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Integrated UAS Platform with 5G Technology and Non-Terrestrial Networks: Orkney Islands Scenario

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***Abstract*—The integration of fifth-generation (5G) technology with Non-Terrestrial Networks (NTN) holds transformative potential for Beyond Visual Line of Sight (BVLOS) operations of Uncrewed Aerial Systems (UAS) in rural regions. This paper presents a comprehensive architectural design that leverages satellite-enabled 5G networks to enhance connectivity in the Orkney Islands, Scotland, thereby improving the reliability and operational efficiency of UAS missions. By addressing the limitations of terrestrial networks, particularly in remote and underserved areas, the proposed flowchart ensures seamless data communication and transfer, facilitating real-time control and monitoring within the UAS platform. Simulations are conducted to validate the scenario for remote area connectivity. This work underscores the crucial role of NTN in advancing UAS operations, paving the way for innovative services and broader adoption of UAS technologies in rural settings.**

***Index Terms*—SATCOM, Non-Terrestrial Networks, Network Architecture, UAS**

I. Introduction

The introduction of UAS into commercial service systems is a rapidly emerging trend, particularly in the logistics and delivery sectors. These systems present a promising solution to several logistical challenges, especially in remote and rural areas, like fifth generation (5G) technology is a key enabler of these use cases [1]–[3]. The Orkney Islands, with their geographical remoteness and unique topographical challenges, offer an ideal scenario for exploring the potential of UAS delivery systems facilitated by advanced communication technologies like 5G and satellite communications (SATCOM) [4], [5]. It is one of the locations which has been a testbed for various 5G enabled technologies [6]. The capability of 5G to support high data rates, reduced latency, and increased connectivity provides a robust backbone for Urban Air Mobility (UAM) [7], [8]. Moreover, the integration of SATCOM can extend the reach and reliability of these services, ensuring seamless operation even in areas where terrestrial network coverage is limited [9].

There are multiple network architectures and topologies that utilise satellites to support UAS operations. [14] proposes a 3D network architecture comprising of terrestrial, aerial and satellite layers. All these laters are integrated to the 5G core network. It utilises Software Defined Networking (SDN) controllers across these layers to coordinate between the components of each layer [15]. [16] discusses the network slicing framework, enabling the network to provide support

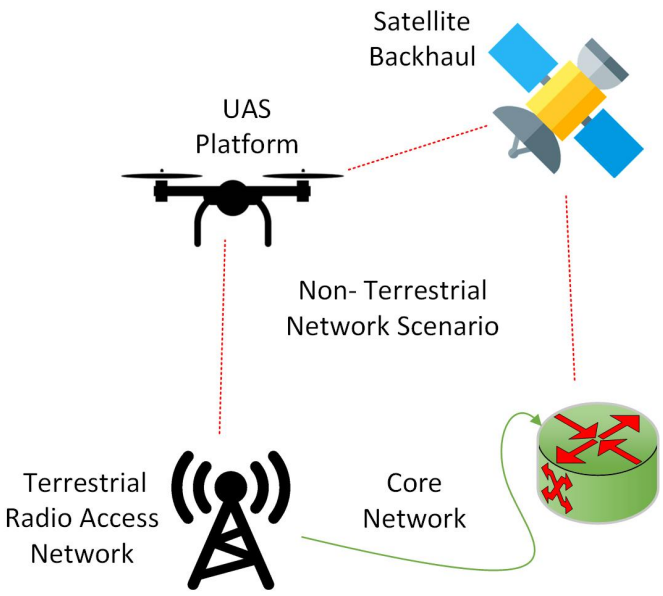


Fig. 1. Illustration of UAS integrated terrestrial, satellite and non-terrestrial networks segment

to UAS with different QoS requirements. [12] compares various use-cases and communication technologies. It points out the requirement of novel networking and handover mechanisms to support upcoming aerial vehicle use-cases (eVTOLs, multipilot UAS operations, medical UASs etc) all of which have distinct requirements. This study compares cellular and SATCOM network architectures. Although it explains and compares various technologies, it does not state which network architectures or combinations are most suitable for remote pilot operations.

While 5G network architecture and LEO satellites are to be used for the simulations, inspirations can be taken from 6G and other heterogeneous network architectures [19]–[23]. Third Generation Partnership Project (3GPP) TR 38.811 [24] has many satellite and High Altitude Platform (HAP) access network principles. Low Earth orbit satellites are currently being extensively researched and proposed for various communication use-cases as they have significantly less link delays and losses compared to the Medium Earth Orbit (MEO) and

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Geostationary Orbit (GEO) satellites [17], [18]. The Third Generation Partnership Project (3GPP) has explored integrating satellites into 5G via Low Earth Orbit (LEO) constellations starting from Release-15, focusing on non-terrestrial network (NTN).

As an alternative to ground-based network identification, UAS platform can be supported by NTNs, such as Low Earth Orbit (LEO) satellite constellations. Although NTNs are primarily aimed at serving undeserved regions, they can also be used to enhance remote connectivity. For example, a terrestrial network (TN) operator could opportunistically lease spectrum and infrastructure from an NTN provider to augment its coverage, as this paper proposed in Figure 1.

This study explores the development and validation of a satellite-enabled network architecture and topology specifically designed for UAS operations in the Orkney Islands. It covers the definition of a UAS delivery scenario, followed by a detailed simulation to analyse the communication link's performance under operational conditions. Key aspects such as link margin, E_b/N_0 (Energy per bit to Noise power spectral density ratio), and handover processes during the mission are thoroughly examined to assess the network's reliability for supporting continuous UAS operations in remote and challenging environments.

II. Network Architecture

This section outlines the methodologies employed in designing and evaluating a satellite-enabled 5G network architecture to support UAS deliveries. The objective is to establish a comprehensive approach that combines theoretical planning with practical simulations to validate the network's effectiveness and reliability for BVLOS operations. The study area description, network design approach, and the simulation and modelling tools utilised are discussed further. The delivery scenario is simulated at Orkney Islands, located off the northern coast of Scotland. This location presents unique geographic and environmental challenges that influence UAS operations.

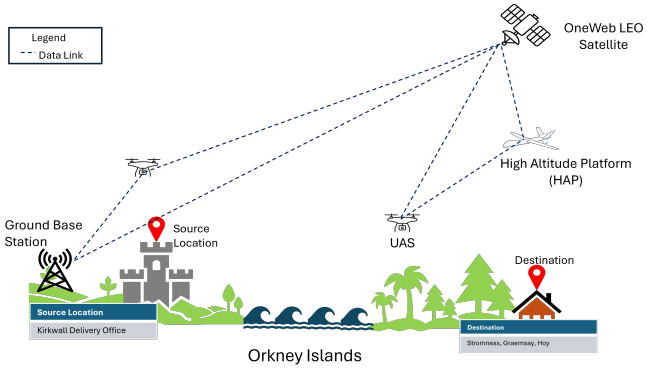


Fig. 2. NTN System Design for last-mile delivery scenario

A. System Design

Designing a network architecture for a satellite-enabled 5G network to support UAS operations in a specific area such as the Orkney Islands in Scotland involves several critical components. The primary challenge is ensuring robust, reliable, and real-time communications in a remote and potentially harsh environment. Here's a high-level overview of the system architecture:

- Core Network Elements: A cloud-based, fully virtual core network that supports the service-based architecture. This core will handle user data and control planes with high throughput and low latency, which is essential for UAS operations. Implementing Multi-access Edge Computing (MEC) to process data closer to the end-user (UAS in this case) reduces latency and bandwidth usage.
- Ground Base Stations: Orkney already has ground infrastructure with active network towers installed as a part of Scottish 4G Infill (S4GI) programme [25]
- Satellite Communication: Integration of 5G with satellite communications to ensure coverage across the Orkney Islands, including areas where terrestrial infrastructure is not economical or feasible. For this purpose, One-Web Satellite constellation is considered [26]. This satellite constellation has 648 satellites with capabilities of 10,000 handovers per second [27].
  OneWeb's Low Earth Orbit (LEO) satellite constellation is an ambitious project designed to provide global broadband internet coverage from space, making it particularly well-suited for enhancing connectivity in remote areas. The specifications of OneWeb's LEO constellation is shown in table I.

TABLE I
SPECIFICATIONS OF THE ONEWEB SATELLITE CONSTELLATIONS

Specification	Description
Orbit Type	Low Earth Orbit (LEO)
Altitude	1,200 km
Bandwidth	High throughput capable of delivering gigabit links
Constellation Size	648 (631 deployed)
Coverage	Global coverage, including polar regions
Operational Life	Designed for around 5 years per satellite
Deployment Strategy	Phased deployment intended to gradually increase coverage and capacity
Orbit Inclination	87.9°

An overview of the proposed network architecture is shown in figure 2. The UAS relies on continuous connectivity throughout its path, which is achieved through smooth handovers between ground base stations and Non-Terrestrial Networks (NTN) such as SATCOM or High Altitude Platforms (HAP), depending on which provides the stronger signal. The detailed architecture which is derived from 5G network based architecture is shown in figure 3.

In figure 3, the architecture is divided into two main planes: the Control Plane and the User Plane. The control plane functions are described in table II below.

The User Plane is responsible for forwarding user data between the devices and the data network. The components involved are:

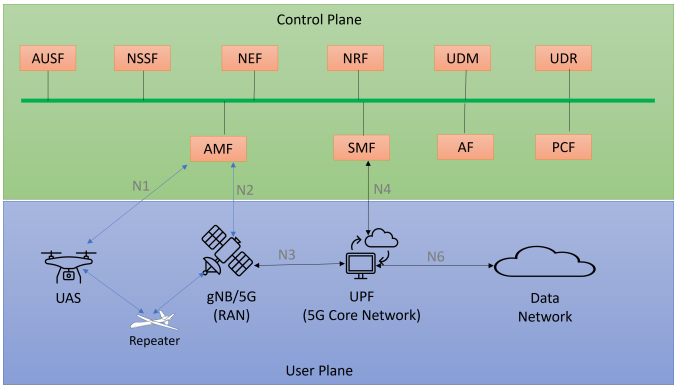


Fig. 3. UAS integrated with 5G architecture

TABLE II
CONTROL PLANE FUNCTION

Acronym	Full Form	Function Description
AUSF	Authentication Server Function	Responsible for authenticating users and devices.
NSSF	Network Slice Selection Function	Manages network slice selection for different services.
NEF	Network Exposure Function	Provides secure and controlled exposure of network services and capabilities.
NRF	Network Repository Function	Maintains a repository of available network functions and their profiles.
UDM	Unified Data Management	Handles user data management, including subscription information.
UDR	Unified Data Repository	Stores user data for policy, charging, and other functions.
AMF	Access and Mobility Management Function	Manages registration, connection, reachability, and mobility of user equipment.
SMF	Session Management Function	Manages sessions, including IP address allocation and traffic routing.
AF	Application Function	Provides application-related information to other network functions.
PCF	Policy Control Function	Manages policy rules for control plane and user plane functions.

- UE (User Equipment): The end-user device. This is the UAS in the given case.
- gNB (gNodeB): The base station (satellites in this case) providing connectivity to the the UAS (or UE).
- Repeater/gNB: Extends the range of the gNB, using airborne (HAP) or satellite relays.
- UPF (User Plane Function - 5G Core Network): Handles data routing, forwarding, and packet inspection.
- Data Network: The external network providing services and internet connectivity.

The 5G network architecture integrates various interfaces to facilitate communication and data transfer between different components. The N1 interface connects the UE with the Access and Mobility Management Function (AMF) to handle control signaling, ensuring proper device registration and mobility management. The N2 interface links the gNB, which is the Radio Access Network (RAN), with the AMF for additional control signaling, supporting the handover and

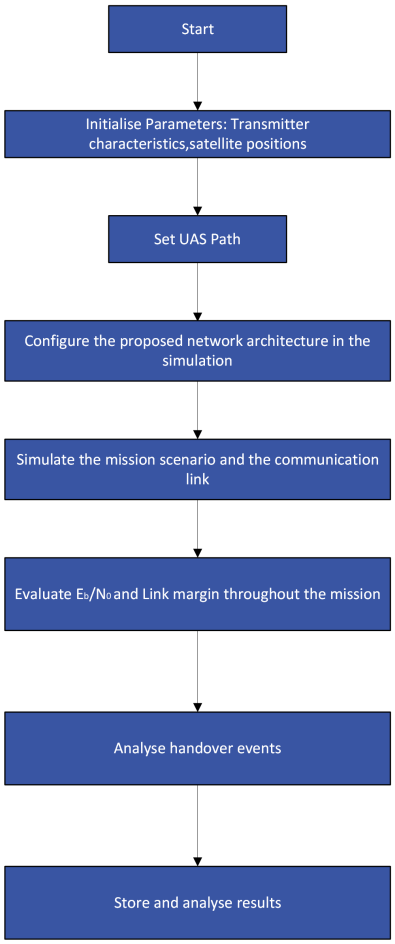


Fig. 4. Flowchart for proposed network procedure

connectivity management processes. For user data transmission, the N3 interface connects the gNB to the User Plane Function (UPF) in the 5G core network, enabling efficient data routing and forwarding. The N4 interface serves as the control signaling link between the Session Management Function (SMF) and the UPF, managing session establishment, modification, and release. Finally, the N6 interface facilitates the transfer of user data between the UPF and the external data network, providing access to internet services and other network resources. These interfaces collectively ensure seamless operation and connectivity in the 5G network, supporting advanced use cases like BVLOS operations in rural regions.

B. Network Topology

Network topology refers to the arrangement of various elements (nodes and links) in a communication network. It defines how these elements are interconnected and how data flows within the network [28]. In the context of our paper, the network topology integrates satellite and terrestrial 5G components to support BVLOS operations in rural regions. This hybrid topology is crucial as it ensures reliable connectivity and efficient data transmission where traditional infrastructure is insufficient, thereby enabling advanced applications

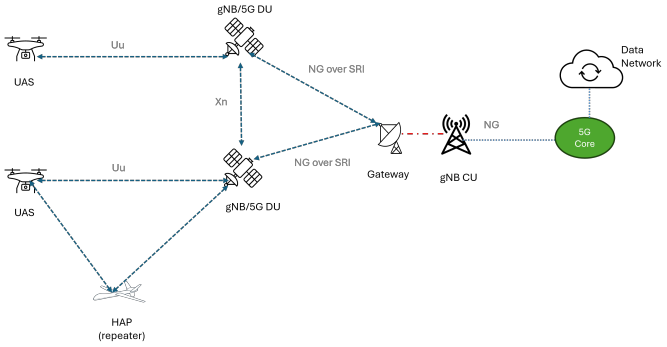


Fig. 5. Network topology for UAS delivery scenario in rural areas

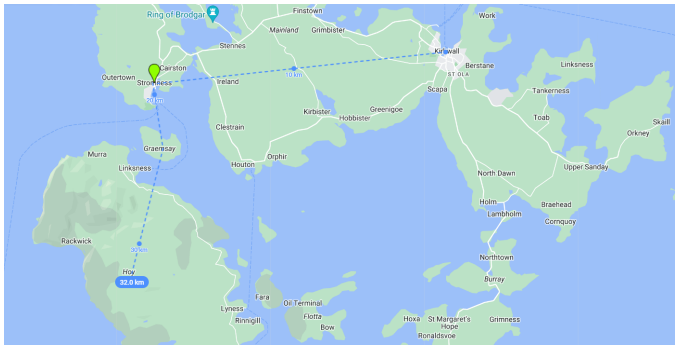


Fig. 6. Delivery path for the UAS

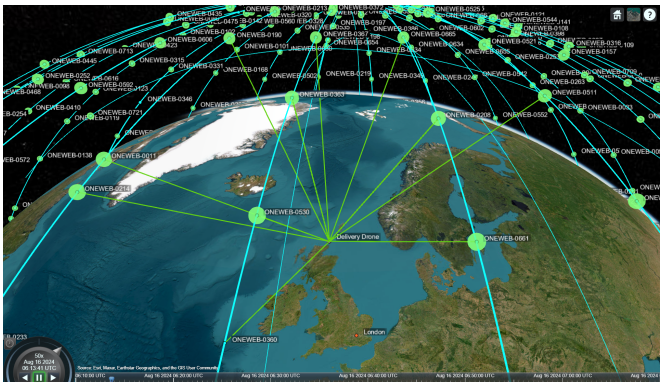


Fig. 7. Delivery Scenario modelled in MATLAB

like UAS operations for agriculture, disaster management, and remote monitoring. The effective design of this network topology is pivotal in bridging the digital divide and enhancing communication capabilities in underserved areas.

The proposed network topology for the UAS delivery use case at Orkney islands is shown in figure 5

This topology is designed to ensure seamless connectivity and data transmission between the UAS, terrestrial gNBs, and the 5G core network, thereby enabling reliable and robust communication. In this topology, the UAS acts as the UE, which communicates with the network through the Uu interface. The Uu interface utilizes standard 5G NR (New Radio) protocols to establish a wireless connection between the UAS and the gNB. The gNB, serving as the RAN component, provides the necessary wireless connectivity to both aerial and terrestrial UEs. It connects to the 5G core network using the NG interface and supports communication and handover between different gNBs (inter-satellite handovers) through the Xn interface. The 5G core network is the central part of this architecture, responsible for the overall control and management of network functions, user data, and mobility. The NG interface, which links the gNB to the 5G core network, is divided into two main parts: NG-C (Control Plane) for managing signaling and control messages, and NG-U (User Plane) for handling user data transfer. Additionally, the Xn interface facilitates coordination and seamless handover between gNBs, ensuring uninterrupted connectivity when the UAS moves across different coverage areas.

A notable feature of this topology is the NG over SRI (Satellite Radio Interface), which extends the NG interface via satellite links. This is particularly advantageous in rural or remote regions where terrestrial infrastructure is sparse or non-existent. By leveraging satellite communication, the robust and reliable connectivity can be maintained between the gNB and the 5G core network, thereby supporting BVLOS operations even in challenging weather conditions.

III. Simulation and Analysis

The UAS delivery scenario was simulated in MATLAB 2024a. A simple mission profile was conceptualised and is shown in figure 6. The UAS would cover 32 kilometres to reach its final delivery location. The UAS was set to move at a constant speed of 45 metres per second at an altitude of 120 metres from ground. The orbit data for the satellites were obtained from 'Celestrak' which is a non-profit organisation providing satellite data [29]. The transmitter characteristics on the satellite were considered as per 3GPP TR 38.811 [24]. The scenario can be visualised using figure 7.

The communication link was analysed. Link margin and latency were studied to determine the reliability of the link. The result is shown in figure 8. The Link margin represents the excess power available, calculated as the difference between the received signal strength and the minimum power required for the receiver to maintain a reliable communication [10]. A positive link margin is obtained throughout the mission which indicates that the UAS has a reliable communication till the end of the mission.

The variation of latency is shown in figure 9. The latency observed is well within the limits of 20 ms [30], hence a robust communication link is maintained. By adhering to this latency constraint, the system effectively prevents any significant delays that could compromise data transmission or the overall performance of the network. The stability in latency is crucial for applications that require real-time data exchange. Furthermore, the consistent performance within these limits suggests that the system is resilient to potential sources of delay, such as network congestion or variations in processing time, thereby ensuring uninterrupted and efficient

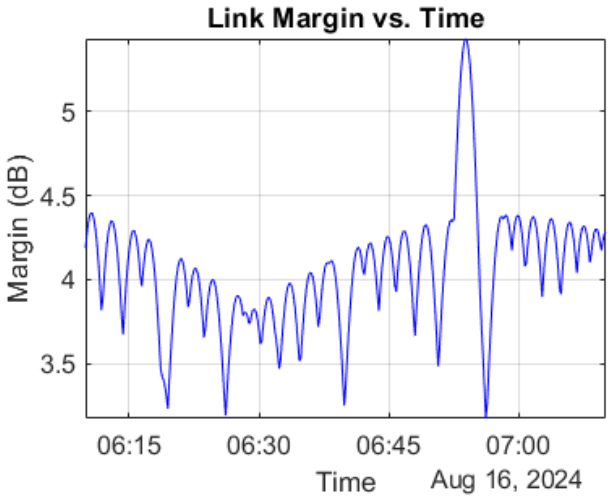


Fig. 8. Link margin variation of the communication link throughout the mission

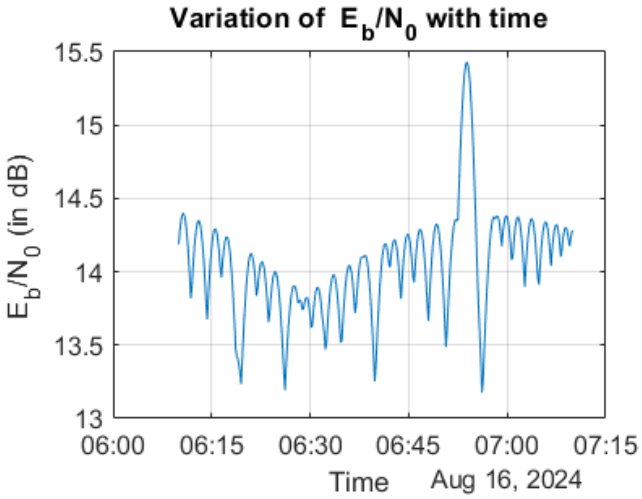


Fig. 10. E_b/N_0 variation during the mission

communication.

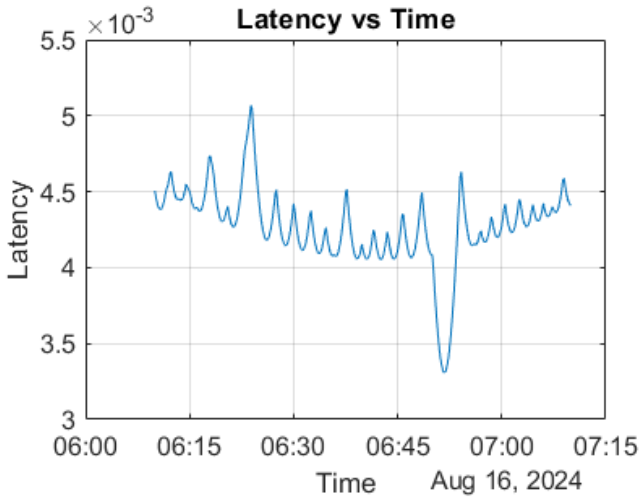


Fig. 9. Latency variation throughout the mission

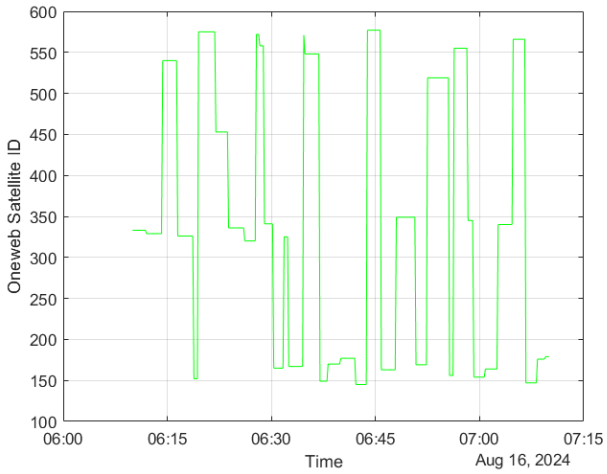


Fig. 11. Handovers during the mission

Minimum latency occurs when the UAS is connected to the closest satellite available, minimizing the propogation distance of the signal. Received signal strength also increases when the satellite is closer hence improving the link margin.

E_b/N_0 is a fundamental measure used in digital communication systems to assess the efficiency and performance of a communication link. It quantifies the signal strength relative to the noise level affecting the signal and is a key determinant of the quality and reliability of the communication. E_b/N_0 was evaluated at the UAS receiver for the entire mission. This shown in figure 10. The E_b/N_0 values range between approximately 13 dB and 15.5 dB. This range is generally considered adequate for reliable communication in many wireless systems, including those used for UAS operations.

Satellite handovers occur at each local minima of the Link margin vs. Time curve shown in figure 8. After a handover takes place the link margin increases till the satellite is right above the UAS, minimizing the distance. It further decreases, until a handover takes place and the link margin with of the signal from the new satellite is more than the one UAS is currently connected to. The handovers can be studied further through figure 11. The satellites were given ID numbered 1 to 631. So handovers can be seen when the communication link hops from one satellite to another. A total of 35 handovers were observed during the mission.

IV. Conclusion

This paper presented a satellite-enabled 5G network architecture designed to support BVLOS operations in rural regions. By integrating satellite communication with terrestrial 5G infrastructure, the proposed topology addresses the critical challenge of providing reliable and high-bandwidth connectivity in remote and underserved areas. The hybrid network architecture ensures continuous and robust communication

channels essential for applications such as UAS deliveries. The satellite constellation was modelled and the communication link was analysed. Link margin was chosen as the parameter to determine whether the communication link is reliable. Variation of the E_b/N_0 during the mission was also studied indicating the desired performance is achieved. Additionally, the analysis of handover events indicates that the network architecture is well-suited to handle the mobility of the UAS, minimizing the risk of communication loss during critical phases of the mission. The findings underscore the potential of satellite-based communications in expanding the operational capabilities of UAS, particularly in areas where traditional terrestrial networks are insufficient. Future work will focus on real-world deployment and further optimization of the network to address emerging challenges and enhance the system's performance.

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