Integration of Drone Connectivity in 5G: An Examination of the OASEES Framework

Michail-Alexandros Kourtis[1], Georgios Xilouris[1], Andreas Oikonomakis[1], Michael C. Batistatos[2], Ioannis Chochliouros[3]
[1]National Center for Scientific Research "Demokritos", Greece
[2]Department of Informatics and Telecommunications, University of Peloponnese, Tripolis, Greece
[3]Hellenic Telecommunications Organization S.A. (OTE), Athens, Greece

***Abstract*— The present study introduces an innovative perspective on data management and processing by combining the OASEES framework with a decentralized, multimodal approach. While centralized processing and cloud hosting have dominated the industry due to their scalability, security, and cost-efficiency, they often restrict operations to a resource-constrained environment dependent on single, large entities, resulting in limitations in data governance and control over access privileges. By incorporating a drone swarm architecture, we transition away from this traditional model and focus on the underexplored potential of decentralization. Our proposed design outfits each autonomous drone, or Unmanned Aerial Vehicle (UAV), with a lightweight 5G system, converting it into a mobile service provider for ground-based User Equipment (UE). The interplay of these UEs and their respective UAVs creates a versatile and robust network, capable of handling high data rates and ensuring reliable connectivity in different operating environments. Our experimental results indicate a compelling correlation between the uplink bit rate of the node UE and the maximum downlink or uplink bit rates of the UEs, a critical discovery for optimizing the drone swarm's performance.**

Keywords— Decentralized Data Processing, Drone Swarm, 5G, Edge Computing

I. Introduction

The importance of Unmanned Aerial Vehicles (UAVs) in contemporary and future communication infrastructures cannot be overstated. This has been corroborated by numerous studies that have delved into the multifaceted uses of UAVs, especially within the realm of wireless communications. One key driver of this interest in UAVs stems from the anticipated exponential growth within the global UAV market, a projection substantiated by Godage's extensive industry analysis [1]. The incorporation of UAVs into Radio Access Network (RAN) heterogeneity represents a new frontier. The potential of such integration was highlighted by Bor-Yaliniz and Yanikomeroglu, who postulated a model for multi-tier drone cells, shedding light on the novel directions possible for RAN configurations [2]. Along this vein, Zeng, Zhang, and Lim offered a comprehensive investigation into the opportunities and challenges tied to integrating UAVs in wireless communications, thereby highlighting the transformative potential of UAV incorporation [3].

However, to bring these concepts from theory to practice, there are specific limitations within current communication systems that must be resolved. Among the most significant of these challenges is the difficulty of extending 5G technology into underprivileged areas such as rural and low-income regions, an issue underscored by Chiaraviglio et al.'s study [4]. To mitigate this concern, Sharma et al. proposed a solution in the form of intelligent deployment of UAVs within 5G heterogeneous communication environments, aiming to enhance coverage [5]. Insights from this work form a critical foundation for our present investigation. In order to optimize the deployment and utilization of UAVs, a key area our study explores is the scheduling of UAV systems. To do this, we draw extensively from the work of Kim, Song, and Morrison, who proposed methodologies for UAV system scheduling, particularly in relation to fuel service stations for long-term mission fulfillment [6]. However, our research does not exclusively focus on communications.

The paper delves into the realm of transport and logistics. Murray and Chu, for instance, proposed models for optimizing drone-assisted parcel delivery, a pertinent consideration for UAV applications [7]. Further, our experimental setup takes into account Nigam et al.'s control strategies for multiple UAVs for persistent surveillance, an essential feature for security applications [8]. As research delves into the future of communications, the manuscript examines the potential transition to 6G. Raddo et al. offer a glimpse into the future with their study on 6G and Fog Node Mobile Systems for cooperative, autonomous, and dynamic applications [9]. Their predictions, in combination with the work of Stavroulaki et al., who discussed dynamic coverage extension and distributed intelligence for human-centric applications from 5G to 6G, are integral to our approach [10].

The presented research resonate with the findings of Kunst et al., who addressed the role of future 6G technology in supporting heavy data traffic in highly mobile networks [11]. In considering this leap from 5G to 6G, our study endorses the shift toward UAV-supported 6G cellular communications. This perspective aligns with Geraci et al.'s projection of the future of UAV cellular communications [12]. In this respect, our work is informed by the comprehensive surveys provided by Vaezi et al. and Azari et al., who detail the advances in 5G technology and provide a roadmap for the transition to non-terrestrial networks from 5G to 6G [13,14].

Our work aims to make a significant contribution to the ongoing discourse on the future of 6G networks. Bariah et al.'s study that looked at key enabling technologies, applications, and open research topics in 6G networks is especially relevant to our endeavor [16]. Likewise, the work of Zou et al. on cooperative drone communications for Space-Air-Ground integrated networks is invaluable to our research [17]. Finally, the paper navigates the future of 6G, Ali et al.'s is also considered as a review on the Vertical Heterogeneous Network (v-HetNet) as a critical component that will shape this future [18].

In the complex landscape of 5G and upcoming 6G, the OASEES swarm-based approach facilitates seamless operation. By taking advantage of distributed computing capabilities inherent in these technologies, the swarm can adapt intelligently to dynamic networking conditions, ensuring optimal service delivery at all times. This swarm-based approach allows each UAV to serve as an independent

2023 IEEE Future Networks World Forum (FNWF) | 979-8-3503-2458-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/FNWF58287.2023.10520379

5G/6G base station, collaboratively working with others to extend network coverage.

In a bid to address the challenge of providing internet connectivity in remote locations, our paper presents a novel approach of installing a lightweight 5G system onboard Unmanned Aerial Vehicles (UAVs). Traditionally, the weight of the equipment has been a major hindrance, but with the advent of 5G technology and the development of lightweight 5G systems, the designed architecture allows a UAV to serve a number of user equipment (UE) on the ground, with one of the UEs acting as a connection gateway to the internet. This proposed system effectively eliminates the need for a backhaul from the UAV to a ground node, thus significantly reducing the payload weight of the UAV.

The results from our extensive testing show that the proposed architecture performs consistently across various Reference Signal Received Power (RSRP) levels and different Time Division Duplex (TDD) schemes. Our architecture not only overcomes the technical challenge of providing remote location connectivity but also opens up new, potentially lucrative avenues in the telecommunications sector. In essence, the UAV is transformed into a flying 5G base station capable of providing high-speed internet connectivity to different extreme location scenarios.

This paper is organized as follows: Section I presents the premise and objectives of the study. Section II, presents the OASEES architecture for swarm based computing. In Section III, the design and configuration of the lightweight 5G system onboard the UAV is explained, as well as the presentation of the experimental results. Finally, the conclusion section summarizes the paper's key findings and potential implications for the 5G/6G outlook of drone connectivity convergence.

II. OASEES Concept

This section presents the OASEES concept and how its different layers enable enhanced swarm programmability and intelligence. In this study the focus is Drone swarm connectivity and intelligence in the frame of OASEES. In Figure 1 the OASEES conceptual architecture is presented, with the Programmability and Deployment & Execution layer.

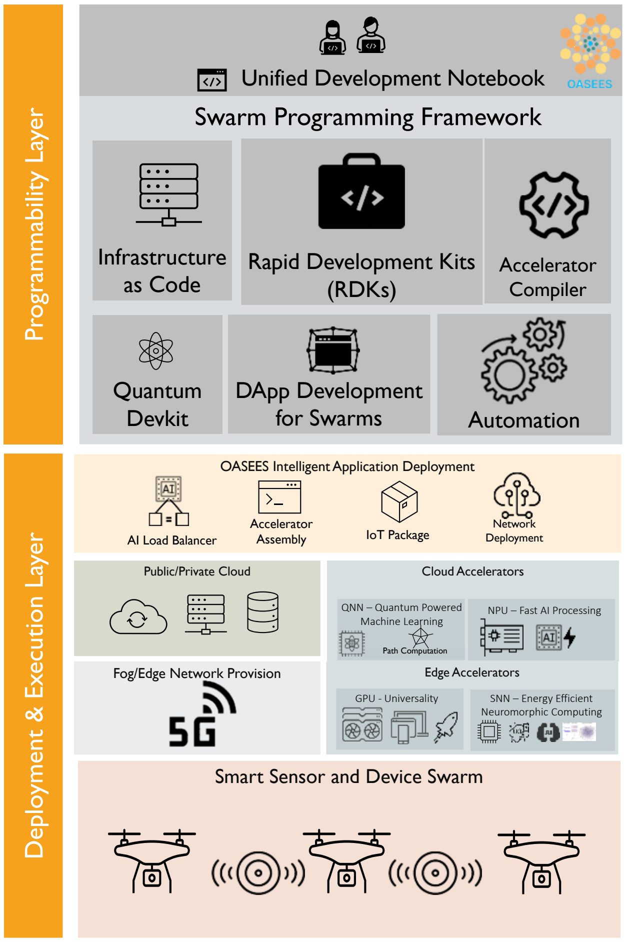

Fig. 1. OASEES Architecture

A. *OASEES Programmability layer*

The OASEES Programmability Layer is a central part of the OASEES framework, designed to address the complexities of writing, modifying, and executing applications across a vast, distributed edge computing environment. This layer presents a unified and abstracted view of the heterogeneous resources available at the edge, enabling developers to design applications without needing to address the intricacies of the underlying hardware.

This layer is built around a comprehensive set of APIs, libraries, and software development kits (SDKs), offering developers a rich toolset to write applications tailored for a variety of use cases. This flexibility facilitates cross-platform development, minimizing the time and resources required for application porting. The Programmability Layer also promotes code reusability and reduces maintenance overhead, resulting in a more efficient development process.

Beyond APIs and libraries, the Programmability Layer introduces an extensive suite of tools for application profiling, debugging, and performance tuning. These tools provide valuable insights into the performance and efficiency of applications, allowing developers to identify bottlenecks and optimize their code. This set of tools not only increases the overall productivity of developers but also enhances the performance and reliability of the applications running at the edge.

Moreover, the OASEES Programmability Layer offers a versatile software-defined environment. This aspect enables developers to control and manage various network elements programmatically. By leveraging software-defined networking (SDN), network function virtualization (NFV), and software-defined radio (SDR) capabilities, developers can design applications that adapt and respond dynamically to changes in the network, enhancing the overall system's flexibility and agility.

The programmability layer extends its reach by incorporating support for 5G/6G drone connectivity. With an increasing reliance on drones in sectors such as logistics, surveillance, and environmental monitoring, it becomes critical to have a system that can handle the unique requirements of drone communications. The OASEES Programmability Layer, with its flexible and dynamic software capabilities, is well-positioned to manage and control drone swarms effectively.

The Programmability Layer supports the development of sophisticated drone applications that require high-speed data transmission and real-time processing. Through APIs and libraries, it offers an extensive set of tools to develop applications for drone-based imaging, surveillance, and logistics services. By leveraging the high-speed, low-latency communication offered by 5G/6G connectivity, developers can design drone applications that maximize the efficiency of operations.

Extending the capabilities of the Programmability Layer, the system provides a framework for developing machine learning algorithms that can be trained and executed at the edge. This framework includes support for distributed training and inference, allowing developers to leverage the full potential of edge computing for AI workloads. The machine learning framework supports a variety of AI models and platforms, further enhancing the versatility of the OASEES Programmability Layer.

In the realm of security, the Programmability Layer incorporates an extensive suite of security features. It offers developers the ability to implement secure communication protocols, data encryption mechanisms, and robust authentication systems. Moreover, the layer promotes the development of applications that adhere to privacy-preserving principles, ensuring that user data is handled in accordance with the highest standards of data protection.

In conclusion, the OASEES Programmability Layer delivers a comprehensive, robust, and adaptable solution for the development and execution of applications in a distributed edge environment. Its capacity to facilitate drone connectivity in a 5G/6G context underscores its potential to play a pivotal role in shaping the future of edge computing.

In terms of 5G/6G drone connectivity, the OASEES Programmability Layer provides substantial enhancements. Drones, functioning as part of the IoT infrastructure, demand low latency, high reliability, and efficient communication – requirements met through the capabilities of the OASEES programmability layer. It supports the seamless orchestration of services across heterogeneous resources, including drone swarms, while maintaining high levels of performance and energy efficiency. Its ability to manage and facilitate DApps can enable more autonomous drone operations, taking full advantage of 5G and 6G's low latency and high bandwidth. Thus, the OASEES Programmability Layer could be crucial in advancing drone swarm technologies and their integration into the 5G/6G landscape, leading to new levels of efficiency and automation in various sectors, including delivery services, environmental monitoring, and public safety.

B. OASEES Deployment & Execution layer

The OASEES Deployment and Execution Layer is a fundamental component of the OASEES framework, responsible for the dynamic orchestration and effective management of a multitude of resources. These resources, including Central Processing Units (CPUs), Graphics Processing Units (GPUs), Neural Processing Units (NPUs), Field Programmable Gate Arrays (FPGAs) bespoke chips, and Quantum processors, are spread across a broad spectrum of environments ranging from the edge to the cloud. In ensuring seamless operation across these disparate systems, the Deployment and Execution Layer exhibits a unique degree of interoperability that underscores the strength of OASEES as an edge solution.

This layer leverages the Enhanced Platform Awareness (EPA) capability, which supports a granular understanding of the features and benefits of each resource within the distributed environment. EPA aids in identifying the most suitable resources for specific tasks or services, contributing significantly to the efficient utilization of the available computing power. By discerning the optimal use-cases for each resource type, this layer significantly enhances the overall performance of the system, thereby aiding in maintaining service-level agreements and Quality of Service (QoS).

Furthermore, the Deployment and Execution Layer enables secure edge infrastructure sharing and monetization. The layer's orchestration mechanism operates across the network, computation, and storage services, extending the capabilities of the existing infrastructure by creating an environment conducive to shared services. This unique attribute aligns perfectly with the "neutral host" paradigm, making it an essential component in the evolution of edge networks, especially in the context of 5G/6G infrastructures.

By creating an ecosystem that promotes cooperation and resource sharing, the Deployment and Execution Layer is an ideal solution for handling hyper-distributed applications. These applications demand a high degree of computational efficiency, low latency, and robust data processing capabilities. To address these requirements, the layer employs secure data spaces for storage and Federated Learning, a form of privacy-preserving Machine Learning (ML) technology. This approach allows for continuous learning and model refinement without compromising the integrity or privacy of the data, enabling the system to evolve and improve over time.

Another significant advantage of the OASEES Deployment and Execution Layer is its stringent focus on security. The layer incorporates a "zero-trust" architecture, a paradigm that ensures the highest level of security by authorizing only trusted and verified edge nodes to participate in the system. This stringent security approach defends against a broad range of potential threats, including hardware supply chain attacks, bootkits, rootkits, and malware, thus guaranteeing system integrity.

The scope of the Deployment and Execution Layer extends further, incorporating 5G/6G drone connectivity into its ambit. The anticipated surge in drone usage in the Internet of Things (IoT) ecosystem in a 5G/6G world necessitates a system capable of managing such a massive influx of devices. The layer's ability to discover, pool, and manage edge

platform acceleration capabilities creates a comprehensive view of the available resources, including drone swarms.
By running customizable optimization algorithms, the Deployment and Execution Layer can ensure the best mapping of service demands onto the physical infrastructure, which includes drones. This unique feature leverages the high-speed, low-latency communication offered by 5G/6G connectivity to manage and control drone operations efficiently. Consequently, the Deployment and Execution Layer significantly enhances the performance and efficiency of drone swarm operations in a 5G/6G context.

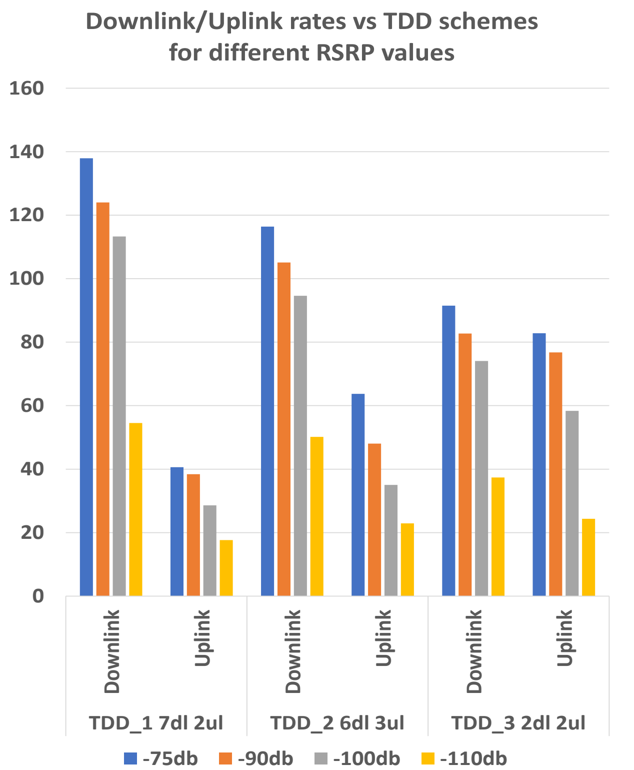

Fig. 2. Downlink and Uplink measurement vs different TDD schemes for different RSRP values

Additionally, the Deployment and Execution Layer can help enable the development and deployment of sophisticated drone services. For instance, drone-based imaging and surveillance services, which require high-speed data transmission and real-time processing, can significantly benefit from the enhanced 5G/6G connectivity and the robust edge computing capabilities of OASEES. By supporting high data throughput and low-latency processing, the OASEES layer can help deliver high-quality, real-time drone services. Thus, through effective management and coordination of resources, the OASEES Deployment and Execution Layer sets a strong foundation for the evolution and expansion of edge networks in the 5G/6G era.

III. OASEES Drone Connectivity Experimental Evaluation

Drones can potentially provide the basis for a lightweight 5G systems to enhance Internet connectivity in a myriad of situations. Traditional configurations entail the drone carrying an access network, such as a Wi-Fi or a 4G/5G small cell, which provides connectivity to user terminals within its coverage area. This setup necessitates a backhaul link with a ground-based Internet provision node, incurring a weight penalty for the UAV. In contrast, the OASEES framework advocates for an alternate architecture that diminishes this reliance while preserving robust connectivity.
Our proposed architecture situates a comprehensive lightweight 5G system on board the UAV, serving a collection of user equipment (UE) on the ground. One of these UEs plays the role of an Internet gateway for the entire system, essentially a hub for all network traffic. A lightweight router (such as a Raspberry Pi) on the UAV, connected to the Internet connection port of the 5G core, ensures the correct routing of IP packets from the UEs to this gateway UE. This arrangement essentially transforms the UAV into a flying 5G base station, with the ability to route IP packets from multiple user terminals to the internet gateway.

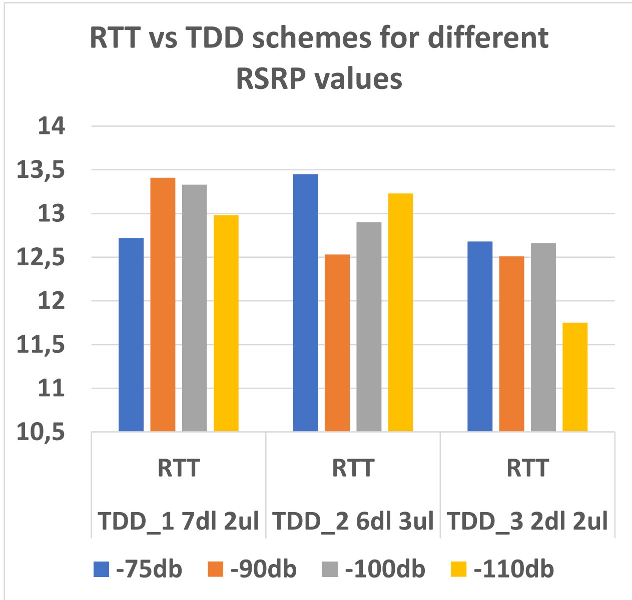

Fig. 3. RTT vs different TDD schemes for different RSRP values

An interesting phenomenon occurs when an IP packet from a UE targets the Internet. It reaches the onboard 5G NPN and subsequently the router. Guided by the IP table routes, the packet is then directed to the IP of the node UE acting as the internet gateway of the system. This UE subsequently routes the packet to the Internet. Any reply from the Internet traces the reverse path, arriving at the originating UE. This efficient routing mechanism forms a critical component of the OASEES architecture and provides a flexible and scalable solution for varied connectivity scenarios.
To understand the performance characteristics of this setup, the paper has conducted comprehensive tests to measure downlink and uplink bit rates (Figure 2) and Round Trip Time (RTT) (Figure 3) for different Reference Signal Received Power (RSRP) levels for the UE and node equipment. The presented research also evaluated the performance across three different Time Division Duplex (TDD) schemes. The results provide insightful observations and validate the efficiency of our proposed architecture.
Interestingly, the maximum downlink or uplink bit rates of the UEs appear to be limited by the uplink bit rate of the node UE. This underlines the importance of the node UE's performance in the overall functioning of the system. Further analysis shows that the TDD scheme with an equal number

of time slots for downlink and uplink (TDD_3) provides the maximum bit rates for both downlink and uplink, reaching up to about 70 Mbps. The near parity in downlink and uplink bit rates reiterates the robustness of the proposed architecture and its ability to support such levels effectively.

The superiority of the TDD_3 scheme, where time slots allocated for downlink and uplink are equal, offers an intriguing aspect to consider during the system setup. The performance superiority of this scheme suggests that a balanced allocation of resources between downlink and uplink operations can lead to enhanced system performance. This insight can be instrumental in determining the TDD scheme choice, especially in scenarios demanding high data rates.

The evaluation of different Time Division Duplex (TDD) schemes has brought out their potential to be associated with distinct network slicing strategies. Network slicing, in essence, is the subdivision of a single network into multiple isolated virtual networks, each optimally configured for a specific type of service or application. Each TDD scheme with its particular time slot allocation for downlink and uplink operations can align with a corresponding network slice. Taking the TDD_3 scheme as an example, which allocates an equal number of time slots for downlink and uplink, it is found to provide the maximum bit rates for both types of data transfer. This symmetrical data rate support is perfect for network slices designed for applications requiring balanced downlink and uplink performance. Such applications may include teleconferencing or remote control scenarios where data needs to flow equally in both directions. On the other hand, TDD schemes with more time slots allocated for either downlink (e.g., TDD_1) or uplink could be mapped to network slices that are more downlink or uplink centric. These could be associated with services like video streaming, which is predominantly downlink, or IoT sensor networks, which might involve considerable uplink traffic. The ability to match different TDD schemes with suitable network slices further highlights the flexibility and effectiveness of our proposed architecture under the OASEES framework. The appropriate selection and assignment of TDD schemes can thereby ensure optimal network performance and resource allocation for various application scenarios.

Incorporating the OASEES UAV architecture substantially simplifies the provision of internet connectivity by mitigating the weight and power requirements of the UAV. This could potentially extend flight times and augment coverage areas, thereby making the UAV a more viable and efficient tool for providing network connectivity. This unique approach aligns with the trend towards network decentralization, where end-users play a more active role in the network, enhancing the efficiency and resilience of connectivity.

This unique blend of drone technology and the capabilities of the OASEES framework provides an innovative solution to address the complexities of edge networking and computing. It not only addresses technical challenges but also presents an opportunity to harness the potential of UAVs in new and exciting ways. The results gathered thus far underscore the promise of this approach, highlighting the considerable potential for advancements in this field.

IV. Conclusion

The advent of lightweight 5G systems, coupled with innovative use of drones or UAVs, signifies a critical juncture in the quest for ubiquitous Internet connectivity. With this study, the potential of a groundbreaking architecture is proposed under the OASEES framework, demonstrating its viability and effectiveness in addressing the complexities of advanced networking and computing.

Our research has revolved around installing a complete 5G system onboard a UAV to provide network connectivity. The node UE, acting as an Internet gateway, collaborates with the lightweight onboard router to achieve efficient and robust routing of IP packets. This configuration drastically reduces payload weight and power requirements, potentially extending UAV flight times and widening coverage areas, key aspects that improve the overall efficacy of the system.

The performance characteristics, gleaned from intensive testing of downlink and uplink bit rates and RTT for various RSRP levels for the UE and node equipment across different TDD schemes, were insightful. The data demonstrated a near parity between the downlink and uplink bit rates, highlighting the robustness of the proposed architecture. Furthermore, the equal allocation of time slots for downlink and uplink operations in the third scheme led to the maximum bit rates for both, suggesting the benefits of a balanced resource distribution between these operations.

These findings affirm the utility of the OASEES framework in managing the operational demands of 5G/6G-enabled UAVs in various situations. The proposed architecture aligns with the trend towards network decentralization, empowering end-users and enhancing the efficiency and resilience of connectivity. The concept of a UAV acting as a flying 5G base station underlines a fresh perspective in network connectivity solutions. It presents not only a technical innovation but also an intriguing business opportunity. Our research underscores the immense potential of this approach, thereby marking an important milestone in the journey towards universal Internet access.

Based on the outlook of UAV-enabled connectivity solutions, it is clear that the OASEES framework will play a vital role. The potential of the technology and the opportunities it presents warrant further exploration and development. Future work in this area will delve deeper into the nuances of the proposed architecture and seek ways to improve and optimize it for a variety of applications and scenarios.

Acknowledgment

The research work presented in this article has been supported by the European Commission under the Horizon Europe Programme and the OASEES project (no. 101092702).

References

[1] Godage, L. Global Unmanned Aerial Vehicle Market (UAV) Industry Analysis and Forecast (2018–2026); Montana Ledger: Boston, MA, USA, 2019. [Google Scholar]

[2] Bor-Yaliniz, I.; Yanikomeroglu, H. The New Frontier in RAN Heterogeneity: Multi-Tier Drone-Cells. IEEE Commun. Mag. 2016, 54, 48–55. [Google Scholar] [CrossRef][Green Version]

[3] Zeng, Y.; Zhang, R.; Lim, T.J. Wireless communications with unmanned aerial vehicles: Opportunities and challenges. IEEE Commun. Mag. 2016, 54, 36–42. [Google Scholar] [CrossRef][Green Version]

[4] Chiaraviglio, L.; Blefari-Melazzi, N.; Liu, W.; Gutierrez, J.A.; van de Beek, J.; Birke, R.; Chen, L.; Idzikowski, F.; Kilper, D.; Monti, P.; et al. Bringing 5G into Rural and Low-Income Areas: Is It Feasible? IEEE Commun. Mag. 2017, 1, 50–57. [Google Scholar] [CrossRef]

[5] Sharma, V.; Srinivasan, K.; Chao, H.-C.; Hua, K.-L.; Cheng, W.-H. Intelligent deployment of UAVs in 5G heterogeneous communicationenvironment for improved coverage. J. Netw. Comput. Appl. 2017, 85, 94–105. [Google Scholar] [CrossRef]

[6] Kim, J.; Song, B.D.; Morrison, J.R. On the scheduling of systems ofuavs and fuel service stations for long-term mission fulfillment. J. Intell. Robot. Syst. 2013, 70, 347–359. [Google Scholar] [CrossRef]

[7] Murray, C.C.; Chu, A.G. The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery. Transp. Res. Part C Emerg. Technol. 2015, 54, 86–109. [Google Scholar] [CrossRef]

[8] Nigam, N.; Bieniawski, S.; Kroo, I.; Vian, J. Control of multiple UAVs for persistent surveillance: Algorithm and flight test results. IEEE Trans. Control Syst. Technol. 2012, 20, 1236–1251. [Google Scholar] [CrossRef]

[9] T. R. Raddo, R. Nobrega, S. Rommel, B. Cimoli, A. L. Sanches and I. T. Monroy, "6G and Fog Node Mobile Systems for Cooperative, Autonomous, and Dynamic Applications," 2019 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), Aveiro, Portugal, 2019, pp. 1-3, doi: 10.1109/IMOC43827.2019.9317640.

[10] V. Stavroulaki et al., "DEDICAT 6G - Dynamic Coverage Extension and Distributed Intelligence for Human Centric Applications with Assured Security, Privacy and Trust: from 5G to 6G," 2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), Porto, Portugal, 2021, pp. 556-561, doi: 10.1109/EuCNC/6GSummit51104.2021.9482611.

[11] R. Kunst, E. Pignaton, T. Zhou and H. Hu, "Application of future 6G technology to support heavy data traffic in highly mobile networks," 2020 First International Conference of Smart Systems and Emerging Technologies (SMARTTECH), Riyadh, Saudi Arabia, 2020, pp. 144-148, doi: 10.1109/SMART-TECH49988.2020.00044.

[12] G. Geraci et al., "What Will the Future of UAV Cellular Communications Be? A Flight From 5G to 6G," in IEEE Communications Surveys & Tutorials, vol. 24, no. 3, pp. 1304-1335, thirdquarter 2022, doi: 10.1109/COMST.2022.3171135.

[13] M. Vaezi et al., "Cellular, Wide-Area, and Non-Terrestrial IoT: A Survey on 5G Advances and the Road Toward 6G," in IEEE Communications Surveys & Tutorials, vol. 24, no. 2, pp. 1117-1174, Secondquarter 2022, doi: 10.1109/COMST.2022.3151028.

[14] M. M. Azari et al., "Evolution of Non-Terrestrial Networks From 5G to 6G: A Survey," in IEEE Communications Surveys & Tutorials, vol. 24, no. 4, pp. 2633-2672, Fourthquarter 2022, doi: 10.1109/COMST.2022.3199901.

[15] M. M. Azari et al., "Evolution of Non-Terrestrial Networks From 5G to 6G: A Survey," in IEEE Communications Surveys & Tutorials, vol. 24, no. 4, pp. 2633-2672, Fourthquarter 2022, doi: 10.1109/COMST.2022.3199901.

[16] L. Bariah et al., "A Prospective Look: Key Enabling Technologies, Applications and Open Research Topics in 6G Networks," in IEEE Access, vol. 8, pp. 174792-174820, 2020, doi: 10.1109/ACCESS.2020.3019590.

[17] Y. Zou, J. Zhu, T. Wu, H. Guo and H. Wei, "Cooperative Drone Communications for Space-Air-Ground Integrated Networks," in IEEE Network, vol. 35, no. 5, pp. 100-106, September/October 2021, doi: 10.1109/MNET.111.2100016.

[18] S. Ali, A. Abu-Samah, N. F. Abdullah and N. L. M. Kamal, "A Review of 6G Enabler: Vertical Heterogeneous Network (v-HetNet)," 2022 IEEE 20th Student Conference on Research and Development (SCOReD), Bangi, Malaysia, 2022, pp. 180-183, doi: 10.1109/SCOReD57082.2022.9974155.