Sub-3 GHz: primarily for covering suburban and rural areas. The 5G mobile communication system has the aforementioned band types to effectively utilize communication resources based on data rate requirements on various occasions. However, the problem is that the coverage of mmWave is relatively small, although it has excellent transmission capacity. At the beginning of 2020, many Asian countries launched 5G, including South Korea, Japan, and Singapore, and assigned their wireless users to use the c-band. A considerable amount of money has been invested in the rapid deployment of 5G. However, due to the coverage limitations of c-band, the communication authorities of the aforementioned Asian countries are not well satisfied. The c-band coverage capacity is enough for large urban areas rather than rural ones. Therefore, the ITU has decided to allow the utilization of traditional LTE-A resources, i.e., sub-3 GHz bands, for 5G rural users. Sub-3 GHz bands have excellent coverage but poor transmission capacity, which makes the 5G communication system a non-standalone technology. An example of 5G band types is shown in Fig. 4. Several challenges are mentioned in [16] regarding the 5G spectrum plan above. The mmWave band, due to its extra capacity and good QoS of traffic, will be reused for the upcoming communication giant, 6G.

mmWave frequency ranges are 30 to 300 GHz. Unlike THz, bands from 300 to 3,000 GHz can be conferring to some assumptions and can be utilized in 6G. In January 2022, Purple Mountain Laboratories of China announced that its research team had attained a global innovation of 206.25 gigabits per second (Gbit/s) data rate. It is unprecedented in a lab atmosphere inside the range of THz frequency band, which is theoretically to be the fundamentals of 6G cellular technology [44–46]. Respectively, RIS, with a combination of

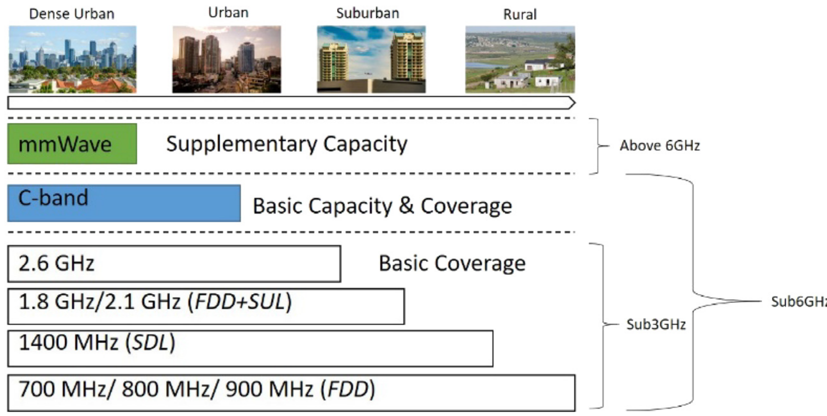

Fig. 4. 5G frequency bands for different scenarios.

Table 3
Literatures on joint transmit and passive beamforming using RIS.

Papers	Scenario	Phase Shift	CSI	Aims	Technique
[50]	MU-DL-MISO NOMA	Continuous/Discrete	Perfect	Sum rate	Consecutive rank-one constraint relaxation method
[51]	MU-DL-MISO	Continuous	Imperfect	Transmit power	Worst-case robust beamforming strategy
[52]	SU-DL-MIMO mmWave	Continuous	Perfect	SE	Broadband hybrid beamforming
[53]	SU-DL-MIMO	Continuous	Estimated	EE	Overhead model for channel estimation and RIS configuration
[54]	MU-DL-MISO NOMA	Continuous	Perfect	Transmit power	Enhanced quasi-degradation case
[55]	MU-DL-MISO	Discrete	Statistical CSI	Sum rate	Low channel training overhead

mmWave, can serve rural 6G wireless users suffering from spectrum shortage, blockage, and an accidental roaming connection present in densely populated villages adjacent to the border areas. RIS functions according to the elementary rules of altering electromagnetic waves via replication and changing their phase shifts. In this manner, RIS can obtain cost-effective, maintainable performance [47]. Furthermore, RIS is not only effective for QoS but also efficient to deploy as a relaying mediator between UAVs as aerial BSs and GUs to improve throughput maximization and optimal power allocation [48, 49]. Several recent papers on RIS joint transmit and passive beamforming are summarized in Table 3. The electromagnetic features of metasurfaces are thoroughly related to meta-atom patterns.

Thus, the rugged design of meta-atoms allows them to reproduce or reflect EM waves, while others can entirely produce them. Such metasurfaces contain submissive replication components that are non-static; therefore, these shells can hand-pick obligatory EM replies, or a peripheral bias can tune their environments. The smattering factors of these planes can turn into input or output transmitters. Hence, when an occasional wave penetrates from the input transmitter, communication arises on the foundation of the switch position, and the EM wave withdrawal from the output antenna with a favorite replication. Some ICT companies' projects from research papers are summarized in Table 4.

3. Future emerging technologies

Herein, the future of emerging wireless communication technologies is discussed by briefly introducing future emerging technologies and their impacts on RIS and UAV, as well as several works that will be future research trends.

3.1. Cloud or mobile edge computing

According to the National Institute of Standards and Technology (NIST), cloud computing is a model for empowering ubiquitous, suitable, on-demand network access to a shared pool of adjustable computing resources, such as networks, servers, storage, applications, and services, that can be quickly provisioned and released with minimal management effort or service provider collaboration [56].

Later, the European Telecommunications Standards Institute (ETSI) defined a new concept called "multiaccess edge computing" (MEC) to apply cloud computing services at the edge of the cellular network. The primary idea behind a MEC system is that by running and executing specific applications related to processing tasks nearer to the cellular client, network congestion can be minimized, and applications can excellently perform an allocated task [63]. With the assistance of RIS, UAVs can be deployed as a MEC for traffic offloading and energy minimization problems. In such a way, that UAV helping as a MEC-server to gather/receive data from multiple

Table 4
Several R&D Projects on RIS.

Duration of project	Project references	Research project name	Objective of research on RIS technology
2020	[57]	NTT DOCOMO and AGC Inc.	Its main objective is to propose first prototype of translucent dynamic metasurface for 6G communication.
2020	[58]	RIS-based MIMO QAM	To display an RIS framework to achieve amplitude-and-phase-varying modulation, which chains the design of MIMO quadrature amplitude modulation (QAM) communication.
2020	[59]	Rfocus	Largest number of transmitters used for a one link communication
2018	[60]	NTT DOCOMO and Metawave	To provide 5G communication of 28 GHz-band using metasurfaces reflect array
2017	[61]	Reconfigurable active Hygen's metalens	To gain efficient management of the intruding wave front
2017	[62]	VisorSurf	The main aim of this project is to develop a hardware framework for software-driven metasurface

GUs and multiple sets of RISs can expressively improve the concurrent wireless data and power transmissions [64]. On the other hand, in [65], the ground BS performed the function of MEC when continuous blockage occurred between GUs and the ground BS. Accordingly, combined BS and UAV-assisted RIS were present for finding the suboptimal solution for the UE delay minimization and improving their computation tasks through proper hovering position and trajectory optimization. According to [21], RIS-carried UAV is a practical approach for scenarios where the cell edge GUs have limitations for QoS and energy. Especially in the scenarios when RIS manages the UE satisfaction for attaining phase shifting, and proper beamforming is managed by BS. RIS-carried UAV aided MEC service is shown in Fig. 5. Shen Hua et al. have been studied green edge interferences. The primary aim of green edge interference is to minimize power consumption for data communication, computation overloading, and optimization techniques for RIS-aided MEC services. RIS with MEC technology is an efficient technique for enhancing channel conditions [66]. By contrast, the THz spectrum has high-intensity requirements to support a higher data rate. Thus, evolving MEC in THz can reduce obstructions such as extreme offloading delays [67]. This combination of MEC and THz has a problem with unbalanced offloading in THz, which influences latency and battery utilization. In such circumstances, RIS can be deployed to prevail over latency and throughput challenges. Furthermore, there are several security issues during the deployment of the Cloud for the communication environment. For instance, according to [68], some commercial UAVs for transmission enhancement store data in the Cloud, which can cause data tampering, disclose private data and disturb flying ad-hoc network (FANET) processes.

3.2. Non-orthogonal multiple access

NOMA is one of the promising schemes in the next-generation wireless communication system that will improve mobile user's LoS and NLoS channel models. However, it depends on various communication parameters, including UE's angle of elevation, coverage radius, altitude of UAV, the number of GUs, proper UAV hovering position over UE's and the environmental condition of mobile GUs. According to [69], the excessive path loss η impacts the air-to-ground (ATG) link, which depends mainly on the propagation group compared to the elevation angle. Thus, the distance between UAV altitude and cell radius is summarized as follows:

$$\begin{aligned} PL_{LoS} &= 20\log d + 20logf + 20log\left(\frac{4\pi}{c}\right) + \eta LoS \\ PL_{NLoS} &= 20\log d + 20logf + 20log\left(\frac{4\pi}{c}\right) + \eta NLoS \end{aligned} \tag{1}$$

Wherever d is the distance among the UAV and a GU at a cell of radius r, specified by $d = \sqrt{h^2 + r^2}$, while f is the electromagnetic wave. NOMA prevails over the traditional orthogonal frequency-division multiple access (OFDMA) schemes due to its unique factors, such as enhanced spectrum efficiency (SE), reduced traffic latency with high reliability, and gigantic connectivity [70]. Antoine Kizli et al. addressed the integration of NOMA and coordinated multipoint (CoMP) systems to improve user experiences at the cell edge and global system performance. The authors investigate the situations for a joint SIC strategy for a NOMA cluster with double coordinated antennas. The joint SIC strategy proposed two-user and three-user clusters for the combined dynamic point selection (DPS) and joint transmission (JT). It was observed that the proposed scheme is one of the most efficient techniques for system throughput and user fairness in recent years, which confirms the potential of B5G and future mobile communication technologies [71]. One of the most efficient methods to improve the system performance of a 6G communication system is integrating multiple technologies, including NOMA-based RIS-carried UAV systems [72]. NOMA is a modern and efficient prototype for 6G communication network. Specifically, NOMA can serve multiple GUs when high coverage performance, optimal transmit power allocation, and minimum latency are required [73]. Furthermore, it is important to note that a higher network capacity can be attained using the optimal deployment of RISs. According to Fawad Khan et al. [74],

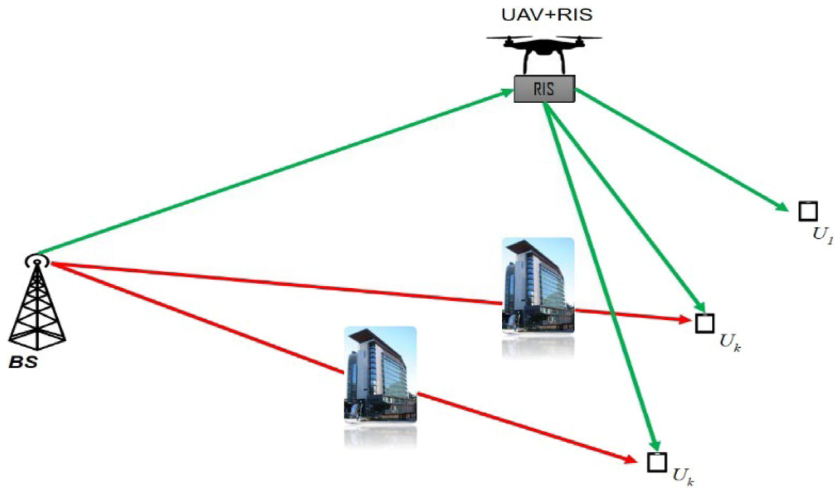

Fig. 5. A RIS-carried UAV aided MEC application scenarios. . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

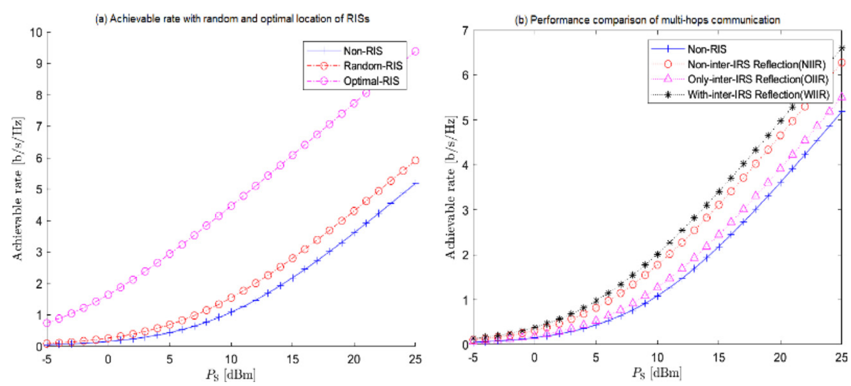

Fig. 6. Performance analysis of optimal deployment of multi-RIS using multi-hop communication [74].

deployment plays a crucial role in enhancing the performance of a communication network. Fig. 6(a) indicates that the achievable rate is increased when the RISs are optimally placed rather than randomly. Moreover, Fig. 6(b) shows that network performance is enhanced by using multi-RIS multi-hop signal reflection. As the received signal combines the direct and the reflected path, the signal strength is potentially increased at the receiving end. In summary, the network's overall performance can be significantly increased by deploying the RISs optimally and using several reflection paths.

However, it is essential to note that the implementation of NOMA through the assistance of UAVs has several limitations, such as efficient power allocation and fair communication scheduling. Specifically, it is a difficult task for a single UAV when it is deployed in a scenario where the number of GUs are not balanced according to its resource capability. Xin Liu et al. presented join optimization algorithms to solve efficient power allocation in [75] and fair communication scheduling optimization in [76]. Moreover, it is important to note that only the deployment of NOMA for an enhanced 6G communication environment can cause data privacy issues. For instance, information leakage can occur for cell edge GUs due to inter-cell interference (ICI) and unequal transmission power [77].

3.3. Internet of things

The IoT nomenclature was introduced in 1999 by British computer scientist and pioneer Kevin Ashton. The basic understanding of IoT is that all kinds of electronic and physical assets can exchange information through Internet access in today's world. In the past two decades, IoT research has expanded exponentially in different areas, including computer science and engineering, AI, astronomy, animal science, social networking, and agriculture. Similarly, new names, such as the Internet of Vehicles (IoV), the Internet of Drones (IoD), the Internet of Everything (IoE), and the Internet of medical things (IoMT), have emerged. It shows that we can perform any activity for the benefit of humanity using the Internet in modern times. Especially after the first wave of COVID-19 began at the end of 2019, the vast majority of global activity became possible through Internet access, such as the rapid increase in online university students and online meetings. Research in the different fields of IoT still is in demand. The authors of [78] presented work empowering RIS-assisted UAV communication to enhance communication reliability and extend wireless network coverage. The authors of the study believe that spectral efficiency can be enhanced by combining RIS-mounted UAVs with IoT networks. A study has been conducted in [79] on a RIS-carried UAV for facilitating simultaneous wireless information and power transfer in an IoT network with many users. The authors of the study have implemented a TDMA-based technique for UAV communication to achieve remarkable RIS performance in the UAV system. From a fairness viewpoint, the author's objective is to maximize the average communication rate and user integration, the phase shifter at the RIS, the UAV's dynamic trajectory, and the energy splitting ratio in all IoT devices. The authors of [80] have proposed a novel IoT network (RIS-MAIN) supported by RIS-carried master-auxiliary UAVs. RIS-MAIN is effective for coverage extension and can enhance the condition of the channel through RIS elements. The authors of the study asserted that the trajectory and throughput of the master UAV were completely maximized using a combination of energy transmission and optimization. Several security and privacy issues exist in the different types of IoT environments. For instance, as our main aim is to review on Drone based communication, the IoD has the issue of data leakage. Notably, potential eavesdroppers can easily identify geographical positions, drone owner names, travel routes, and identities, which can cause a physical attack on important buildings [68].

3.4. mmWave and THz bands

THz and mmWave, which have high-frequency bands in the tens of GHz range, are expected to be utilized by the sixth-generation mobile network, or 6G. A RIS-carried UAV is deployed to maximize the minimum feasible data rate. Due to passive and analog beamforming, RIS is effective for deployment in millimeter-wave bands to maximize the achievable rate for different user clusters [81]. Deployment of UAV-BS and RIS technology effectively employs mmWave in anti-eavesdropper scenarios where artificial noise (AN) is used. By exploiting AN, the wireless network can remain stable and safe when the secrecy rate is maximized when ground (BS) and aerial (RIS-carried UAV) BSs execute joint optimization [82]. mmWaves can solve the problem of communication blockage. Thus, for the combined deployment of RIS and UAV, the RIS should be dynamic to provide better power control and preserve better LoS links between senders and receivers [83]. To sustain reliability and maximize sum rate performances, RIS-assisted UAVs must use THz spectrum bands. THz spectrum bands are influential for short-range communication and prone to signal blockage [84]. However, the THz and mmWave bands will be severely impacted by atmospheric difficulties such as molecular absorption and signal attenuation [85]. Nevertheless, these two technologies will be required to deploy B5G mobile networks. Lastly, as reported in [68], if mmWave technology is deployed in high-frequency signals and high transmit power, there are high chances of causing vulnerability for achieving a higher secrecy rate. Similarly, THz bands also have the security issue of eavesdropping attacks. According to Jianjun Ma et al. in [86], the THz bands are vulnerable due to wiretapping when the data is transmitted over LoS links.

3.5. Machine learning

ML is an application of artificial intelligence (AI) that allows a system to automatically learn from and improve on its experience. Innovative research can be gained via AI and ML. Particularly, this transformational technology can support the RIS-carried UAV system in terms of QoS, consistency, network performance, and network security. ML algorithms can be classified as supervised, unsupervised, semi-supervised, and reinforcement learning. Some supervised ML algorithms are Linear regression, Logistic regression, Neural network algorithms, SVM algorithm and Naive Bayes algorithms. ML-supervised algorithms are efficient for predictive analytics [87], classification, sentiment analysis, and spam detection. K-means clustering, Gaussian mixture model (GMM), dimension reduction, and principle component analysis (PCA) are ML unsupervised learning algorithms. ML unsupervised learning algorithms are effective for news sections, computer vision, medical imaging, anomaly detection, consumer personas, and recommendation engines, among other applications. Remarkably, semi-supervised learning algorithms can perform the tasks of both supervised and unsupervised algorithms. Monte Carlo, Q-learning, State–action–reward–state–action (SARSA), and Proximal Policy Optimization (PPO) are examples of ML reinforcement learning algorithms. ML reinforcement learning algorithms benefit applications such as industrial automation, self-driving cars, trading and finance, healthcare, and telecommunication. Several studies have been conducted on ML-based RIS-carried UAV communications [88–90]. Deep reinforcement learning (DRL) is an efficient computation method for controlling RIS phase shift, UAV height, and information summation minimization. Due to the UAV's static environment, this solution is infeasible and impracticable for practical use cases [91]. Moreover, the authors of [92] discussed the DRL algorithm to optimize the BPSK of RIS and transfer the directional wave path to boost the overall sum rate. K. K. Nguyen et al. proposed a DRL method for enhancing the RIS shift to schedule the energy collecting time for UAV-aided D2D communications [93]. However, like other progressing future technologies, ML also has security and privacy issues. As the authors of [94] surveyed, future ML is vulnerable due to several adversarial attacks. Specifically, data poisoning is one of the main challenges which an outdoor intruder can perform to change input datasets to mislead ML algorithms and cause sophisticated editing.

4. Open research challenges and future trends

This section provides detailed information regarding the recent research challenges for RIS and UAV technology. In addition, we have articulated future research challenges and requirements of RIS and UAV in academia and industry.

4.1. Power consumption

Power consumption is an absolute necessity for activating all electronic and physical assets. RIS technology requires continuous energy when carried by a UAV due to the lack of an energy amplifier [25]. Similarly, a UAV cannot be active for a long duration with the capacity of modern batteries. In areas where winter does not exist, or sunlight is available year-round, it is possible to charge UAV batteries using sunlight. Regardless of the season, transferring energy through wireless UAV-carried power transfer (WPT) provides an alternative approach. Additional challenges associated with UAV activation include generating noise and boosting of speed based on the requirements of particular tasks [8]. Recent times have witnessed a rise in the volume of noise produced by large drones. The open challenge for the researchers is to develop energy-efficient techniques and practical frameworks for the stable-and-aerial long-life RIS deployment without the help of UAVs and remove the noise of large UAVs.

4.2. Channel estimation

RIS is based on some replication elements to gain optimal beamforming via a manageable radio emission technique. Nevertheless, it can be attained only by choosing proper signal processing and channel sensing techniques. Therefore, it is disapprovingly important to discover maintainable channel estimation techniques. The existing key solution uses RIS with a low-energy detector, which can achieve channel detection and estimation [25]. Using precise channel state information (CSI) to implement perfect signal reflection using RIS-carried UAVs is critical. However, some existing solutions are available in [95,96]. Tang et al. presented some methods in [97] to optimize the information secrecy rate considering (CSI) channel state information. For the sake of comprehensive channel state information and the jamming power strategy, the authors of the study have used a bi-section search and presented a data-trained deep neural network (DNN) to estimate an efficient UAV placement. In addition, for the scenario of partial CSI, a deep Q network (DQN) was used to acquire an efficient UAV placement due to the complication of specifying jamming into channel statistics.

4.3. Physics and signal submissive model

Many scholarly articles have asserted that spectrum allocation for GUs will be optimized when UAVs carry out the RIS features. It shows that the RIS is a physical reflector. However, when other wireless communication parameters are assumed, reflecting the signal alone is insufficient. It is essential to study the functional ability of RIS with varying communication requirements. For instance, the wave response of RIS is related to features such as emission, occasional failure, replication angle, hardware design, and other design components [98]. The physical shape of RIS depends on different features, including size and reflecting elements. Therefore, the research community must consider the physical shape of RIS to provide more convenient services.

4.4. Environmental factors

Due to several environmental issues, it is not easy to guarantee the QoS necessities of UAVs in dynamic environments. In practical cases, UAVs have a problem due to air winds and vibrations, which can cause misalignment of the information beams among UEs and UAV BSs [99]. Consequently, this leads to unbalanced performance and an insignificant channel estimation loss. Joint beamforming design improvements can be problematic for RIS-carried UAVs. In contrast, airflow can negatively impact the UAV's velocity and trajectory when flying at altitudes that exceed its minimum requirements.

4.5. Scheme of applicable security measures

UAVs are primarily deployed in vulnerable conditions [100], such as those with physical layer security vulnerabilities that allow potential eavesdroppers access. Recent publications have focused mainly on UAVs' benefits, not security concerns. In the UAV environment, many vulnerabilities exist, such as the coverage of the jumper [68]. Meanwhile, coverage for jumpers consists of two typical attacks: misleading directions and counterfeit signals. Similarly, it is assumed that another type of vulnerability exists in UAV-based aerial communications when malicious attackers conduct spoof attacks and gain unauthorized access to wireless communication services. Such unauthorized access is known as malicious connection attacks [68]. Malicious connection attacks are divided into subcategories such as blackhole attacks, gray hole attacks, modification attacks, rushing attacks, and wormhole attacks. It is vital to design new security frameworks to defend against similar attacks in the future.

5. Conclusion

This study provides a thorough analysis of RIS-carried UAV technologies. The most recent papers on RIS-carried UAVs are summarized to provide efficient information to modern 6G communication researchers and practitioners. We have separately discussed research related to UAVs and RISs. In addition, we reviewed future emerging technologies that can incorporate RIS-carried UAVs to advance the 6G communication system. Finally, current research challenges and future directions were discussed to bridge the gap between recent and future research. This study will be a valuable reference for future research by providing trends for theoretical research, motivation, experimental research, and instantaneous implementations of RIS-carried UAVs. In the future, we have planned to provide a survey regarding beyond the 6G (B6G) communication network.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by both the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2022-00166267) and the MSIT (Ministry of Science and ICT), Korea, under the Innovative Human

Resource Development for Local Intellectualization support program (IITP-2022-RS-2022-00156389) supervised by the IITP (Institute for Information & Communications Technology Planning & Evaluation).

References

[1] Y. Cai, Z. Wei, S. Hu, D.W.K. Ng, J. Yuan, Resource allocation for power-efficient IRS-Assisted UAV communications, in: 2020 IEEE Int. Conf. Commun. Work. ICC Work. 2020 - Proc., 2020, http://dx.doi.org/10.1109/ICCWorkshops49005.2020.9145224.

[2] P. Release, Press Release Fourth radio interface technology added to 5G standards additional 5G technology meets IMT-2020 requirements including worldwide compatibility, 2022, pp. 22–25.

[3] H. Tataria, M. Shafi, A.F. Molisch, M. Dohler, H. Sjoland, F. Tufvesson, 6G wireless systems: Vision, requirements, challenges, insights, and opportunities, Proc. IEEE 109 (7) (2021) 1166–1199, http://dx.doi.org/10.1109/JPROC.2021.3061701.

[4] X. Zhang, J. Wang, H.V. Poor, Joint optimization of ship, 2022, pp. 55–63, no. June.

[5] Y. Zeng, Q. Wu, R. Zhang, Accessing from the sky: A tutorial on UAV communications for 5G and beyond, Proc. IEEE 107 (12) (2019) 2327–2375, http://dx.doi.org/10.1109/JPROC.2019.2952892.

[6] S.A.H. Mohsan, M.A. Khan, F. Noor, I. Ullah, M.H. Alsharif, Towards the unmanned aerial vehicles (UAVs): A comprehensive review, Drones 6 (6) (2022) http://dx.doi.org/10.3390/drones6060147.

[7] H. Nawaz, H.M. Ali, A.A. Laghari, UAV communication networks issues: A review, Arch. Comput. Methods Eng. 28 (3) (2021) 1349–1369, http://dx.doi.org/10.1007/s11831-020-09418-0.

[8] M. Mozaffari, W. Saad, M. Bennis, Y.H. Nam, M. Debbah, A tutorial on UAVs for wireless networks: Applications, challenges, and open problems, IEEE Commun. Surv. Tutor. 21 (3) (2019) 2334–2360, http://dx.doi.org/10.1109/COMST.2019.2902862.

[9] M.H.T. Nguyen, E. Garcia-Palacios, T. Do-Duy, L.D. Nguyen, S.T. Mai, T.Q. Duong, Spectrum-sharing UAV-assisted mission-critical communication: Learning-aided real-time optimisation, IEEE Access 9 (2021) 11622–11632, http://dx.doi.org/10.1109/ACCESS.2021.3050522.

[10] H. Niu, X. Zhao, J. Li, 3D location and resource allocation optimization for UAV-enabled emergency networks under statistical QoS constraint, IEEE Access 9 (2021) 41566–41576, http://dx.doi.org/10.1109/ACCESS.2021.3065055.

[11] Q. Wu, R. Zhang, Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network, IEEE Commun. Mag. 58 (1) (2020) 106–112, http://dx.doi.org/10.1109/MCOM.001.1900107.

[12] Q. Wu, R. Zhang, Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming, IEEE Trans. Wirel. Commun. 18 (11) (2019) 5394–5409, http://dx.doi.org/10.1109/TWC.2019.2936025.

[13] J. Chen, Y.C. Liang, Y. Pei, H. Guo, Intelligent reflecting surface: A programmable wireless environment for physical layer security, IEEE Access 7 (2019) 82599–82612, http://dx.doi.org/10.1109/ACCESS.2019.2924034.

[14] Q. Wang, F. Zhou, R.Q. Hu, Y. Qian, Energy efficient robust beamforming and cooperative jamming design for IRS-assisted MISO networks, IEEE Trans. Wirel. Commun. 20 (4) (2021) 2592–2607, http://dx.doi.org/10.1109/TWC.2020.3043325.

[15] S. Li, B. Duo, X. Yuan, Y.C. Liang, M. DI Renzo, Reconfigurable intelligent surface assisted UAV communication: Joint trajectory design and passive beamforming, IEEE Wirel. Commun. Lett. 9 (5) (2020) 716–720, http://dx.doi.org/10.1109/LWC.2020.2966705.

[16] S. Agha, H. Mohsan, M.A. Khan, M.H. Alsharif, P. Uthansakul, A.A.A. Solyman, For massive networks : Current trends, challenges, and, Sensors 2022 (2022).

[17] Q. Zhang, W. Saad, M. Bennis, Reflections in the sky: Millimeter wave communication with UAV-carried intelligent reflectors, in: 2019 IEEE Glob. Commun. Conf. GLOBECOM 2019 - Proc., 2019, http://dx.doi.org/10.1109/GLOBECOM38437.2019.9013626.

[18] S.Y. Jiao, F. Fang, X.T. Zhou, H.X. Zhang, Joint beamforming and phase shift design in downlink UAV networks with IRS-assisted NOMA, J. Commun. Inf. Netw. 5 (2) (2020) 138–149, http://dx.doi.org/10.23919/jcin.2020.9130430.

[19] S. Fang, G. Chen, Y. Li, Joint optimization for secure intelligent reflecting surface assisted UAV networks, IEEE Wirel. Commun. Lett. 10 (2) (2021) 276–280, http://dx.doi.org/10.1109/LWC.2020.3027969.

[20] L. Ge, P. Dong, H. Zhang, J.B. Wang, X. You, Joint beamforming and trajectory optimization for intelligent reflecting surfaces-assisted UAV communications, IEEE Access 8 (2020) 78702–78712, http://dx.doi.org/10.1109/ACCESS.2020.2990166.

[21] Z. Mohamed, S. Aissa, Leveraging UAVs with intelligent reflecting surfaces for energy-efficient communications with cell-edge users, in: 2020 IEEE Int. Conf. Commun. Work. ICC Work. 2020 - Proc., 2020, http://dx.doi.org/10.1109/ICCWorkshops49005.2020.9145273.

[22] M. Hua, L. Yang, Q. Wu, C. Pan, C. Li, A.L. Swindlehurst, UAV-assisted intelligent reflecting surface symbiotic radio system, IEEE Trans. Wirel. Commun. 20 (9) (2021) 5769–5785, http://dx.doi.org/10.1109/TWC.2021.3070014.

[23] Q. Wu, et al., A Comprehensive Overview on 5G-and-beyond Networks with UAVs: From Communications To Sensing and Intelligence, Vol. 39, IEEE, 2021, http://dx.doi.org/10.1109/JSAC.2021.3088681, no. 10.

[24] R. Liu, M. Li, Q. Liu, A.L. Swindlehurst, Joint symbol-level precoding and reflecting designs for IRS-enhanced MU-MISO systems, IEEE Trans. Wirel. Commun. 20 (2) (2021) 798–811, http://dx.doi.org/10.1109/TWC.2020.3028371.

[25] X. Pang, M. Sheng, N. Zhao, J. Tang, D. Niyato, K.K. Wong, When UAV meets IRS: Expanding air-ground networks via passive reflection, IEEE Wirel. Commun. 28 (5) (2021) 164–170, http://dx.doi.org/10.1109/MWC.010.2000528.

[26] H. Lu, Y. Zeng, S. Jin, R. Zhang, Aerial intelligent reflecting surface: Joint placement and passive beamforming design with 3D beam flattening, IEEE Trans. Wirel. Commun. 20 (7) (2021) 4128–4143, http://dx.doi.org/10.1109/TWC.2021.3056154.

[27] C. You, Z. Kang, Y. Zeng, R. Zhang, Enabling smart reflection in integrated air-ground wireless network: IRS meets UAV, IEEE Wirel. Commun. 28 (6) (2021) 138–144, http://dx.doi.org/10.1109/MWC.001.2100148.

[28] L. Yang, F. Meng, J. Zhang, M.O. Hasna, M. Di Renzo, On the performance of RIS-assisted dual-hop UAV communication systems, IEEE Trans. Veh. Technol. 69 (9) (2020) 10385–10390, http://dx.doi.org/10.1109/TVT.2020.3004598.

[29] K.K. Nguyen, S.R. Khosravirad, D.B. Da Costa, L.D. Nguyen, T.Q. Duong, Reconfigurable intelligent surface-assisted multi-UAV networks: Efficient resource allocation with deep reinforcement learning, IEEE J. Sel. Top. Signal Process. 16 (3) (2022) 358–368, http://dx.doi.org/10.1109/JSTSP.2021.3134162.

[30] X. Liu, Y. Liu, Y. Chen, Machine learning empowered trajectory and passive beamforming design in UAV-RIS wireless networks, IEEE J. Sel. Areas Commun. 39 (7) (2021) 2042–2055, http://dx.doi.org/10.1109/JSAC.2020.3041401.

[31] A. Brighente, M. Conti, H. Idriss, S. Tomasin, Unmanned aerial vehicles meet reflective intelligent surfaces to improve coverage and secrecy, 2022, pp. 1–7, [Online]. Available: http://arxiv.org/abs/2205.02506.

[32] D. Tyrovolas, S.A. Tegos, P.D. Diamantoulakis, G.K. Karagiannidis, Synergetic UAV-RIS communication with highly directional transmission, IEEE Wirel. Commun. Lett. 11 (3) (2022) 583–587, http://dx.doi.org/10.1109/LWC.2021.3136912.

[33] H. Cho, J. Choi, IRS-aided energy efficient UAV communication, 2021, pp. 1–11, [Online]. Available: http://arxiv.org/abs/2108.02406.

[34] L. Jiang, H. Jafarkhani, Reconfigurable intelligent surface assisted mmWave UAV wireless cellular networks, in: IEEE Int. Conf. Commun., 2021, http://dx.doi.org/10.1109/ICC42927.2021.9500484.

[35] D. Ma, M. Ding, M. Hassan, Enhancing cellular communications for UAVs via intelligent reflective surface, in: IEEE Wirel. Commun. Netw. Conf. WCNC, Vol. 2020-May, 2020, http://dx.doi.org/10.1109/WCNC45663.2020.9120632.
[36] M. Shin, J. Kim, M. Levorato, Auction-based charging scheduling with deep learning framework for multi-drone networks, IEEE Trans. Veh. Technol. 68 (5) (2019) 4235–4248, http://dx.doi.org/10.1109/TVT.2019.2903144.
[37] M. Zhao, Q. Shi, M. Zhao, Efficiency maximization for UAV-enabled mobile, IEEE Trans. Wirel. Commun. 19 (5) (2020) 3257–3272.
[38] N. Lin, L. Fu, L. Zhao, G. Min, A. Al-Dubai, H. Gacanin, A novel multimodal collaborative drone-assisted VANET networking model, IEEE Trans. Wirel. Commun. 19 (7) (2020) 4919–4933, http://dx.doi.org/10.1109/TWC.2020.2988363.
[39] N. Lin, Y. Liu, L. Zhao, D.O. Wu, Y. Wang, An adaptive UAV deployment scheme for emergency networking, IEEE Trans. Wirel. Commun. 21 (4) (2022) 2383–2398, http://dx.doi.org/10.1109/TWC.2021.3111991.
[40] V. Tapio, I. Hemadeh, A. Mourad, A. Shojaeifard, M. Juntti, Survey on reconfigurable intelligent surfaces below 10 GHz, Eurasip J. Wirel. Commun. Netw. 2021 (1) (2021) http://dx.doi.org/10.1186/s13638-021-02048-5.
[41] J. Zhao, A Survey of Intelligent Reflecting Surfaces (IRSs): Towards 6G Wireless Communication Networks, no. mm, pp. 1–7.
[42] L.C.C. By, S. Date, P. Date, C. Sarker, D. Seog, R.H. Beamforming, RIS-assisted hybrid beamforming with connected autonomous user, 2022, pp. 0–6, http://dx.doi.org/10.36227/techrxiv.20318238.v1.
[43] M. DIamanti, M. Tsampazi, E.E. Tsiropoulou, S. Papavassiliou, Energy efficient multi-user communications aided by reconfigurable intelligent surfaces and UAVs, in: Proc. - 2021 IEEE Int. Conf. Smart Comput. SMARTCOMP 2021, 2021, pp. 371–376, http://dx.doi.org/10.1109/SMARTCOMP52413.2021.00075.
[44] R. Greener, Chinese lab reaches breakthrough in 6G research purple mountain labs achieves record-breaking 6G speeds to boost China ' s metaverse and XR standards terahertz technology, 2022, pp. 1–10.
[45] E. Björnson, S. Member, Ö. Özdogan, S. Member, E.G. Larsson, Intelligent reflecting surface versus decode-and-forward : How large, 9 (2) (2020) 244–248.
[46] R. Alghamdi, et al., Intelligent Surfaces for 6G Wireless Networks : A Survey of Optimization and Performance Analysis Techniques, pp. 1–23.
[47] H. Pang, M. Cui, G. Zhang, Q. Wu, Joint beamforming design and resource allocation for double-IRS-assisted RSMA SWIPT systems, Comput. Commun. 196 (2022) 229–238, http://dx.doi.org/10.1016/J.COMCOM.2022.10.004.
[48] X. Liu, Y. Yu, F. Li, T.S. Durrani, Throughput maximization for RIS-UAV relaying communications, IEEE Trans. Intell. Transp. Syst. 23 (10) (2022) 19569–19574, http://dx.doi.org/10.1109/TITS.2022.3161698.
[49] S.K. Singh, K. Agrawal, K. Singh, C.P. Li, Z. Ding, NOMA enhanced hybrid RIS-UAV-assisted full-duplex communication system with imperfect SIC and CSI, IEEE Trans. Commun. 70 (11) (2022) http://dx.doi.org/10.1109/TCOMM.2022.3212729.
[50] X. Mu, Y. Liu, L. Guo, J. Lin, N. Al-Dhahir, Exploiting intelligent reflecting surfaces in noma networks: Joint beamforming optimization, IEEE Trans. Wirel. Commun. 19 (10) (2020) 6884–6898, http://dx.doi.org/10.1109/TWC.2020.3006915.
[51] G. Zhou, C. Pan, H. Ren, K. Wang, M. Di Renzo, A. Nallanathan, Robust beamforming design for intelligent reflecting surface aided MISO communication systems, IEEE Wirel. Commun. Lett. 9 (10) (2020) 1658–1662, http://dx.doi.org/10.1109/LWC.2020.3000490.
[52] K. Ying, Z. Gao, S. Lyu, Y. Wu, H. Wang, M.S. Alouini, GMD-based hybrid beamforming for large reconfigurable intelligent surface assisted millimeter-wave massive MIMO, IEEE Access 8 (2020) 19530–19539, http://dx.doi.org/10.1109/ACCESS.2020.2968456.
[53] A. Zappone, M. Di Renzo, F. Shams, X. Qian, M. Debbah, Overhead-aware design of reconfigurable intelligent surfaces in smart radio environments, IEEE Trans. Wirel. Commun. 20 (1) (2021) 126–141, http://dx.doi.org/10.1109/TWC.2020.3023578.
[54] J. Zhu, Y. Huang, S. Member, Power efficient IRS-assisted NOMA, 69 (2) (2021) 900–913.
[55] M.M. Zhao, Q. Wu, M.J. Zhao, R. Zhang, Intelligent reflecting surface enhanced wireless networks: Two-timescale beamforming optimization, IEEE Trans. Wirel. Commun. 20 (1) (2021) 2–17, http://dx.doi.org/10.1109/TWC.2020.3022297.
[56] G.A. Osorio, C.S. Del Real, C.A.F. Valdez, M.C. Miranda, A.H. Garay, Effect of inclusion of cactus pear cladodes in diets for growing-finishing lambs in central Mexico, Acta Hortic. 728 (2006) 269–274.
[57] A. Prof, C. Yuen, Reconfigurable intelligent surface (RIS)-assisted wireless networks, 2023, Accessed: Feb. 06, 2023. [Online]. Available: https://spcc.committees.comsoc.org/files/2021/06/RIS-YC-SPCE-SIG-2021-06-2.pdf.
[58] W. Tang, et al., MIMO transmission through reconfigurable intelligent surface: System design, analysis, and implementation, IEEE J. Sel. Areas Commun. 38 (11) (2020) 2683–2699, http://dx.doi.org/10.1109/JSAC.2020.3007055.
[59] V. Arun, H. Balakrishnan, RFocus: Practical beamforming for small devices, 2019, pp. 28–29, [Online]. Available: http://arxiv.org/abs/1905.05130.
[60] NTT DOCOMO and Metawave Announce Successful Demonstration of 28GHz-Band 5G Using World ' s First Meta-Structure Technology.
[61] K. Chen, et al., A reconfigurable active huygens' metalens, Adv. Mater. 29 (17) (2017) 1–7, http://dx.doi.org/10.1002/adma.201606422.
[62] F. Novel, I. Uml, A hardware platform for software-driven functional metasurfaces, 2020, pp. 1–57.
[63] ETSI, MEC in an Enterprise Setting: A Solution Outline - 2018, Vol. 2, ETSI White Pap. No. 30, 2018, p. 20, no. 30. [Online]. Available: www.etsi.org.
[64] F. Wang, X. Zhang, IRS/UAV-Based edge-computing/traffic-offloading over RF-powered 6G mobile wireless networks, in: IEEE Wirel. Commun. Netw. Conf. WCNC, Vol. 2022-April, 2022, pp. 1272–1277, http://dx.doi.org/10.1109/WCNC51071.2022.9771971.
[65] C. He, J. Xiao, Joint optimization in intelligent reflecting surface-aided UAV communication for multiaccess edge computing, Wirel. Commun. Mob. Comput. 2022 (2022) http://dx.doi.org/10.1155/2022/5415562.
[66] S. Hua, Y. Zhou, K. Yang, Y. Shi, K. Wang, Reconfigurable intelligent surface for green edge inference, IEEE Trans. Green Commun. Netw. 5 (2) (2021) 964–979, http://dx.doi.org/10.1109/TGCN.2021.3058657.
[67] O.A. Amodu, C. Jarray, S.A. Busari, M. Othman, THz-enabled UAV communications: Motivations, results, applications, challenges, and future considerations, Ad Hoc Netw. 140 (December 2022) (2023) 103073, http://dx.doi.org/10.1016/j.adhoc.2022.103073.
[68] K.Y. Tsao, T. Girdler, V.G. Vassilakis, A survey of cyber security threats and solutions for UAV communications and flying ad-hoc networks, Ad Hoc Netw. 133 (December 2021) (2022) 102894, http://dx.doi.org/10.1016/j.adhoc.2022.102894.
[69] A. Al-Hourani, S. Kandeepan, S. Lardner, Optimal LAP altitude for maximum coverage, IEEE Wirel. Commun. Lett. 3 (6) (2014) 569–572, http://dx.doi.org/10.1109/LWC.2014.2342736.
[70] T. Hou, Y. Liu, Z. Song, X. Sun, Y. Chen, Exploiting NOMA for UAV communications in large-scale cellular networks, IEEE Trans. Commun. 67 (10) (2019) 6897–6911, http://dx.doi.org/10.1109/TCOMM.2019.2929806.
[71] A. Kilzi, J. Farah, C. Abdel Nour, C. Douillard, Mutual successive interference cancellation strategies in NOMA for enhancing the spectral efficiency of CoMP systems, IEEE Trans. Commun. 68 (2) (2020) 1213–1226, http://dx.doi.org/10.1109/TCOMM.2019.2945781.
[72] S. Solanki, J. Park, I. Lee, On the performance of IRS-aided UAV networks with NOMA, IEEE Trans. Veh. Technol. 71 (8) (2022) 9038–9043, http://dx.doi.org/10.1109/TVT.2022.3171271.
[73] C.H. Liu, M.A. Syed, L. Wei, Toward ubiquitous and flexible coverage of UAV-IRS-assisted NOMA networks, in: IEEE Wirel. Commun. Netw. Conf. WCNC, Vol. 2022-April, 2022, pp. 1749–1754, http://dx.doi.org/10.1109/WCNC51071.2022.9771729.

[74] M.F. Khan, H. Mei, S. Rahim, L. Peng, P.H. Ho, Multi-RIS deployment for high data-rate communications, in: Proc. - 2022 Int. Conf. Netw. Netw. Appl. NaNA 2022, 2022, pp. 411–414, http://dx.doi.org/10.1109/NaNA56854.2022.00076.

[75] X. Liu, Z. Liu, B. Lai, B. Peng, T.S. Durrani, Fair energy-efficient resource optimization for multi-UAV enabled internet of things, IEEE Trans. Veh. Technol. (2022) 1–11, http://dx.doi.org/10.1109/tvt.2022.3219613.

[76] X. Liu, B. Lai, B. Lin, V.C.M. Leung, Joint communication and trajectory optimization for multi-UAV enabled mobile internet of vehicles, IEEE Trans. Intell. Transp. Syst. 23 (9) (2022) 15354–15366, http://dx.doi.org/10.1109/TITS.2022.3140357.

[77] K. Xiao, L. Gong, M. Kadoch, Opportunistic multicast NOMA with security concerns in a 5G massive MIMO system, IEEE Commun. Mag. 56 (3) (2018) 91–95, http://dx.doi.org/10.1109/MCOM.2018.1700671.

[78] A. Mahmoud, S. Muhaidat, P.C. Sofotasios, I. Abualhaol, O.A. Dobre, H. Yanikomeroglu, Intelligent reflecting surfaces assisted UAV communications for IoT networks: Performance analysis, IEEE Trans. Green Commun. Netw. 5 (3) (2021) 1029–1040, http://dx.doi.org/10.1109/TGCN.2021.3068739.

[79] Y. Liu, F. Han, S. Zhao, Flexible and reliable multiuser SWIPT IoT network enhanced by UAV-mounted intelligent reflecting surface, IEEE Trans. Reliab. 71 (2) (2022) 1092–1103, http://dx.doi.org/10.1109/TR.2022.3161336.

[80] J. Xu, X. Kang, R. Zhang, Y.C. Liang, Joint power and trajectory optimization for IRS-aided master-auxiliary-UAV-powered IoT networks, in: 2021 IEEE Glob. Commun. Conf. GLOBECOM 2021 - Proc., 2021, http://dx.doi.org/10.1109/GLOBECOM46510.2021.9685217.

[81] K. Guo, C. Wang, Z. Li, D.W.K. Ng, K.K. Wong, Multiple UAV-Borne IRS-aided millimeter wave multicast communications: A joint optimization framework, IEEE Commun. Lett. 25 (11) (2021) 3674–3678, http://dx.doi.org/10.1109/LCOMM.2021.3111602.

[82] G. Sun, X. Tao, N. Li, J. Xu, Intelligent reflecting surface and uav assisted secrecy communication in millimeter-wave networks, IEEE Trans. Veh. Technol. 70 (11) (2021) 11949–11961, http://dx.doi.org/10.1109/TVT.2021.3109467.

[83] Y. Pan, K. Wang, C. Pan, H. Zhu, J. Wang, UAV-assisted and intelligent reflecting surfaces-supported terahertz communications, IEEE Wirel. Commun. Lett. 10 (6) (2021) 1256–1260, http://dx.doi.org/10.1109/LWC.2021.3063365.

[84] Y. Pan, K. Wang, C. Pan, H. Zhu, J. Wang, Sum-rate maximization for intelligent reflecting surface assisted terahertz communications, IEEE Trans. Veh. Technol. 71 (3) (2022) 3320–3325, http://dx.doi.org/10.1109/TVT.2022.3140869.

[85] I.F. Akyildiz, C. Han, S. Nie, Combating the distance problem in the millimeter wave and terahertz frequency bands, IEEE Commun. Mag. 56 (6) (2018) 102–108, http://dx.doi.org/10.1109/MCOM.2018.1700928.

[86] J. Ma, et al., Security and eavesdropping in terahertz wireless links, Nature 563 (7729) (2018) 89–93, http://dx.doi.org/10.1038/s41586-018-0609-x.

[87] N. Rahmatov, F. Saeed, A. Paul, Analysis of the vulnerability estimation and neighbor value prediction in autonomous systems, Sci. Rep. 12 (1) (2022) 1–15, http://dx.doi.org/10.1038/s41598-022-13613-3.

[88] M. Learning, X. Cao, S. Member, B. Yang, C. Huang, Reconfigurable intelligent surface-assisted aerial-terrestrial communications, 39 (10) (2021) 3035–3050.

[89] H. Mei, K. Yang, Q. Liu, K. Wang, 3D-trajectory and phase-shift design for RIS-assisted UAV systems using deep reinforcement learning, IEEE Trans. Veh. Technol. 71 (3) (2022) 3020–3029, http://dx.doi.org/10.1109/TVT.2022.3143839.

[90] J. Yu, X. Liu, Y. Gao, C. Zhang, W. Zhang, Deep learning for channel tracking in IRS-assisted UAV communication systems, IEEE Trans. Wirel. Commun. 21 (9) (2022) 7711–7722, http://dx.doi.org/10.1109/TWC.2022.3160517.

[91] M. Samir, M. Elhattab, C. Assi, S. Sharafeddine, A. Ghrayeb, Optimizing age of information through aerial reconfigurable intelligent surfaces: A deep reinforcement learning approach, IEEE Trans. Veh. Technol. 70 (4) (2021) 3978–3983, http://dx.doi.org/10.1109/TVT.2021.3063953.

[92] C. Huang, R. Mo, C. Yuen, Reconfigurable intelligent surface assisted multiuser MISO systems exploiting deep reinforcement learning, IEEE J. Sel. Areas Commun. 38 (8) (2020) 1839–1850, http://dx.doi.org/10.1109/JSAC.2020.3000835.

[93] K.K. Nguyen, N.A. Vien, L.D. Nguyen, M.T. Le, L. Hanzo, T.Q. Duong, Real-time energy harvesting aided scheduling in UAV-assisted D2D networks relying on deep reinforcement learning, IEEE Access 9 (2021) 3638–3648, http://dx.doi.org/10.1109/ACCESS.2020.3046499.

[94] V.L. Nguyen, P.C. Lin, B.C. Cheng, R.H. Hwang, Y.D. Lin, Security and privacy for 6G: A survey on prospective technologies and challenges, IEEE Commun. Surv. Tutor. 23 (4) (2021) 2384–2428, http://dx.doi.org/10.1109/COMST.2021.3108618.

[95] Y. Chen, Z. Zhang, UAV-aided secure transmission in MISOME wiretap channels with imperfect CSI, IEEE Access 7 (2019) 98107–98121, http://dx.doi.org/10.1109/ACCESS.2019.2929844.

[96] B. Wang, J. Ouyang, W.P. Zhu, M. Lin, Optimal altitude of UAV-BS for minimum boundary outage probability with imperfect channel state information, in: 2019 IEEE/CIC Int. Conf. Commun. China, ICCC 2019, no. Iccc, 2019, pp. 607–611, http://dx.doi.org/10.1109/ICCChina.2019.8855938.

[97] X. Tang, N. Liu, R. Zhang, Z. Han, Deep learning-assisted secure UAV-relaying, 71 (5) (2022) 5048–5059.

[98] E. Basar, M. Di Renzo, J. De Rosny, M. Debbah, M.S. Alouini, R. Zhang, Wireless communications through reconfigurable intelligent surfaces, IEEE Access 7 (2018) (2019) 116753–116773, http://dx.doi.org/10.1109/ACCESS.2019.2935192.

[99] W. Yuan, C. Liu, F. Liu, S. Li, D.W.K. Ng, Learning-based predictive beamforming for UAV communications with jittering, IEEE Wirel. Commun. Lett. 9 (11) (2020) 1970–1974, http://dx.doi.org/10.1109/LWC.2020.3009951.

[100] W.U. Khan, et al., Opportunities for physical layer security in UAV communication enhanced with intelligent reflective surfaces, 2022, http://dx.doi.org/10.1109/MWC.001.2200125.