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UAV-Assisted IoT Applications, QoS Requirements and Challenges with Future Research Directions

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ABSTRACT: Unmanned Aerial Vehicle (UAV)-assisted Internet of Things application communication is an emerging concept that effectuate the foreknowledge of innovative technologies. With the accelerated advancements in IoT applications, the importance of this technology became more impactful and persistent. Moreover, this technology have demonstrated useful contributions across various domains, ranging from general to specific applications. Examples include wildfire monitoring, coastal area monitoring, deforestation monitoring, and sensitive military operations, where human access is limited or not feasible. These examples underscore the technology's importance in scenarios where direct human involvement is challenging or impossible. Although this technology offers numerous benefits, it is essential to note that it also faces several challenges. Among these, Quality of Service (QoS) is a key concern, which limits its useability in various applications. Unfortunately, most researchers in the present literature have overlooked this important factor without giving it considerable attention. To fill this gap, we are presenting a systematic review of the present literature associated with the QoS metrics of this emerging technology from 2015 to 2023 to highlight their contributions and limitations. Based on the systematic review, we highlight the open challenges of this technology to set a roadmap for futuristic research. Finally, we compared each portion of this work with the previously published review articles to confirm the essence of this work, along with an explanation of why this survey is needed and in-time.

Additional Key Words and Phrases: : Wireless communication, IoT applications, QoS in UAV-assisted-IoT application, Routing protocols, Interoperability Challenges.

1 INTRODUCTION

The use of Unmanned Aerial Vehicle (UAV) for communication is gaining attention in many Internet of Things (IoT) applications, such as smart cities, disaster management, healthcare, intelligent transportation systems (ITS), smart agriculture, forest monitoring, and military operations, etc., [31, 69]. In this setup, IoT devices can send their data through UAVs in the network. At present, UAV-assisted communication is most commonly used in targeted

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military operations, transportation, and agriculture to handle various tasks [112, 126]. This technology has the potential to intensify the economic growth of a country with much more improved safety, better healthcare services, and effective defense systems [63]. However, it also faces various challenges related to connectivity, interoperability, security, scalability, and adaptability, etc., [101]. When implementing this technology, it is important to pay attention to these challenges to achieve the best results.

In [7] the authors discussed challenges related to UAV-assisted IoT applications by focusing on the communication and interoperability aspects of this technology. They also explored dynamic and trajectory-based schemes to highlight their limitations. Naqvi et al. [85] continued this discussion, and talk about the interconnectivity and communication challenges of this technology, especially in the context of multi-face antenna operation. Additionally, they highlighted challenges related to the Quality of Service (QoS) that are generated during antenna transmission and reception. Košmerl et al. [59] proposed an intelligent protocol to resolve the communication issues of this technology by combining local and aerial vehicular networks. They utilized evolutionary algorithms to efficiently utilize available bandwidth with an objective to maximize the coverage area, and improve QoS metrics. In [7] the authors analyzed a contingency-based UAV-assisted IoT application scenario by taking into account the traffic offloading and overloading metrics of these applications. The objective of this work was to provide a pre-path for future research. Following this discussion, reference [5] proposed an optimal station-based communication infrastructure for this technology. The objective was to promote and satisfy the QoS metrics in different applications. Admitting the importance of this topic, we realized to examine the existing literature. Surprisingly, we did not find a single article that comprehensively addresses all the challenges faced by UAV-assisted IoT applications, particularly those affecting the QoS metrics.

To fill this gap, in this paper, we conduct an extensive survey of existing literature to provide a comprehensive overview of both the merits and drawbacks of adapted techniques. We begin by reviewing published survey papers on this subject, with the objective of highlighting their contributions and limitations. Additionally, we pay close attention to often-overlooked aspects within these papers, aiming to create a valuable resource for researchers and practitioners working in this field. This effort is essential in identifying and comprehending the Quality of Service (QoS) requirements of this technology, as well as understanding its unconventional components and attributes in detail. This paper will help the academia, industry, market, and scientific communities to effectively address the identified QoS and interoperability challenges in the presence of current literature limitations and this technology requirements. This paper will help academia, industry, market, and scientific communities to effectively address the identified QoS and interoperability challenges.

The utmost contributions of this review article are summarized as follows.

- (1) In the beginning, we review the existing survey papers about the QoS of UAV-assisted IoT applications. This helps us to understand what has been done and what is missing and needed to be done in the future. We also compare the strengths and weaknesses of these papers in Table 1 as part of our analysis.
- (2) In the second phase (literature review), we follow up on the identified limitations of the existing review articles to examine relevant literature. For this task, we searched recognized databases such as IEEE Xplore, ScienceDirect, Scopus Web of Science, etc, to extract relevant papers published between 2015 to 2023.
- (3) Consequently, we go through different entities of this technology such as network architecture, UAVs mobility dynamics, routing protocols, interoperability, security, and software challenges that have been overlooked in the current review articles to present a complete package for the people working in this domain.
- (4) Based on evaluated literature and review articles, we underscore the open challenges with potential future research preprints. We believe that these research insights can be extremely useful in the redressal of problems associated with QoS metrics of UAV-assisted IoT applications. To claim the originality and uniqueness of this work, we conduct a comparative analysis presented in Tables 6 and 7, contrasting

our approach with the existing state-of-the-art review articles. This comparison illustrates the unique contributions and differences that set our work apart from existing literature.

The rest of the paper is organized as follows; In Section II, we evaluate existing review articles associated with the QoS metrics of UAV-assisted-IoT applications. Section III covers the related work to highlight their contributions and limitations. Section IV underscores the security challenges that can hamper the QoS standards of these applications, while In Section, we summarized the lesson learned. In Section VI, we discuss identified open challenges, while Section VII presents the comparative analysis of this work in the presence of rival review articles. Finally, Section VIII summarizes the work in this paper to conclude the paper.

2 EXISTING SURVEY ARTICLES

In recent years, UAVs have gained significant attention from the scientific community and the business worldwide due to its ability of quickly adaptation with the environment to manage various tasks, both in civil and military settings. Although we discuss a few existing review articles in Table 1, we have yet to come across a single article that provides a comprehensive review of the challenges related to the QoS and interoperability of UAV-assisted-IoT applications. Therefore, we believe that our article is the first comprehensive source of information that not only identifies the limitations in the existing literature but also outlines the open challenges of this technology, all within a single package. Moreover, our goal is to empower both the research community and stakeholders in the enterprise market to develop effective solutions. These solutions may involve the design of compatible hardware, software, protocols, and machine learning-driven algorithms, to improve the QoS metrics and interoperability within this technology. Furthermore, we align our efforts with recognized works in the field to highlight the possible research directions in the presence of comparative published papers. In Table 1, we provide an overview of the advantages and disadvantages of previously published review papers related to this topic.

Table 1. Existing review articles related to UAV-assisted-IoT applications pros and cons

References	Description of review article	Limitations of an individual paper
Khuwaja et al. [58]	In this review article, the authors provided a short overview of the challenges associated with the communication of UAVs. They also point out some unique aspects of UAV communication, which are different from regular cell phones and satellites, to understand why UAV networks are a bit different from traditional networks.	In terms of limitation, this survey paper lacks the presentation of other associated challenges of UAV-assisted-IoT applications, because the authors only talk about the communication channel problems.
Aloqaily et al. [10]	In this article, the authors talk about the 5G-enabled blockchain-communication paradigm by assuming UAV-assisted-IoT applications. Moreover, they highlight the dynamic resources management challenges of this technology in the context of the supply chain.	The authors only acknowledged the challenges, which are associated with a centralized controller in a distributed environment and importance of block-chain technology.
Ray et al. [99]	In this paper, the authors have talked about the importance and challenges of using UAVs for IoT applications in healthcare by considering the blockchain technology communication paradigm.	The authors only highlighted the challenges associated with 5G communication infrastructure rather than identifying and giving a broad overview of architectural, routing and interoperability issues of this technology.
Ullah et al. [117]	In this paper, the authors presented a detailed survey of the current literature to highlight the challenges associated with modeling UAV communication channels, collision management strategies, and interference avoidance techniques. Furthermore, they looked at these challenges within the context of using deep reinforcement learning (RL) algorithms.	The authors only focused on the challenges related to Deep Reinforcement Learning (DRL), which means that this paper does not provide a complete picture of all the problems associated with this technology in the form of one document.
Fotouhi et al. [44]	In this paper, the authors explored the challenges of this technology, when IoT applications rely on UAVs for sharing data with remote destinations. Considering that, the authors only talk about the challenges of cellular communications infrastructure.	The authors overlooked the essential aspects such as routing protocols, hardware, software, and interoperability prototypes, which are crucial to achieve QoS metrics.
Mozaffari et al. [82]	In this review paper, the authors highlighted the key challenges of UAV-assisted-IoT applications such as 3D deployment, and channel modeling, accompanied by energy efficiency techniques.	This article completely ignores the challenges associated with interoperability and routing protocols of this technology.
Yan et al. [134]	This review article discussed the challenges associated with air-to-ground (A2G), air-to-air (A2A), and ground-to-ground (G2G) communication by focusing on the communication channels.	Only transmission channel challenges are highlighted, while the other quandaries are entirely neglected.
Shakhatreh et al. [106]	In this survey paper, the authors presented UAV-assisted civil applications with their correlated challenges i.e., collision, swarming, networking, and security, etc.	QoS of challenges in terms of Interoperability, routing protocols, and networks architecture are not highlighted properly, which makes this work in a fuzzy state.

3 RELATED WORK

In this section, we review relevant publications to summarize their contributions, limitations, advantages, and disadvantages that help us to set the path for open research challenges. However, we have also realized the importance of the OSI (Open System Interconnect) model, which helps us comprehensively address various aspects of connectivity and communication in UAV-assisted-IoT applications. Unlike the existing review articles, our paper aims to comprehensively present the existing problems associated with this emerging technology under one umbrella. The communication infrastructure of UAV-assisted-IoT applications is shown in Fig. 1.

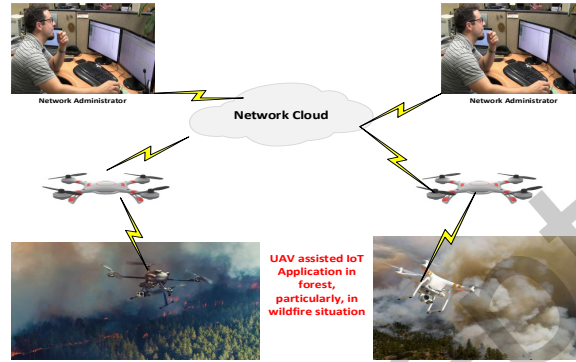


Fig. 1. Introductory diagram of UAV-assisted-IoT applications

3.1 Role of UAVs in Different IoT applications:

In many IoT applications, the incorporation of UAVs provides numerous advantages. These UAVs can establish reliable connections for IoT devices to communicate, even in challenging and dynamic communication environments. Unlike conventional IoT setups with fixed communication rules, UAV-assisted-communication can adapt to the situation to meet customer requirements. However, this adaptability also presents certain challenges for this technology. To address these challenges, Fan et al. [105] proposed a latency-efficient load-balancing scheme for this technology. They used a hybrid algorithm to establish a coordinated communication environment between UAV-based base stations and traditional IoT terrestrial base stations. While this model was tested in a simulation, implementing it in a real environment was costly, so its real-world practicality remains uncertain, and further research is needed in this area. Sharma et al. [108] continued this discussion by presenting a comprehensive survey on the optimization and communication challenges faced by UAV-assisted-IoT applications. They explored various technologies that enable IoT applications to use UAVs for efficient communication and rapid information exchange in the network. They also highlighted and discussed various mobility-related issues associated with this technology, which can improve or degrade the performance of communication metrics.

3.1.1 Mobility Importance.

In recent literature, various algorithms have been employed to control and manage the communication between UAVs and IoT devices in different applications. For instance, in [66] the authors introduced a swarm optimization algorithm to manage the communication of IoT devices with mobile UAVs. However, they check the comparative metrics in the simulation environment, which is far away from the actual results. In [12] the authors extended this discussion and proposed an intelligent routing scheme for drone-assisted-IoT applications. In this scheme, the authors used an alternative connectivity framework for UAVs and IoTs to ensure reliable and congestion-free

communication in these networks. Despite the existing literature [60, 96] highlighted problems, managing network traffic with seamless connectivity in this technology is still an open research area due to the undermentioned constraints.

- (1) During UAVs mobility, ensuring smooth connectivity and effective traffic scheduling with IoT devices is a primary concern. This issue gives rise to various communication problems such as collisions, congestion, and contention. To address these challenges, efficient traffic management schemes, along with reliable channel allocation and routing strategies are crucial to achieve desirable results.
- (2) In UAV-assisted-IoT applications, the scalability and expand-ability of IoT applications is another very challenging issue. This is because UAVs continuously fly and we need flexible rules for communication with static IoT devices. Unfortunately, this crucial element has been ignored in current literature.
- (3) In UAV-assisted-IoT applications, another challenging problem is security, due to the mobility of UAVs. Dynamic authentication is a tough ask with resource limited devices such as IoT. Therefore, ensuring the future success of this technology requires careful attention to security concerns.

3.1.2 *Architecture Importance in UAV-assisted-IoT Applications.*

In UAV-assisted-IoT applications, cellular networks play a crucial role in communication environment where many IoT devices and UAVs communicate within a single network framework. The network architecture is vital in ensuring timely communication between network components and remote destinations. Despite the benefits of cellular networks, the literature has highlighted various network architecture that did not achieve optimal results in this integrated technology. To tackle these challenges, Moradi et al. [80] proposed a SkyCore-based framework called the Evolved Packet Core (EPC) scheme. In this scheme, the authors addressed the network architectural issues in the context of inter-networking of IoTs, UAVs, and cellular networks, but they did not manage the computation complexities effectively while integrating these technologies, which as a whole affected the communication process of these network in terms of latency and throughput in the real deployment. In [46] the authors highlighted different challenges associated with UAV-assisted-IoT applications in terms of predetermined communication, airway routes, and intersections points, etc. These hurdles were further elaborated in [22] by taking into account additional parameters such as the end side device's safety, energy consumption, and communication complexities.

3.1.3 *Offloading Importance in UAV-assisted-IoT Applications.*

In UAV-assisted-IoT applications, the adaptation of offloading paradigm empowers IoT devices to process their acquired data in the network with the help of involved entities by utilizing the best use of available resources. In [36], the authors claimed that the distribution of load among all entities involved in the communication process can improve the overall performance of an employed network. Building upon this idea, recent research has highlighted that latency issues in UAV-assisted-IoT applications are often addressed by outsourcing data transfer to UAVs when an IoT device needs to send data across the network. Managing this problem throughout the communication process is still an open research issue for the scientific and enterprise community, as discussed in references [73, 86]. Dinh et al. [38] conducted a comprehensive study on offloading challenges in UAV-assisted-IoT applications. The authors specifically highlighted challenges such as client-side communication, data optimization, and offloading rates, which still skips many aspects such as flight height, mobility, communication complexity, security, etc. In another study, Lakew et al. [61], discussed the offloading issues in multi-IoT applications. This analysis took into account communication involving edge servers, edge devices, mobility, line of sight, fidelity, height, and space, etc, but ignores issues like collision, transmission range, channel estimation, channel interference, congestion and contention, etc.

3.2 Resource Management in UAV-assisted-IoT Applications

In UAV-assisted-IoT applications, resource management has several challenges such as load balancing, traffic scheduling, energy consumption scalability, etc. All of this needs to be ensured with high QoS metrics and cost-effective communication. Fig. 2, illustrates these challenges visually to help understand the overall picture.

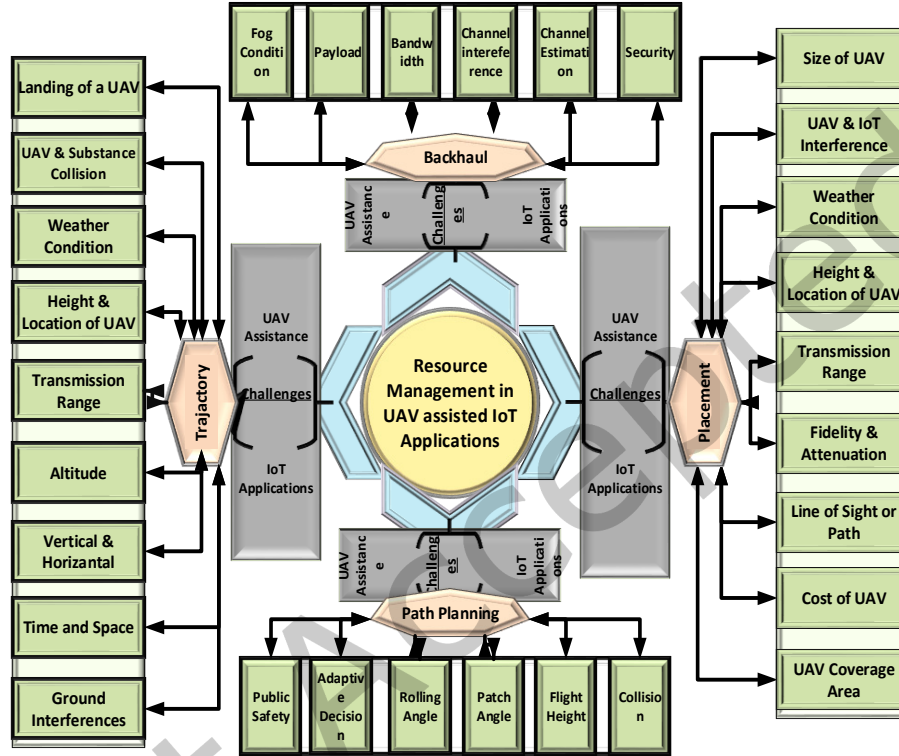


Fig. 2. Resource management challenges in UAV-assisted-IoT-applications

To explain these entities in textual format (Fig. 2), it is crucial to understand each of them i.e. communication path, planning the flight path, managing the power of both UAVs and IoT devices, allocating bandwidth, setting up backhaul connections, and placing relays. These factors play a pivotal role in maintaining high-quality communication, interoperability, and efficient operation in these networks. Given that, all these parameters can be treated as an optimization challenge. By addressing this optimization problem, we can create single or multi-objective solutions for UAV-assisted-IoT applications. Once these parameters are considered and applied within the network, we can effectively improve various aspects such as communication costs, energy consumption for IoT devices and UAVs, end-to-end delays, interference, collisions, transmission and path losses, outage probabilities, UAV trajectories, flight times, mission completion times, addition or removal of UAVs, signal-to-noise ratios, and many more. We can also help to improve network scalability, spectrum efficiency, revenue, data rates, energy efficiency, traffic management, Quality of Service (QoS), and security, etc.

It is clearly presumable that no system is perfect in terms of the highlighted limitations since they change throughout the operational processes. Nevertheless, we must consider these constraints to create comprehensive

solutions that can enhance QoS metrics in this technology. In the following subsections, we will delve into the existing literature on each highlighted attribute related to resource management in UAV-assisted-IoT applications to identify the specific challenges depicted in Fig. 2.

3.2.1 Positioning Importance in UAV-assisted-IoT Applications. In UAV-assisted-IoT applications, placement or positioning is an important factor in resource management. It affects transmitter and receiver power, coverage area, line of sight, communication cost, QoS metrics, and many other aspects, as mentioned in Fig. 3. Proper positioning of interconnected entities can significantly enhance network performance. For this, we have examined different challenges of positioning in the context of horizontal and vertical dimensions of this technology to provide a clear overview to the readers [13]. Vashist et al. [118] presented a thorough review of the challenges associated with the horizontal and vertical communication infrastructure of this technology. Moreover, they suggested that a mobile-based communication framework is useful to address these issues. Although this is an interesting idea, but the authors focused too much on the installation and communication of mobile base stations rather than working on the whole network topology. Therefore, this model is still unclear and leaves room for more research in this field. In response to the same challenge, Sun et al. [113] proposed an advanced optimization technique called Particle Swarm Optimization (PSO). This approach aimed to reduce transmission delay and energy consumption while maximizing coverage in both horizontal and vertical positions. In [118] the author introduced a mathematical framework using a mixed-integer non-linear programming paradigm to address positioning problems in UAV-assisted-IoT applications. This framework included a new variable that connected the altitude and coverage radius of communicating entities to improve the communication statistics. To address the positioning challenge in this technology, Ranjha et al. [98] proposed a perturbation-based iterative optimization approach. This approach works in coordination with uplink power management that helps to determine the optimal UAV position by considering factors such as altitude, antenna block length, beam width, etc. To implement this model in the real environment, it is still hard to achieve the simulated result statistics, because there are various external hurdles, which can affect the performance of this technology.

Moreover, we have explored various challenges related to the positioning of UAVs and IoT devices, which can contribute to maximizing device coverage while fulfilling diverse QoS requirements in the context of bit/byte rate, packet loss ratio, throughput, spectrum efficiency, etc. [4, 102, 131] in this technology. Now getting back to Fig. 3, its time to discuss the positioning challenges in the context of UAV landing.

UAVs Landing Importance.

The challenges that arise with UAVs landing would be quite tricky when it comes to ensuring good quality service in these UAV-assisted-IoT applications. One big problem is keeping a strong and steady connection between the flying UAV and the IoT devices on the ground when the UAV is landing. Things like signal interference, crowded networks, and delays need careful handling to make sure data and control signals with smooth operation. Also, the UAV's ability to land accurately is really important to avoid disruptions in the communication process. Solving these challenges is crucial to make the most out of UAV-assisted-IoT applications. In [23], the authors proposed a pattern creation model for UAV-assisted-IoT applications. They used the ergodic characteristics of network connected entities to create patterns and improve quality of service (QoS) by optimizing positioning in a single time slot. In [132], Xiong et al. introduced an energy-efficient framework for UAV-assisted-IoT. They considered placement issues and utilized mobile micro base stations to reduce communication costs and improve network efficiency.

UAVs and IoT Connectivity Importance.

In UAV-assisted-IoT applications, the connectivity challenges create significant problems. Maintaining a robust and consistent connection between the UAV and the IoT devices on the ground is crucial for reliable data transmission. Factors such as signal strength, interference, collision, contention, and limited battery backup can

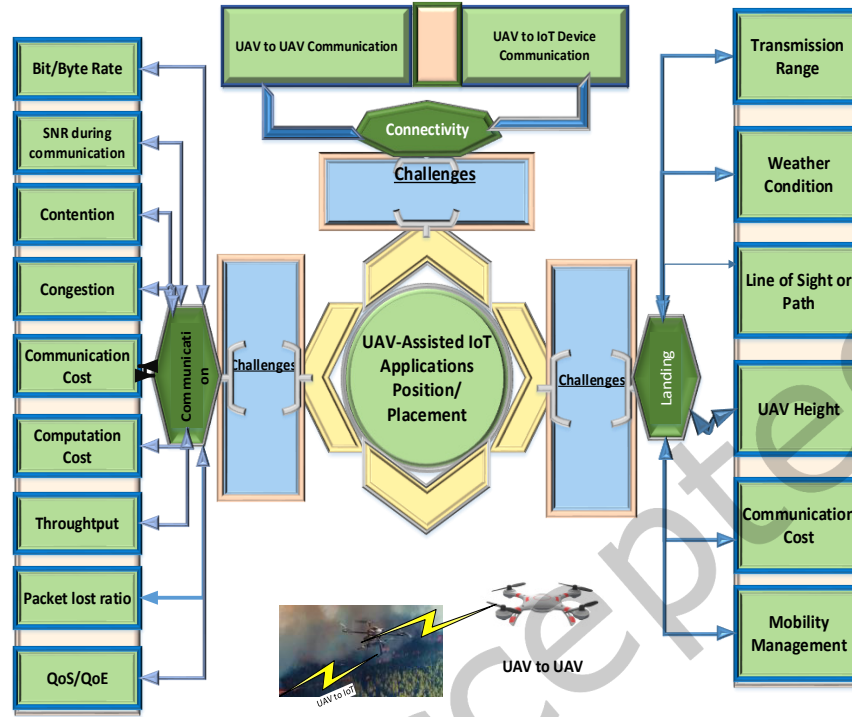


Fig. 3. Positioning challenges in UAV-assisted-IoT applications

impact connectivity that potentially leads to data loss or disruptions in communication. Therefore, ensuring QoS metrics such as low latency and high reliability becomes challenging when UAVs move through different environments and altitudes. In [52] a cache optimization model was proposed to improve the throughput and latency of UAV-assisted-IoT applications by considering the position of employed IoT devices. In this model, maximum QoS standards were achieved in simulation as the authors claimed, but the real implementation is still in a fuzzy state, due to its complex processes. Therefore, addressing these connectivity challenges is essential to achieve effective results in this technology.

Ultra-fast communication Importance.

In UAV-assisted-IoT applications, ultra-fast communication poses notable challenges for this technology, while maintaining high (QoS) metrics. Considering the rapid data exchange between UAVs and IoT devices, it is essential to take care of various factors such as limited bandwidth, signal interference, communication complexity, contention, congestion, computation cost, and fidelity, etc. Keeping communication fast and smooth in this technology is tough because UAVs move continuously through different places. We must solve these communication challenges to make UAV-assisted-IoT applications more productive. In [49] the authors conducted a survey highlighting the shortcomings in existing literature concerning UAV-assisted-IoT applications. They considered issues like congestion, contention, interference, and signal quality (SNR) with an objective of acknowledging how we can maintain the QoS metrics with ultra-fast communication.

3.2.2 Fronthaul/Backhaul Challenges in UAV-assisted-IoT Applications. In UAV-assisted-IoT applications, Fronthaul and Backhaul are crucial for managing connectivity between IoT devices and UAVs [40]. To explain further, when data is gathered and sent from one place to another through an intermediary, it's called backhauling. In the context of UAV-assisted-IoTs, UAVs act as intermediaries between IoT devices and the main network components. Therefore, IoT devices relies on both backhaul and fronthaul for efficient data processing and communication in the network. Therefore, in this technology, backhauling significantly reduces communication costs compared to traditional IoT networks. Researchers are actively exploring various methods to boost the use of backhauling in IoT applications and make them more productive. Considering the dynamic deployment and communication of IoT applications, UAVs offer a promising solution to improve the geographical accessibility of data in this emerging technology, as mentioned in reference [114]. Now, let's focus on the current challenges related to backhaul and fronthaul that can affect the QoS metrics in UAV-assisted-IoT applications. We have used Fig. 4, to illustrate these challenges in visual format.

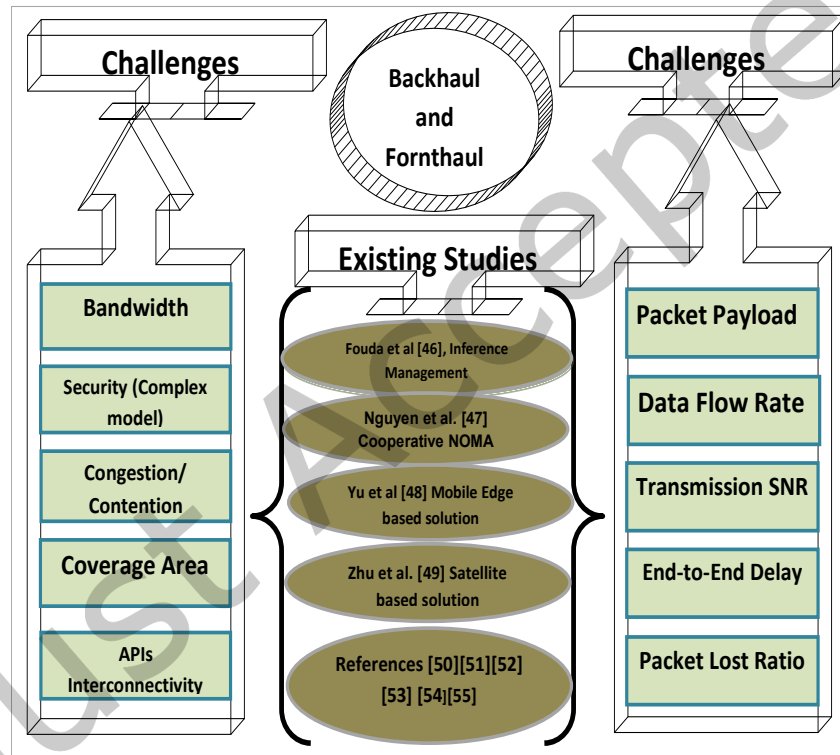


Fig. 4. Backhaul and Fronthaul challenges in UAV-assisted-IoT applications

To improve the connection between IoT devices and UAVs in terms of backhaul, Fouda et al. [45] proposed a novel scheme for this task. They used the distance inter-site distance with spatial dynamics of communicating entities. The authors claimed that this approach resolved connectivity problems between IoT and UAVs and produces optimal communication results. Nguyen et al. [88] continued this discussion and proposed a non-orthogonal multiple access (NOMA) framework in coordination with transmission bandwidth to resolve the backhaul and fronthaul problems in UAV-assisted-IoT applications. Besides, the authors used an optimization

problem to determine the radio resource allocation rate at the macro base station (MBS), UAVs and IoT side for better communication metrics. Consequently, Yu et al. [136] proposed a mobile edge computing framework for UAV-assisted-IoT applications by taking into consideration the backhaul scenario to tackle latency issues in these networks. To continue this discussion, a geostationary orbit (GEO) satellite backhaul framework was suggested and used by Zhu et al. [143] to establish a reliable communication infrastructure among UAVs and employed IoT devices to address the throughput and packet loss issues in these networks. Likewise, references [51, 105] presented detailed surveys on the traffic management of these networks to improve the communication parameters using multi-hauling via UAVs. In these articles, it was highlighted that the reliability of backhauling could be increased with the height and convergence parameters. In short, the authors predominantly concentrated on these articles on the bit/byte rate, data flow rate, latency, throughput, coverage area, communication cost, etc.

3.2.3 Trajectory Challenges in UAV-assisted-IoT Applications. In UAV-assisted-IoT applications, the continuous movement of UAVs requires distinct points and angles for communication with employed devices, which acknowledge the importance of trajectory or path planning for integration with other technologies. Following the different points and angles of communication, trajectory could play an incredible role by demonstrating the path of a UAV throughout its flying phase that is assumed to be helpful, while establishing communication links with other devices. In addition, it also stimulates a UAV movement with reduced arbitration and improved transmission coverage [42]. In [139], the authors proposed a hybrid trajectory and communication model for UAV-assisted-IoT applications. In this model, the objective was to improve the throughput and minimize congestion and contention. Fig. 5 comprehensively demonstrate the challenges connected with trajectory of UAV-assisted-IoT applications.

Continuing this discussion, Khan et al. [56] proposed a low altitude quad-rotor-based trajectory optimization framework for these networks. This framework helps collect data from stationary IoT devices using UAVs in mobile communication environment. In [54] the authors provided a comprehensive review discussing UAV landing challenges. They considered various communication and trajectory factors that could hinder UAV connectivity and communication. Additionally, they briefly addressed trajectory and safety issues impacting UAV landings. In [87] the author introduced a trajectory model for UAVs in Intelligent Transportation Systems. They used GPS to plan vehicle routes in coordination with roadside units to improve the communication statistics of this technology. Continuing this discussion, Wang et al. [124] proposed a trajectory control algorithm for UAV-assisted-IoT applications. They aimed to improve connectivity through proper time synchronization by using a convex optimization approach. Moreover, they employed the block coordinate descent (BCD) technique to enhance real-time decision-making processes in these networks.

In [20], the authors presented a novel approach to help UAVs in path planning to avoid collisions with obstacles. This approach uses mathematical principles to demonstrate that the UAV can prevent collisions, even when there is some uncertainty in its movements. It considers scenarios where the UAV might slightly deviate or overshoot its intended position. The technique utilizes obstacles represented as rectangles with special points at their corners to guide the UAV in selecting a collision-free path. By connecting these points in a specific manner and employing the well-known Dijkstra algorithm, the UAV can determine a safe and obstacle-free route to follow. This approach ensures the drone's safe flight, even in uncertain conditions. However, it remains essential to assess the algorithm's performance under adverse weather conditions, where factors like signal attenuation and fidelity can affect the transmitted signals. Sonny et al. [111] introduced a Q-learning algorithm to make path planning better for UAVs. This algorithm helps UAVs avoid obstacles and reach their destination safely. The authors used a grid-based method to teach the algorithm and make it better at getting rewards based on how the UAV behaves. When they tested it against other methods like A-star, Dijkstra, and Sarsa, they observed that the proposed outperform these schemes in terms of learning speed and the length of the path it chose. In [141], the works on how to improve the UAV's path planning to avoid obstacles collisions, even when there are lots of dangers around. They use Sequential Quadratic Programming and Nonlinear Programming to make sure the

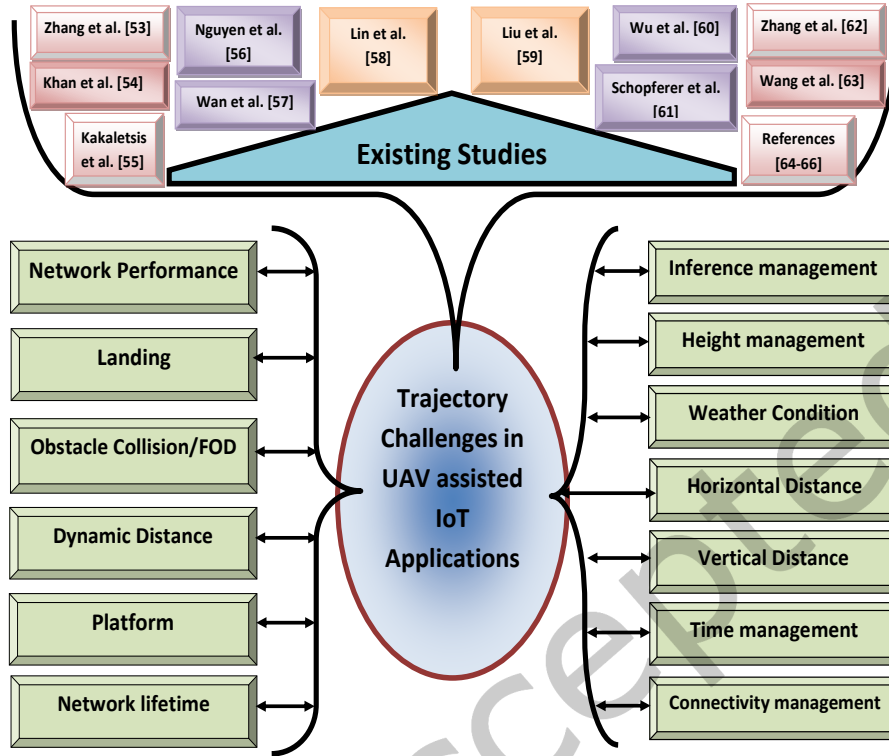


Fig. 5. Trajectory challenges in UAV-assisted-IoT applications

UAVs find a safe path. It also improves the Bézier curve algorithm to resolve path planning issues under uncertain situations by considering moving objects, and showed that this approach works better than existing techniques in comparative metrics.

In [120], the authors talked about how UAVs communicated with each other and with things on the ground using wireless networks. The authors also showed how UAVs can use other drones to make the network work better and improve the QoS metrics. Furthermore, They looked at how UAVs can find the best way to move around, avoid obstacles and crashes, and how they can make their own path planning with controlled movements. In [72], the author used the pre-coding method to solve the path planning-related problems in UAV-assisted-IoT applications. They break down complex problems into simpler ones in the context of UAV path selection. Wu et al. [130] proposed a smart scheme to to handle takeoff and landing issues of UAVs in different situations such as emergency landings. Schopferer et al. [104], comprehensively discussed the challenges faced by low-flying UAVs such as collisions with obstacles that can cause damage. Their goal was to offer readers a clear understanding of how to enhance the safety and productivity of UAVs in various IoT applications.

In [138], Zhang et al. proposed a mobile edge computing framework for UAV-assisted-IoT applications using a stochastic approach. The objective of this work was to reduce energy consumption in IoT devices and UAVs during computation, transmission, task handling, and flight path selections. Wang et al. [123] continued the discussion by introducing a novel mobile edge computing scheme for UAV-assisted-IoT applications. They focused on optimizing connectivity and communication fairness among IoT devices and UAVs while considering load balancing and energy consumption of interconnected devices. In references [8, 115, 137], the authors examined

existing research on UAV-assisted-IoT applications related to path planning. They discussed the advantages and disadvantages of various approaches and highlighted unresolved research challenges in the area of path planning. In short, we can simply say that trajectory in UAV-assisted-IoT applications has great importance and its optimization must be considered in terms of interference management, the landing of UAVs, connectivity among IoT devices and UAVs, data flow, energy management at transmitter and receiver, mission control, traffic scheduling, time synchronization, dynamic distance, etc.

3.3 Interoperability Importance in UAV-assisted-IoT Applications

In recent times, UAV-assisted-IoT applications have gained significant attention, and there is a growing need to study their interoperability requirements to improve the performance of various applications. Boursianis et al. [24] introduced an advanced WiMAX framework in collaboration with the SHERPA network to enhance the interoperability between UAVs and IoT devices. The study showed improved communication metrics in the context of latency, throughput, and efficient utilization of bandwidth. Oubbati et al. [90] highlighted in their survey paper that SDN and NFV (Network Function Virtualization) serve as powerful tools to address interoperability challenges in UAV-assisted-IoT applications. They also stressed the significance of these technologies in mobile IoT applications where UAVs assist them in sharing data in the network. Castellanos et al. [26] continued this discussion and proposed Narrow Band IoT (NB-IoT) framework for UAV-assisted-IoT applications by taking into account the agricultural applications scenario. In [76], the authors presented different scenarios of UAV-assisted-IoT applications by illustrating how UAVs enhance efficiency, coverage, and capacity of these applications, which ultimately leads to improved productivity.

Lim et al. [68] introduced a federated learning (FL) framework for UAV-assisted-IoT applications. They used mobile relays to efficiently update and share client data in the network. Similarly, in [103], the authors presented a framework for transmitting messages between ground-based Long Range (LoRa) devices using UAVs and BS. UAVs acted as relays to facilitate communication between LoRa devices and the BS within an ad hoc WiFi network. In [37], the authors proposed a hybrid optimization framework for UAV-assisted-IoT applications. The goal of this work was to minimize transmission power between BS and UAVs in deployed networks, and improve communication statistics. In [83], the authors suggested an architecture-based edge nodes paradigm for UAV-assisted-IoT applications. The authors used the opportunistic ad hoc network scenario to check the comparative results of this model. During analysis, they noted that the proposed model has shown improvement in the latency, packet loss, computation cost, and other parameters affecting QoS standards. In summary, Fig. 6 illustrates the interoperability requirements of UAV-assisted-IoT applications, which is comprehensively discussed in the upcoming sections.

3.3.1 Interoperability Communication Requirements.

In this section, we discuss the entities essential for the communication interoperability of UAV-assisted-IoT applications and how they can potentially impact the QoS metrics in this technology.

Cross-Platform Compatibility Requirements.

Cross-platform compatibility is crucial in UAV-assisted-IoT applications to ensure seamless communication between various IoT devices, UAVs, and systems [18]. It ensures that UAVs can effectively interact with different devices and platforms by enhancing the overall efficiency and functionality of the technology. Readers, students, and researchers interested in exploring this field are recommended to review the following reference [89, 110].

Scalability Requirements .

In IoT applications, scalability is vital because these networks are growing over time. Integrating UAVs into these networks is important to increase their productivity in many domains, but it is crucial to maintain good QoS metrics during communication. Meeting scalability needs helps these networks handle more devices with

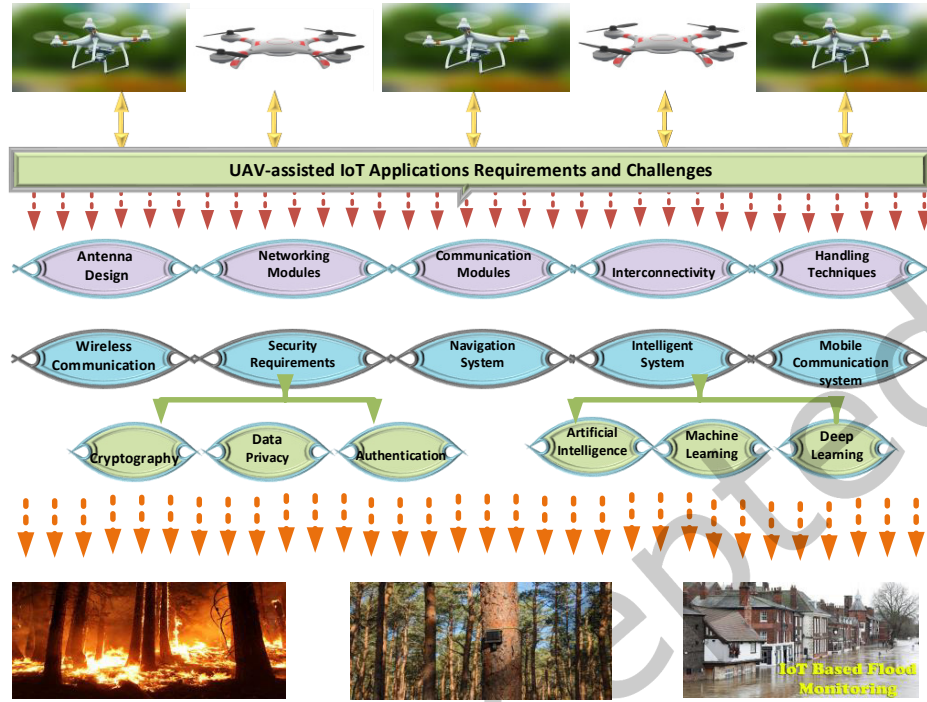


Fig. 6. UAV-assisted IoT applications Interoperability Requirements

the changing demands of the consumer market by ensuring they stay effective in the long run. In [32], the authors explored how UAVs can improve communication statistics in IoT applications with scalability and wireless connectivity. They also talk about the advanced AI techniques and how they can address the communication challenges in this emerging technology.

Interoperable Sensors and Actuators Requirements.

Interoperable sensors and actuators are vital components within UAV-assisted-IoT applications. These devices enable seamless communication and cooperation among UAVs and IoT devices by enhancing the overall communication efficiency. Ensuring that sensors and actuators can work together harmoniously is essential for achieving smooth data exchange, accurate information gathering, and efficient control that ultimately contributes to the success of this technology.

Open APIs Requirements.

Open APIs are crucial for UAV-assisted-IoT applications as they enable seamless integration and communication between various components and systems in this technology. These requirements ensure that different devices and platforms can work together effectively by allowing UAVs and IoT devices to share data in a coordinated and standardized manner. Open APIs facilitate interoperability by making it easier for developers to create applications that can leverage the capabilities of both UAVs and IoT devices, and ultimately improve the overall performance of this technology.

Testing and Certification Requirements. Testing and certification of UAV-assisted-IoT applications involve rigorous evaluation processes to ensure their reliability of communication, security, and compliance with regulatory standards. These tests encompass various aspects such as system performance, data integrity, connectivity robustness, and safety of protocols, etc. Certification ensures that these applications can operate seamlessly in real-world scenarios while meeting stringent quality and safety requirements of world set rules. Given that, they play crucial role in building trust among stakeholders and promoting the widespread adoption of UAV-assisted-IoT application in many industries.

3.4 Communication Modules Role in the Interoperability of UAV-assisted-IoT Applications

In this section, we explore different communication technologies in the context of interoperability to understand how IoT devices, UAVs, base stations, and other network elements are connected in UAV-assisted-IoT applications. When discussing the performance of this technology with a focus on QoS metrics, dependability, expandability, and stability, the various communication aspects and modules should be considered for its better operation. In [28, 47, 81], the authors have examined various wireless communication methods and technologies such as LTE, Bluetooth, WiMAX, Broadcast radio, Microwave radio, MIMO (multiple-Input and Multiple-Output), and ZigBee, in terms of how well they interconnect and operate in this technology to improve its communication statistics.

In [41], the authors used a trajectory-based optimization approach to control the duration of transmission power in communication among all interconnected entities in UAV-assisted-IoT applications. The objective of this work was to improve communication efficiency and minimize energy consumption during transmission. To demonstrate the model's effectiveness, the authors highlighted the weakness of existing studies such as they were slow to estimate channel information of large-scale networks, and require an additional channel estimation mechanism for channel fading, and attenuation management, etc. In our paper, we have summarized the interconnectivity technologies using Table 2 to provide an overview to non-specialist.

Table 2. Different technologies comparative analysis

References	Comparative Metrics	Best Selection	Network Standard	Advantage over the others
Yazid et al. [135]	LTE, Bluetooth, XBee, WiMAX, WiFi, etc.	WiMAX and LTE,	SHERPA standard	Fixed bandwidth, coverage area, low data lost rate, flexible in wireless environment
Maakar et al. [74]	EDSDV, DSDV, AODV, EADOV, & AFAR-D, etc.	EDSR & EDSDV	Dynamic Routes selection or Packet Routing	Less packet lost ratio, low latency
Al-Turjman et al. [9]	Flexibility & Scalability via Routing protocols, SDN, Hardware, other	SDN	Interoperability with OSI model	Improved efficiency and productivity
Chowdhury et al. [34]	Path planning Motion-based, Trajectory-based, & Navigation-based	Trajectory-based-3D	Path planning	Efficient Connectivity, Reliable data exchange, Trust-worthy communication

In [6], the authors describe the importance of different routing protocols such as Enhanced Destination-Sequenced Distance Vector Routing (EDSDV), Destination-Sequenced Distance Vector Routing (DSDV), Ad-hoc On-demand Distance Vector (AODV), Enhanced Ad-hoc On-demand Distance Vector (EAODV), and Enhanced Dynamic Source Routing (EDSR), etc, in the context of in UAV-assisted-IoT applications. Furthermore, the authors

comprehensively evaluated the performance of each protocol to identify their advantages and disadvantages in the context of aforesaid technology. To address communication challenges in UAV-assisted-IoT applications, it's crucial to adopt a three-dimensional (3-D) perspective for understanding the IoT networks, as emphasized by Liu et al. [70]. The authors argue that a traditional two-dimensional (2-D) model falls short in establishing effective connections among connected entities, as it cannot accurately identify objects compared to the 3-D model. Hence, the importance of these aspects cannot be underestimated. It is considered a fundamental requirement for this emerging technology to ensure efficient navigation, surveillance, and reliable communication, particularly in inaccessible locations [62].

Let's assume a 3D space, which contain network entities E , where $E = \{E_1, E_2, E_3, E_4, \dots, E_n\}$ and they are distributed over points P_{st} and P_{dn} , respectively, where P_{st} denoted static location, while P_{dn} is used for distributed locations. Following this, a free space of network entities is symbolized with W_{fr} . To address the connectivity and communication problem of UAV-assisted-IoT applications in 3D space with parameters (P_{st}, P_{dn}, W_{fr}) . Then we can derive various attributes as follows: Let's introduce an attribute, $\lambda[0, \Delta T] \Rightarrow 3D$, which is defined within a bounded space with respect to time (ΔT). Under this condition, the following holds true:

$$\begin{aligned} \lambda(0) &= P_{st} \Rightarrow \text{starting point and time} \\ \lambda(1) &= P_{dn} \Rightarrow \text{destination point and time} \\ \forall, P_{\theta} &= \sigma(\alpha) \in W_{fr} \\ \forall, \sigma &\in [0, \Delta T] \end{aligned}$$

In the given context, P_{θ} represents the connectivity path of UAVs, IoT devices and other communication entities. This information is crucial because it allows us for the straightforward calculation of communication costs, energy consumption during transmission, and computation costs for any newly designed protocol.

Communication Latency Requirements.

In UAV-assisted-IoT applications, ultra-fast communication is very important and one of the basic requirements of this technology that needs to be met. These applications need to send and receive data in real-time, especially in critical situations such as patient monitoring, responding to emergencies, and self-guided navigation, etc. To meet these requirements, we have to make sure that the time it takes for signals to travel is minimized. We also need smart techniques to process data quickly and efficiently. Moreover, for UAVs to work well in IoT networks, we need communication systems that can adapt to changing conditions and always provide ultra-fast communication.

Energy Efficiency Requirements.

Energy efficiency is critical for UAV-assisted-IoT applications. The technology contains resource-limited devices, and saving energy during operation is vital. To achieve energy efficiency, we need to improve different things such as communication techniques, routing protocols, software and hardware, etc. Therefore, it is really important to do thorough research and come up with innovative ways to save energy in UAV-assisted-IoT applications. This will help and make sure that these systems can keep working well for a long time in a friendly communication environment.

Time Complexity Requirements.

In UAV-assisted IoT applications, the speed at which things happen is really important. Because this affects how well the algorithms and protocols are used in these applications. To make sure everything works accurately and efficiently, we need algorithms and protocols with low time complexity. This helps in processing data on time, and making efficient decisions in real-time. If things take too long (high time complexity), it can lead to delays and inefficiencies. This can be a problem, especially in situations where quick decisions are needed, and fast data processing is critical such as surveillance, disaster management, and self-guided navigation, etc. So, making

sure that time complexity is optimized is a top priority when designing and implementing UAV-assisted-IoT applications to meet the demands of different stakeholders.

Spectrum and Bandwidth Efficiency Requirements.

In UAV-assisted-IoT applications, the demands for spectrum and bandwidth efficiency are of great importance. These applications require the optimal utilization of available spectral resources to support the increasing number of connected devices and the diverse range of data traffic generated in this technology. To achieve this, we need advanced techniques such as dynamic spectrum allocation, interference management, and adaptive modulation schemes. Moreover, optimizing bandwidth usage through efficient encoding and compression methods is essential to ensure seamless data transmission and improve the overall performance of this technology. Meeting these stringent requirements is crucial for the success and sustainability of UAV-assisted-IoT applications in various domains, including surveillance, environmental monitoring, healthcare, and disaster management, etc.

3.5 Role of Routing Protocols in Interoperability of UAV-assisted-IoT Applications

In this section, we underscore the importance of routing protocols in UAV-assisted-IoT applications. First, we provide the technical details of different routing protocols to knowledge of their importance and how we can ensure the the future of this emerging technology with the help of these protocols (Table 3).

Table 3. Technical Details on How UAV-Assisted-IoT Applications Utilize Various Communication Protocols in Their Architecture

Air-to-Ground Communication & Connectivity	References	Application Domain	Network Architecture	Testing Environment
LoRaWAN for access, and 4G/5G/Wi-Fi as a backbone	Castellanos et al. [26] NB-IoT	Agricultural monitoring	Edge computing	Simulations and UAV-to-Ground proof of concept
LoRaWAN and Bluetooth both for access, Wi-Fi for backbone	Arafat et al. [15] LADTR	Search and rescue operations	Edge computing	Simulations and UAV-to-Ground proof of concept
LoRaWAN for access and backbone	Data	Disaster monitoring	Fog computing	Simulations
LoRaWAN for access and 802.11g for backbone	Panda et al. [93] IEEE 802.11ac, IEEE 802.11n	Emergency response	Cloud computing	Simulation Environment
5G cellular, 802.11s and LoRaWAN for access and backbone	Athanasiadou et al. [17] LTE	Flight telemetry and agriculture sector	Edge and Cloud computing	UAV-to-Ground proof of concept
LoRaWAN for access and Wi-Fi for backbone	Pen et al. [92] ALOHA	Environmental monitoring	Cloud computing	UAV-to-Ground proof of concept

Therefore, it is imperative to examine existing protocols comprehensively, as without summarizing these protocols, we cannot proceed effectively. Given that, we have provided summaries of various protocols as follows:

1. **MAC Layer Protocol:** In UAV-assisted-IoT applications, the Medium Access Control (MAC) layer is crucial for network communication as it manages interconnectivity and communication between the physical and data link layers. However, current MAC protocols in this context often rely on omnidirectional antennas, which are

less suitable for networks with long-distance communication between paired UAVs, IoT devices, and BSs [11]. The MAC layer is essential for governing data exchange within a network and ensuring efficient data transmission. To improve interconnectivity and communication in this technology, it is important to explore the advanced MAC protocols tailored to the specific needs of this emerging technology. These protocols should consider factors such as using directional antennas to address long-distance communication, adapting to dynamic of network conditions, and efficiently managing scarce resources for reliable, low-latency communication. Furthermore, ongoing research and innovation in MAC layer design are crucial for realizing the full potential of these advanced network systems. In [57, 64, 97], the authors discussed the importance of MAC layer protocols such as CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance), CSMA/CD (Carrier Sense Multiple Access with Collision Detection), TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access), CDMA (Code Division Multiple Access), ALOHA, Slotted ALOHA, Wi-Fi (IEEE 802.11), Bluetooth and Zigbee (IEEE 802.15.4), etc. Therefore, we recommend that readers interested in this domain review these articles.

2. Physical Layer Protocols:

The Physical Layer in the OSI (open system Interconnection) model handles the physical aspects of network connectivity. In simpler terms, it includes hardware such as cables, ethernet cabling, optical fibers, and deals with things like electrical pulses, and frequencies used for transmitting data packets or signals [65]. Continuing this discussion, the IEEE 802.11 standard serves as a physical layer protocol in UAV-assisted IoT applications [55]. Originally designed for wireless LANs (local area networks), this standard enables data transmission at speeds of 1 to 2 Mbps using a 2.4 Gigahertz frequency. Over time, the existing version of IEEE 802.11 is upgraded to IEEE 802.11p by adding the functionality of wireless access for vehicular networks. The upgraded IEEE 802.11p worked well for static IoT devices and did not lose data or connectivity. But when it came to high-speed UAV-assisted-IoTs, it could not handle the mobility problems. Therefore, it was not used in real-world applications. In [109, 125], the authors pointed out various problems associated with the physical layer protocols of this new technology.

3. Network Layer Protocols:

In UAV-assisted-IoT applications, network-layer protocols play a crucial role in establishing connections among devices. They are like the basic building blocks that help devices connect and send data to remote destinations over the network [16]. Moreover, this layer makes it possible for data to travel in packets through routers and switches. These packets have special headers that include where they are coming from and where they are going to be sent. Jobaer et al. [53], introduced an improved version of the ad hoc on-demand distance vector (AODV) routing protocol. The objective of this work was to manage the technical challenges faced by this technology in the context of routing, and improve the communication statistics. Continuing this discussion, Vasiliev et al. [119], suggested a special protocol for these networks known as AL-ARQ. This protocol helps with the routing challenges faced by these networks. In another paper, Shao et al. [107], introduced a protocol called PaFiR, which uses something called a Particle filter to improve routing among connected devices. They also talked about how UAVs can help regular IoT devices work better by sharing some of their tasks by demonstrating their achieved results. Notably, the network layer protocols include IP (Internet Protocol), which is the foundation of the internet, and routing protocols such as AODV, DSDV (Destination Sequenced Distance Vector), OSPF (Open Shortest Path First), BGP (Border Gateway Protocol), RIP (Routing Information Protocol), and EIGRP (Enhanced Interior Gateway Routing Protocol), and many more, determines the best paths for data to travel from source to destination in the network [14, 119, 140]. Overall, the network layer protocols play a critical role in ensuring data packets reach their intended destinations across interconnected networks.

4. Application Layer Protocols:

In this section, we talk about the application layer protocols by exploring both their advantages and disadvantages. These protocols hold immense importance in the context of UAV-assisted-IoT applications, as they are considered essential components of any network. Their significance cannot be overstated, as they directly impact the effectiveness and efficiency of communication and data exchange in this emerging technology. Moreover,

these protocols offer several advantages by providing a wide range of services and functionalities that can adapt to diverse application scenarios. These protocols promote interoperability by facilitating communication between different devices and platforms to ensure seamless integration of this technology in different networks. However, there are also disadvantages to consider, as these protocols introduce additional data overhead. Moreover, vulnerabilities in these protocols can pose security concerns that potentially compromise sensitive data and the integrity of IoT devices. In [39, 129], authors explored various challenges related to application-layer protocols by drawing insights from existing literature to highlight their drawbacks. Moreover, the application layer protocols such as MQTT (Message Queuing Telemetry Transport), CoAP (Constrained Application Protocol), HTTP (Hypertext Transfer Protocol), AMQP (Advanced Message Queuing Protocol), DDS (Data Distribution Service), and OPC UA (Open Platform Communications Unified Architecture), etc, are summarized and explained in references [35, 79, 91].

5. Crossed Layer Protocols:

UAVs can communicate and connect with IoT devices effectively because they can move around easily. In our previous discussion, we focused on routing protocols that work at different layers to improve the QoS metrics in this technology. Now, let's look at cross-layer protocols that also help make data transmission, resource management, and network reliability better. These cross-layer protocols can work together or individually to achieve these goals. They include various standards like IEEE 802.11p (DSRC), IEEE 802.15.4, LoRaWAN, NB-IoT (Narrowband IoT), Device-to-Device (D2D) Communication, and Low-Power Wide Area Network (LPWAN) Protocols like Sigfox and NB-IoT. Additionally, the User Datagram Protocol (UDP) and Transmission Control Protocol (TCP) are vital parts of this technology. Moreover, custom or special protocols designed for specific needs play a significant role in improving communication metrics in this technology by making data exchange easier, and to achieve high QoS metrics in UAV-assisted-IoT applications.

3.6 Summary of Discussion

In summary, when it comes to connecting UAVs with IoT devices and highly mobile network components, intelligent positioning systems become indispensable. Routing protocols play a pivotal role in ensuring seamless communication with the mobility of UAVs to manage traffic effectively in the network and improve communication statistics. These protocols are valuable tools for sharing information in UAV-assisted-IoT applications, as they improve communication and productivity of different applications, where human access is not possible. In simple terms, intelligent routing acts as a potent asset for efficient UAV-assisted-IoT applications. Therefore, we encourage stakeholders interested in improving routing protocols for such applications to explore relevant literature.

4 SECURITY CONCERNS THAT EFFECT QOS OF UAV-ASSISTED IOT APPLICATIONS

In UAV-assisted-IoT applications, maintaining the QoS metrics is impossible without considering the security aspects of this new technology [2]. Wireless communication technologies face several security challenges, both from within the network and outside the network due to their unstructured communication and deployment. For example, if an attacker compromises the flying base station (FBS) or UAV, unlike traditional base stations (BS), it can lead to a loss of connection with the IoT network, and as a result, the operation of these networks could be disrupted or inaccessible. Furthermore, there's a possibility of an intruder disrupting line-of-sight communication, which could also result in IoT applications becoming inaccessible. Given the potentially severe consequences of security vulnerabilities in this technology, it is crucial for researchers to focus on this area while upholding QoS metrics. In the following sections, we explore different security threats and attacks that could disrupt QoS standards in UAV-assisted IoT applications. For visualization of this, we add Fig. 7 in the paper.

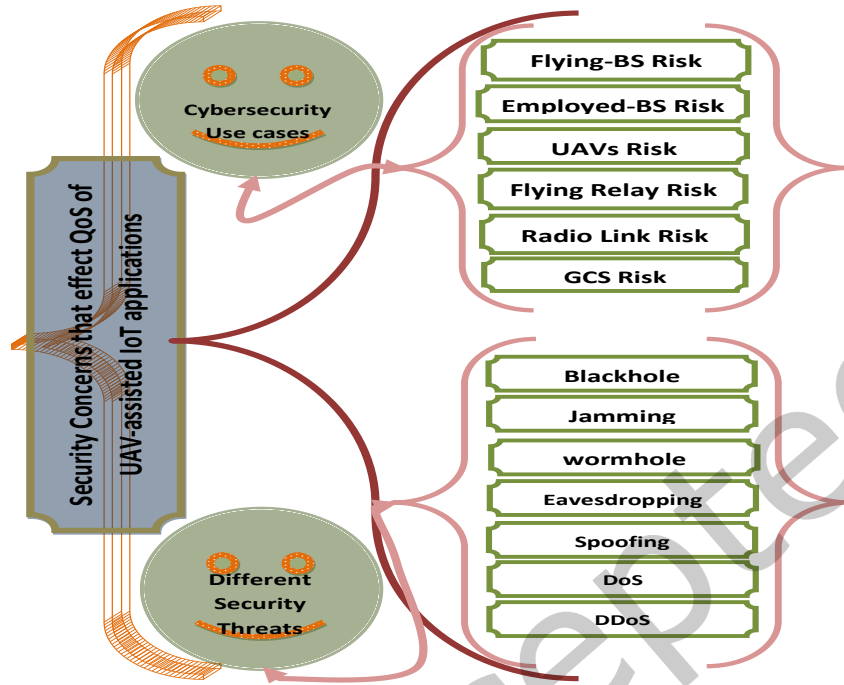


Fig. 7. Security Challenges in UAV-assisted-IoT applications

Since the adoption of UAVs in different IoT applications, the productivity of these applications has increased with time. Given that, they get the attention of new stakeholders, which is a sign of their bright future. However, this technology, while poised to be a game-changer, is also vulnerable to adversaries who may target it to access valuable information and misuse it in criminal activities. When an adversary launches a cyber-attack on these networks and compromises their security, they can gain access to critical information about the devices involved, including FBS, UAVs, IoT devices, ground control stations (GCS), BS, transmission channels, global positioning systems (GPS), and data, etc [122, 126]. With this information, they can target clients, business stakeholders, and organizations, demanding money and potentially threatening to expose their information publicly or disrupt network communication infrastructure. Such a scenario could significantly impact the quality of service (QoS) metrics of the network. To prevent such catastrophic situations, it becomes paramount to prioritize the security of the devices in use, the data being transmitted, and the control signals when deploying these networks to ensure reliable operation.

Using Fig. 7 as a reference point, we aimed to familiarize readers with various attacks and how to ensure reliable operations. In the next phase, we delved into these scenarios to identify potential risk categories related to network components, including UAV connection types, GPS, cellular network communication links, FBS, GCS, and Wi-Fi links. Subsequently, we conducted an analysis of a potential list of attacks, along with their respective solutions. This approach is aimed at enhancing the security and overall effectiveness of these applications by implementing robust defense strategies.

Flying-BS Risks 1:

In UAV-assisted IoT applications, Flying-BS (FBS) encounter security threats that are vital to prevent in order to secure this technology. Designing strong defenses against potential FBS vulnerabilities is crucial [29]. This

involves employing advanced encryption methods for data protection, implementing real-time threat monitoring and analysis through intrusion detection systems, and adopting secure device authentication protocols. Moreover, regular security checks, firmware updates, and compliance to operational protocols are essential for maintaining security [30]. Combining these technical measures with user education greatly enhances the technology's ability to handle security threats and ensures reliable operations.

UAVs and IoT Connectivity Risks 2:

In UAV-assisted-IoT applications, the connectivity between UAVs and IoT devices presents various risks that necessitate robust security measures to protect this technology [121]. The network structure and complex communication paradigm of this technology requires comprehensive strategies such as encryption protocols, secure device-to-device authentication methods, and intrusion detection systems to counter possible attacks. Furthermore, compliance to strict regulations and ongoing monitoring are essential for mitigating potential vulnerabilities. These scenarios highlight the importance of proactive security strategies to guarantee the confidentiality, integrity, and availability of data in this technology.

Flying Relays Risks 3:

In UAV-assisted-IoT applications, addressing the inherent vulnerabilities with flying relays acknowledges the need of a strong security framework. To effectively manage the potential security challenges of this technology, a multi-layered approach is essential [116]. This involves the use of encryption protocols to protect transmitted data, intrusion detection systems for identifying unauthorized access, and resilient communication channels that can adapt to changing conditions. Moreover, regular software updates and firmware patches are crucial to address vulnerabilities, while strict access control measures ensure that only authorized personnel can interact with the UAVs. Implementing these technical strategies, along with comprehensive risk assessments, is crucial for establishing a secure foundation for this technology.

Radio Link Risks 4:

In UAV-assisted-IoT applications, securing the radio link has great importance in today's interconnected world. The vulnerabilities associated with wireless communication demand rigorous measures to safeguard sensitive data and ensure the reliability of these systems [7]. Employing encryption protocols, such as Advanced Encryption Standard (AES), alongside authentication mechanisms such as Public Key Infrastructure (PKI), and Multi-Factor Authentication can fortify the confidentiality and integrity of the transmitted information. Furthermore, continuous monitoring and anomaly detection algorithms play a pivotal role in proactively identifying and mitigating security threats. Therefore, the involved stakeholders are advised to make collective efforts and ensure the future of this technology.

Other Risks 4:

From the previous discussion, we can see that UAVs play a crucial role as intermediaries for transmitting data from network components to a remote destination. When UAVs act as a FBS, they can be controlled in real-time through Ground Control Stations (GCS) or Base Stations (BS) using wireless links. For instance, Maimaitijiang et al. [77] demonstrated that drones/UAVs can be remotely controlled through GCS, even via satellite connections like Predator. Furthermore, the authors emphasized that when UAVs function as FBS or relays, they may encounter similar challenges as conventional operational network base stations. In such scenarios, third-party GCS and terrestrial BS information need to be shared within the network to effectively manage communication processes. To facilitate this, navigation information, including timing, placement, velocity, and Line of Sight (LoS), can be obtained from GPS satellites, which offer three categories of connectivity: Wi-Fi, Cellular, and satellite. While ensuring these aspects, it is essential to consider numerous communication and interoperability factors while implementing adequate security protocols for reliable operation of this technology. In [67], the authors highlighted that Wi-Fi and GPS networks are insecure in presence of cellular networks, due to the lack of proper authentication and data preservation schemes. In [50], the authors extend this discussion by stating that retail market drones working with Wi-Fi connectivity are susceptible to primary security threats, and an attacker can easily target

them to hijack their security. To defend their arguments, the authors exploit the security of Wi-Fi access points followed by the ARDiscovery Connection Processes. In addition, the authors acknowledge that the Wi-Fi signal format is easy for attackers to launch an attack as compared to satellite and cellular connections. Following these obstacles, we have evaluated the security risk levels of these connections in table 4 in terms of low, medium, and high, respectively in the UAV-assisted-IoT application connectivity paradigm.

Table 4. Different technologies comparative analysis

Security Risk Level	Satellite	Cellular	Wi-Fi	GPS	GCS
UAV to Terrestrial BS	High	Low	Ext-High	High	High
UAV to FBS	Ext-Low	High	High	Low	High
UAV to flying relay	Ext-Low	Low	High	Low	High
UAV to GCS	High	Low	High	High	High
UAV to GPS	Low	High	High	Low	Low
UAV to Satellite	Low	Low	High	Low	High
UAV to IoT (Wi-Fi)	High	Low	High	High	Ext-High

4.1 Threat Detection and Countermeasures in UAV-assisted-IoT Applications

In the preceding part of this section, we talked about the security risks associated with various aspects of UAV-assisted-IoT applications. In Table 5, we assess and discussed different types of security attacks that could potentially disrupt the legitimate communication in this technology.

5 LESSON LEARNED IN THIS SURVEY

1. Section 2: In this section, we have examined several survey papers that discuss communication and QoS metrics in UAV-assisted-IoT applications. Subsequently, we provided detailed analyses of each paper by discussing their strengths and weaknesses. Our aim was to create a clear road-map for our paper. In pursuit of this goal, we focused on the disadvantages of these papers to present a concrete review regarding this emerging technology in terms of a complete package that could be helpful for all stakeholders working in this domain. Based on distinctions, we have conducted a comparative analysis to highlight the uniqueness and novelty of our work among these existing review papers.

2. Section 3: In this section, we have extended our previous discussion by examining various aspects of this emerging technology. Our goal was to provide readers with a concise overview of what we have learned so far and what areas require improvement to enhance the QoS metrics in UAV-assisted-IoT applications.

3.1 Standardization: Major organizations involved in UAV-assisted-IoT applications closely monitor the importance of standardization, as highlighted in the literature. Given the rapid growth of this technology, we recommend that concerned stakeholders pay more attention to issues arising with standardization. While there are numerous studies in the literature, we have not found a single article that comprehensively addresses this issue. Therefore, it is pertinent to acknowledge the importance of this technology to concerned stakeholders by keeping in view its future.

3.2 Interoperability: With the integration of different networks, the role of interoperability cannot be tolerated. In our literature review, we have emphasized various requirements and challenges related to QoS metrics in UAV-assisted-IoT applications that were overlooked in previous review articles. We then outlined the networking components that play direct or indirect roles in the interconnectivity and communication processes of this

Table 5. Different type of attacks that could be launched on UAV-assisted-IoT applications

Attack Types	Full description with references
Man-in-the Middle attacks	In this type of attack, an adversary intercepts valid network traffic during the communication process among UAV-to-UAV, UAV-to-IoT, UAV-to-FBS, UAV-to-BS, and UAV-to-GCS, etc. Following this, an adversary employs a nefarious access point to attract legitimate network traffic during transmission with an intention to misuse them or misguide the legitimate nearby devices with fake information [127]. To overcome this problem, the researchers demonstrated various schemes in the literature in terms of two or three-factor authentication schemes. Moreover, they also suggested that Wi-Fi Protected Access (WAP), Strong Wired Equivalent Privacy (WEP) and HyperText Transfer Protocol Secure (HTTPS) protocols can play a pivotal role in this emerging technology, [19, 128].
DoS and DDoS attacks	In these types of attacks, an adversary uses a huge amount of broadcast packets from centralized or decentralized points to disrupt the operation of one legal device or many legal devices and misuse the network resources in a useless way [33]. In UAV-assisted-IoT applications, the communicating entities use a wireless medium to share data in the network. Therefore, they are always exposed to external attacks. If an attacker wants to hijack their security by forwarding flooding requests to legitimate devices.
Channel Jamming attacks	In this type of attack, an attacker uses or generates the same frequency range of legitimate devices transmission to block or disrupt their communication process [3]. Moreover, the fundamental goal of jamming is to deliberately interrupt the transmission channel of UAV-assisted-IoT applications. Following this, it is clearly visible that vulnerabilities in the transmission channel can cause various catastrophic situations such as the collision of UAVs and FBS followed by non-availability of services from satellite, GCS, and GPS [100].
Routing attacks	In this type of attack, an attacker intercepts the legitimate communication routes or hop count information with fake routes to misguide the interconnected devices of the network and use their resources in a meaningless way. These types of attacks include node isolation, blackhole, flooding, wormhole, and sinkhole attacks, etc [142].
Spoofing attacks	Spoofing is another devastating attack, where an attacker can fiddle the legitimate devices and hijack the security of an employed network [133]. To tackle such kinds of attacks in UAV-assisted-IoT applications, encrypting the identities, passwords, and keys with a one-timestamp pseudo-code could be used as an efficient way [1, 27].
Malware and Software attacks	Malware and software attacks pose significant security challenges in UAV-assisted IoT applications. These attacks encompass a wide range of threats such as viruses, worms, Trojans, and other malicious software that can compromise the integrity and functionality of UAVs and IoT devices [5]. Malware can infiltrate the system through various vectors such as infected software updates or unauthorized downloads, etc.
Navigation and GPS Spoofing attacks	Navigation and GPS Spoofing attacks are a big problem for UAV-assisted-IoT applications. These attacks involve the deceptive manipulation of GPS signals that leads to incorrect locations followed by misguided flight paths [1, 94]. To mitigate such threats, we need strong anti-spoofing methods and secure navigation algorithms that could be capable of checking the signals with the help of multiple sensors.
Eavesdropping attacks	In UAV-assisted-IoT, eavesdropping attacks happen when an attacker secretly listens to the data being sent between UAVs and IoT devices. In these attacks, an attacker can hear what's being sent over the transmission medium without permission of legitimate parties.
Physical attacks	In UAV-assisted-IoT applications, physical attacks encompass a range of threats to this technology where adversaries target the physical infrastructure of the UAV, IoT devices, or even the communication network. These attacks can include tampering with UAV hardware, disrupting IoT sensors or actuators, or physically compromising communication equipment. Such attacks can have severe consequences, potentially leading to loss of control, data breaches, or even damage to critical infrastructure.
Application Layer attacks	In UAV-assisted-IoT applications, application layer attacks poses significant security challenges to this technology [1]. In these attacks, an actors exploit the vulnerabilities of application layer protocols to gain unauthorized access, disrupt services, or steal sensitive data [78]. These attacks includes, SQL Injection, Cross-Site Scripting (XSS), Session Hijacking, Cross-Site Request Forgery (CSRF), etc. [48].

technology, and often posing challenges to QoS metrics due to network interoperability issues. This section provides a concise summary of relevant literature, followed by an exploration of the challenges that arise when networks need to interoperate.

3. Section 4: In this section, we emphasize the importance of the security of UAV-assisted-IoT applications. Without a robust security framework, no networking model, technology, or communication infrastructure can be deemed trustworthy. Given that, it is pretty clear that without a suitable security benchmark, the QoS metrics can not be achieved in this technology. Consequently, we have delved into relevant literature to discuss different attacks with their countermeasures with an objective of how they can influence the QoS metrics of this technology. Furthermore, we have identified various network components and communication attributes that could be vulnerable to attacks, and potentially compromising network security and disrupting QoS standards in operational environments. Considering that, we aimed to raise awareness among the research community and other stakeholders about the importance of addressing this issue to maintain high QoS standards in UAV-assisted-IoT applications.

6 OPEN CHALLENGES

In this section, we discuss the open challenges that have either been overlooked in the existing literature or extend beyond the scope of current research. These unaddressed issues are assumed to be helpful in granting the further exploration and examination of this technology with more productive results.

6.1 Open QoS Challenges with Network Integration

In this part, we focus on the challenges related to the QoS in UAV-assisted-IoT applications that arise during the integration of different technologies and sub-technologies. Integrating networks is crucial for these applications because it allows UAVs and IoT devices to communicate smoothly. This integration not only enables real-time data sharing but also improves the overall system performance by making decision-making more efficient. Considering that scenario, the first challenging problem is, **Does** the existing hardware of both UAVs and IoTs support ultra-fast communication of 5G and 6G technologies? If Yes, **How** the QoS metrics should be ensured in this process with the existing software and hardware, and what strategies should be adopted. If Not, **What** are the available options for the redressal of this problem? Likewise, **Does** the existing routing protocols will satisfy the future communication needs of UAV-assisting-IoT applications, especially, when it comes to ultra-fast communication of 5G and 6G technologies. **How** the existing transmitters, receivers, and antennas will handle such an alter-fast communication. In case, if they manage it, **Does** the QoS metrics should be maintained or improved, if not, **What** we can do for its redressal in the future. These are the common and most important questions that need the attention of involved stakeholders.

6.2 Open QoS Challenges with Network Handover

In UAV-assisted IoT applications, the mobility of UAVs raises several challenges in the context of handover and takeover communication processes, because the location of UAVs will change continuously. Considering that, **How** a UAV can establish a reliable communication link with IoT devices to maintain QoS metrics during continuous location changes? **What** techniques should be used to ensure seamless communication during handovers and takeovers in UAV-assisted IoT applications, and **What** would be their implications in real-world deployment? **Do** the existing protocols and networking hardware possess the capability to effectively address communication challenges that arise during UAV location changes, handover, and takeover? If not, **What** alternatives are available? **How** we can investigate the compatibility of current protocols and hardware with dynamic scenarios, **What** strategies do we need for that, and **How** does this relate to the adoption of future communication technologies like 5G and 6G? The highlighted questions show the challenges that need more research to meet the changing QoS requirements of UAV-assisted-IoT applications.

6.3 Open QoS Challenges with Interoperability

From the literature, we have noted that UAV-assisted-IoT applications need trustworthy interoperability frameworks at different stages to achieve optimal results. However, we have identified several interoperability open challenges that significantly impact the QoS metrics of this technology. These challenges prompt essential questions: **How** traditional techniques be improved or replaced to meet the QoS requirements of UAV-assisted-IoT applications, especially in critical operations and monitoring by considering different hardware and software of UAVs and IoT devices? **How** should the interoperability of existing and emerging technologies be regulated and controlled to ensure seamless integration in UAV-assisted-IoT applications by guaranteeing optimal QoS metrics? **Does** the existing algorithms, software, hardware, and protocols will manipulate them effectively. If not, then, **How** the interoperability of existing and new technologies should be controlled in future UAV-assisted-IoT applications. **Does** the existing standards of interoperability satisfy the future needs of this technology with

higher demand of users? If not, **What** should be done to tackle this issue in the future and ensure the future of this technology?

6.4 Open QoS Challenges with Unidirectional, Bidirectional, and Multi-directional Antenna

In the literature, we noted that IoT devices are resource-limited in the context of transmission, processing, and memory. While UAVs use an omnidirectional antenna for communication in the network with mobility. Keeping in view this paradigm, **Does** the connectivity and communication of UAVs and IoTs are influenced by the direction of the antenna, especially, when it comes to the mobility of UAVs. If yes, **How** the limited resource of IoTs should be utilized effectively during connectivity with UAVs to uphold the standard of QoS in the network. Moreover, we also need to think about the lifetime of these devices, as they have limited battery power. Secondly, **Is** it possible to train the employed IoTs, and they have to change the direction of transmission with respect to UAVs. If yes, **What** are the possible algorithms that can be used to handle this problem? **Can** we also manage the direction of the antenna of these devices, If yes, **How** the handover process should be tackled, if two UAVs interpreting an IoT device with 180 degrees out of phase (during handover and takeover process). These are very crucial questions that need response from the involved stakeholders.

6.5 Open QoS Challenges with Routing Protocols

In this section, we talk about the open QoS challenges that emerge with the routing protocols, as it is the basic building block of any network to establish communication among connected devices. Considering the literature, it has been noted that traditional routing protocols have been slightly modified or used its vanilla version to facilitate communication among connected devices. Given that, **How** the existing routing protocols will adapt to the dynamic nature of UAVs and IoT devices in the future, where nodes continuously enter and leave the network, without compromising the QoS metrics? **What** methods should be employed to develop energy-efficient routing protocols that extend the operational lifespan of UAVs and IoT devices while maintaining QoS metrics in these networks? **How** the routing protocols can be scaled up effectively to support a growing number of UAVs and IoT devices in large-scale deployments by ensuring efficient data transmission and minimal overhead? **What** strategies should be adopted to address these issues? **How** can routing protocols seamlessly integrate with emerging communication technologies such as 5G and 6G to ensure compatibility and optimize performance for future UAV-assisted IoT applications? **What** strategies and techniques could be employed by the routing protocols to minimize interference, and ensure reliable communication in environments with multiple UAVs and IoT devices operating concurrently? **What** kind of routing protocols should be used to enhance fault tolerance and network strength to recover quickly from disruptions or node failures, ensuring uninterrupted operations in critical applications? **How** can routing protocols collaborate with other layers of the communication stack to optimize data transmission, resource management, and overall network performance in UAV-assisted IoT applications? **What** kind of standardization efforts should be made to streamline the compatibility between different UAVs and IoT devices in the context of routing protocols? These open challenges highlight the complexity of routing protocols in the context of UAV-assisted-IoT applications and need solutions for better operation of this technology.

6.6 Open QoS Challenges with Security

In this section, we talk about the security challenges that influence the QoS metrics of UAV-assisted-IoT applications. The first and foremost challenge in this technology is the authentication of devices, as mobile UAVs interact with different devices in the network continuously. **What** authentication mechanism can be implemented in this technology to prevent unauthorized access to the network without compromising communication speed and QoS metrics? **How** encryption data transmission should be ensured in different networks (different IoT applications).

Does the existing threat detection techniques be able to identify more advanced security or do we need some modification? If yes, how the limited resources of IoT devices would be managed with complex or dynamic authentication? **What** strategies should be used to efficiently allocate network resources for security tasks without adversely affecting the QoS metrics of these networks? **How** the interference and jamming attacks issues can be tackled at different locations and environments? **How** scalability with security should be maintained without losing QoS standards **Does** this technology will accept the existing cybersecurity regulations and compliance standards or they will need some special adjustment? Addressing these questions requires ongoing attention and collaboration among all stakeholders.

7 FUTURE RESEARCH DIRECTIONS

Now, we have set the stage for future research directions, because we have discussed the present literature comprehensively and underscored the requirements and open challenges associated with UAV-assisted-IoT applications.

7.1 Simulator for UAV-assisted-IoT Applications

Evaluating the performance of UAV-assisted-IoT applications in terms of QoS metrics through real-world experimentation poses a significant challenge due to strict regulations in various countries concerning UAV flight spaces. As a result, many researchers rely on simulation tools and environments to test the effectiveness of their proposed algorithms, network architectures, authentication schemes, etc. Considering that, we are aware that in simulations, researchers have control over various aspects like hardware, environmental factors, communication channels and connectivity of devices. These controls help them get the results they want. Moreover, they have control over the movement of UAVs, which means that they can move UAVs freely in any direction without hardware limitations, defined communication rules, and other associated challenges, and achieve what they want. Therefore, we think the data from simulations may not show how things really work in the real world for this technology, because of such wonderful control over many things.

To support this argument, in [43], the authors demonstrated that quadcopter drones have specific hardware requirements, especially when it comes to moving sideways. This demonstrates the shortcomings of simulations in accurately reproducing the technology. Therefore, it's essential to create a simulator that's accessible to everyone, so researchers can test their newly designed prototypes effectively.

There are live examples of open-source simulators like SUMO and OpenStreetMap, which are commonly used for ground vehicles [21, 25]. However, some drone-developing stakeholders such as DroneKit, DJI, and Sphinx, offer their own simulators. These simulators allow researchers in this field to connect drones to a computer and collect data from various aspects without actually flying the drone in a real environment [75, 95]. However, it is important to note that even though these simulators facilitate various aspects, but still, their results may differ from real-world conditions. Therefore, it is necessary for all stakeholders involved in this area to continue working towards improving simulator accuracy or designing a standardize simulator for all drones/UAVs.

7.2 Augmented Reality and Virtual Reality enabled Mobility Control System

Currently, most UAV-assisted-IoT devices are equipped with intelligent systems designed to meet various application requirements. However, when it comes to simulating the performance of these systems in alignment with real-world scenarios, the outcomes often deviate significantly from actual statistics. To address this issue, we propose that augmented reality (AR) and virtual reality (VR) could serve as valuable tools for facilitating realistic simulations in the realm of UAV-assisted-IoT applications. AR and VR can be used to create realistic training simulation environments for UAV operators. These simulations enable operators to practice and refine their control skills within a secure and controlled virtual environment by mitigating the risk of accidents and

operational errors. Moreover, AR has the potential to deliver real-time data overlays to operators by allowing them to monitor UAV status, navigation, and make informed decisions swiftly. AR can assist operators in visualizing IoT data collected by UAVs to make decision easily. to interpret and act upon the information. On the other hand, VR can create immersive environments for data analysis, allowing operators to explore complex datasets and identify trends more effectively. Additionally, both AR and VR support collaborative UAV control, enabling multiple operators to collaborate on complex tasks, which is particularly valuable in scenarios requiring specialized expertise, such as search and rescue missions. AR can assist operators in visualizing IoT data collected by UAVs to make accurate actions. Likewise, VR can create immersive environments for data analysis by allowing operators to explore complex data sets and identify trends more effectively. AR and VR can support collaborative control of UAVs by allowing multiple operators to work together on complex tasks. This can be beneficial for scenarios where specialized expertise is required, such as search and rescue missions. AR and VR systems can help reduce control system latency by ensuring quicker response times and improved real-time control. AR can help in obstacle detection and avoidance systems by navigating UAVs with respect to challenges to reduce the likelihood of collisions. Considering these, we encourage researchers and market stakeholders to explore the utilization of AR and VR in UAV-assisted-IoT applications to address mobility control issues and achieve optimal results.

7.3 Flying Base Station Physical Reliability

FBS face unique challenges compared to terrestrial base stations regarding their physical reliability. Unlike regular base stations, FBS can be affected by environmental factors that may undermine their trustworthiness. For instance, FBS can suddenly become less reliable due to adverse environmental conditions, potentially leading to a loss of control over communication and the risk of collisions. These issues with physical trustworthiness can significantly impact the quality of wireless service and overall network performance in UAV-assisted IoT-applications. Considering that, the research community is advised to explore the implementation of advanced environmental sensing technologies on FBS to continuously monitor and adapt to changing environmental conditions. This will include the sensors for weather, air quality, and other relevant data to make real-time adjustments. Utilization of machine learning and artificial intelligence algorithms can be helpful in predicting and mitigating potential reliability issues. Because these algorithms can help FBS adapt to environmental changes and make informed decisions to avoid communication disruptions.

Another solution should be the utilization of autonomous control systems for FBS that can quickly respond to adverse conditions and maintain communication reliability without human intervention. The utilization of distributed FBS could be another solution, but it is important to check the deployment cost. The development of adaptive communication protocols could be useful too to manage the communication statistics. These are possible solutions that can be helpful to resolve the highlighted problem in an effective way, but collaborative research efforts are needed. Therefore, we suggest the involved stakeholders work together and ensure the future of this technology.

7.4 Role of Machine Learning Algorithms in UAV-assisted-IoT applications

The effective utilization of deep learning, transfer learning and reinforcement learning can maximize the productivity of these applications with significant contributions [71, 117]. Because these algorithms have the capability to make accurate decisions based on previous knowledge, experience, and action taken. They should be very productive in areas such as route management, position placement, task scheduling, and security, etc. However, it is important to choose the most appropriate algorithm or model that can respond to the problem. Because some of the models do one work correctly, but make another wrong. Moreover, the people working in this domain are also encouraged to check the possibility of transfer learning (TL) and reinforcement learning (RL). For example, they can explore the use of advanced techniques such as Bidirectional Encoder Representations from Transformers

(BERT), Residual Neural Network (ResNet), and Visual Geometry Group (VGG) to make it easier for UAVs and IoT devices to work together. And when it comes to reinforcement learning, they can consider using algorithms such as Deep Q-Networks (DQN), Proximal Policy Optimization (PPO), Deep Deterministic Policy Gradients (DDPG), Actor-Critic Models, Multi-Agent Reinforcement Learning, and Hierarchical Reinforcement Learning in the future to improve how UAVs assist with IoT applications.

7.5 Network Architecture for UAV-assisted-IoT applications

UAV-assisted-IoT applications are comprised of a large number of devices like IoT gadgets, FBS, Relays, UAVs, BS, and GPS units, etc. To make all these devices work together smoothly, a well-designed network setup is needed. To deal with such architectural challenges, SDN could be used as a promising technology, because it enables the decoupling of networks, and encourage different data plan with network reconfiguration. This is good for managing tasks both in centralized and decentralized manner. AI-enabled routing protocols are also crucial for improving the quality of service in this technology. We should also pay attention to how data travels between devices, especially when they have a clear line of sight (LoS). For this, cross-layer optimization is essential for handling unexpected wireless problems. Furthermore, blockchain technology can be used to manage network resources in a decentralized way, and improve the communication statistics in this technology. Therefore, every involved stakeholder should work together to make these improvements happen in this field.

7.6 Antenna in UAV-assisted-IoT application

In the literature, we have noted that UAVs can move in many directions at different speeds, and it is important to design special antennas for them to manage communication effectively. These antennas help UAVs share data with remote destinations while maintaining high-quality services in terms of wireless connectivity and QoS metrics. Some people have thought about using tracking antennas on UAVs to handle fast data transfers along with ground-based stations. However, these approaches did not work very well according to reference [84]. Therefore, we suggest that anyone looking to solve this issue should consider using reconfigurable surfaces (RS). RS can help control antennas for better connections and communication. Also, adding machine learning algorithms to RS can be really helpful for solving antenna and communication problems. This can significantly improve how UAVs and IoT devices communicate in this technology.

8 UNIQUENESS AND COMPARATIVE DISCUSSION

In this section, we have discuss the unique aspects that make this paper separated from previously published articles. For this, we conducted a comparative analysis using a table (Table 6) to highlight these differences. This helps address the question of why this paper is needed in light of existing articles and how it can benefit the community in the future. To begin, we conducted a comprehensive review of relevant literature concerning the QoS and interoperability of UAV-assisted-IoT applications. We then organized all the sections, subsections, and topics in a tabular format to compare them with similar articles. Our goal was to identify the areas that our review paper covers that may have been missed in other articles (see Table 6). Throughout this process, we focused on various factors related to QoS in this technology by aiming to provide both academia and industry stakeholders with insights into the challenges that can impact QoS metrics in UAV-assisted-IoT applications.

9 CONCLUSION

In this review article, we have summarized the complementary literature associated with the interoperability and QoS metrics of UAV-assisted-IoT applications from 2015-to-2023. Moreover, we included and covered all the important topics that have a direct or indirect impact on the QoS metrics of this emerging technology. This is the first survey paper, that covers all the important aspects of UAV-assisted-IoT applications from network architecture

Table 6. Distinctive Factors of this article in comparison of existing state-of-the-art review articles
 Considered/Included (✓), Partial Considered/Included ⊖, Not Considered/Included ⊗

Name of Distinctive Factors	Ref [12]	Ref [13]	Ref [14]	Ref [15]	Ref [16]	Ref [17]	Ref [18]	Ref [19]	Our article
Dynamics Role									
Mobility Importance	✓	⊗	✓	⊖	⊗	⊗	✓	⊖	✓
Architecture Importance	⊖	⊗	⊗	⊖	⊗	✓	⊗	✓	✓
Offloading Importance	⊗	⊗	✓	⊗	✓	✓	⊗	⊖	✓
Resource Management	⊖	✓	⊗	✓	⊗	⊖	⊗	✓	✓
Positing Importance	⊗	⊗	⊖	⊖	✓	⊗	✓	⊗	✓
Fronthaul/Backhaul Importance	⊖	✓	⊖	⊗	⊗	✓	⊗	⊗	✓
Trajectory Importance	✓	✓	✓	⊖	✓	✓	⊖	✓	✓
Interoperability Role									
Communication Modules	⊖	⊗	✓	⊗	✓	⊗	✓	⊗	✓
Role of SDN	✓	✓	⊖	⊖	⊖	✓	⊖	✓	✓
MAC Layer Protocols	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓
Physical Layer Protocols	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓
Network Layer Protocols	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓
Application Layer Protocols	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓
Security Concerns									
Threat Detection and Countermeasures	⊗	✓	✓	⊖	✓	⊖	⊗	⊖	✓
Man-in-the Middle	⊗	⊗	⊗	⊗	⊗	⊖	⊗	⊖	✓
DoS and DDoS attacks	⊗	⊖	⊗	⊖	⊗	⊖	⊗	⊗	✓
Channel Jamming attacks	⊖	⊖	⊗	⊗	⊖	⊗	⊗	⊖	✓
Routing attacks	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓
Spoofing attacks	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓

Table 7. Future research directions comparative analysis.
 Considered/Included (✓), Not Considered/Included ⊗

Name of Distinctive Factors	Ref [12]	Ref [13]	Ref [14]	Ref [15]	Ref [16]	Ref [17]	Ref [18]	Ref [19]	Our article
Simulator for UAV-assisted IoT Applications	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓
Deep Learning-based UAV Mobility Control System	⊗	✓	✓	⊗	⊗	✓	⊗	⊗	✓
Flying Base Station Physical Reliability	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓
Role of Artificial Intelligence in UAV-assisted IoT applications in Future	✓	⊗	⊗	⊗	✓	⊗	⊗	⊗	✓
Network Architecture for UAV-assisted IoT applications	⊗	⊗	⊗	✓	⊗	⊗	⊗	✓	✓
Antenna (UAV) in UAV-assisted IoT application	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	✓

to end-employed devices in the context of their communication, interconnectivity, and interoperability. To provide a more detailed overview, our review article extensively examines the existing literature, including network architecture, task offloading, resource management, path placement, trajectory, interoperability, and security. It also delves into related components such as various network topologies, optimization problems, different aspects of interoperability, and security considerations against various types of attacks. Subsequently, we identified and highlighted the current challenges that have been overlooked in the present literature. Through this paper, we present a comprehensive resource for the research community and industry stakeholders in this domain. We have outlined potential research directions that can effectively address the current challenges of this technology in a cost-efficient manner, and yielding productive results. Finally, we compared each section of our paper with the comparative review studies to claim its uniqueness in terms of distinctive factors.

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