D5.2 - Demonstration of MESH in the sky communication infrastructure

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DELIVERABLE INFORMATION

Abstract:	The deliverable reports on the demonstration of Mesh in the Sky wireless communication infrastructure that has been deployed using unmanned aerial vehicles (UAVs). The Mesh in the sky infrastructure will enable communication among the first responders deployed using the forward command centre (FCC). Additionally, the infrastructure will also be utilised to exchange information from the field with the SILVANUS cloud. The communication infrastructure utilises MESH radios that will extend beyond line of sight. The deliverable summarises the technology specification of wireless MESH radio and the demonstration of the wireless interface with the in-situ deployment of the IoT devices.
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List of acronyms and abbreviations

ACRONYM	Description
C2	Control Centre
CONOPS	Concept of Operation
DC	Data Collector
GPS	Global Positioning System
GS	Ground Station
HD	High Definition
IEEE	Institute of Electrical and Electronics Engineers
IGARS	International Geoscience and Remote Sensing Symposium
IoT	Internet of Things
IP	Internet Protocol
LoRa	Long Range
ISO	International Standards Organisation
MAC	Media Access Controller
SOCO	Single Overriding Communications Objective
SDR	Software Defined Radio
TCP	Transmission Control Protocol
ToC	Table of Contents
UAV	Unmanned Aerial Vehicle

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Executive Summary

During the critical "Golden Hour" following the outbreak of a forest fire, secure communication is paramount in ensuring rapid response and saving lives, properties and habitats. There are clearly defined essential requirements for effective communication during this crucial period, which describe how emergency communication systems can help to determine the scale and severity of the fire. All the regular documents emphasise that effective communication during forest fires can save lives, protect property, and mitigate the impact of these devastating events[1].

During forest fires in rural areas communications infrastructure is limited or does not exist[2]. Therefore, it is a common practice that the First Responders bring their own rapidly deployable communication systems, minimising reliance on the existing infrastructure and risks associated with its inadequate performance. Unfortunately, wireless communications in forest environment is also challenging due to objective factors, such as signal attenuation, multi-path, and dispersion, leading to destructive signal interference, signal delays and degradation in overall communication performance. Therefore, significant challenges in establishing reliable, robust, broadband, secure communications during the "Golden Hour" of Forest Fires is a key barrier to the first responders. Following the wide-scale uptake of IP/TCP protocols, there is a strong interest to use open standards for communication instead of proprietary communication signals that often limit the first responders ability to interoperate. The deliverable presents the work conducted by SILVANUS in T5.5 titled "Wireless communication infrastructure setup using SDR", which is reported in D5.2.

This report presents results obtained during the development, implementation, testing and verification of the SILVANUS Mesh in the Sky secure communication solution for Forest Fire Fighters. The developed system eliminates the drawbacks of the legacy communication systems, allowing rapid deployment during the Golden Hour while enabling seamless integration with both ground-based and on-board IoT sensors developed by SILVANUS Partners.

The report describes results of the comprehensive testing in the laboratory conditions, ensuring full compliance with regulatory requirements. In addition, the report presents the results from the tests in live conditions, utilising a UAV in scenario emulating the most common operational scenario of SILVANUS pilots. Detailed results of these trials, including snapshot of video demonstrating performance of the received HD video, are presented in in this report.

Finally, we conclude that the developed SYILVANS Mesh in the Sky radio system provided sufficient bandwidth which ensured uninterrupted transmission of HD video stream, is in full compliance with the requirements and is ready for the pilot trials in real forest environments.

The results of the completed tests and trials were summarised in the scientific paper, which is accepted for publication and presentation at *the 2024 IEEE International Geoscience and Remote Sensing Symposium* (IGARS 2024) in Athens in July 2024

[1] Types and Strategies of Forest Fire Fighting (waldwissen.net)

[2] https://www.fao.org/forestry/communication-toolkit/87164/en/

1 Introduction

During the critical “Golden Hour” following the outbreak of a forest fire, secure communication is paramount in ensuring rapid response and saving lives, properties and habitats. The “Golden Hour” refers to the initial period after an emergency. It demands quick, calm, and accurate communication. The scale of the emergency must be determined, and messages need to be refined and tailored for individual audiences. Appropriate spokespeople are assigned, and the optimal mix of tools to communicate are employed, ensuring the SOCO (single overriding communications objective) [1].

There are clearly defined essential requirements for effective communication during this crucial period, which describe how emergency communication systems can help to determine the scale and severity of the fire, employ the most suitable communication channels, distribution of tailored messages for different audiences (such as residents, emergency responders, and authorities).

During forest fires in rural areas communications infrastructure is limited or doesn’t exist. Therefore, it is a common practice that the First Responders bring their own rapidly deployable communication systems, minimising reliance on the existing infrastructure and risks associated with its not adequate performance. Unfortunately, wireless communications in forest environment are also challenging due to objective factors, such as vegetation absorption and path losses., resulting in short communication ranges. Furthermore, reflections and refractions from trees create multiple paths for signals, leading to destructive signal interference, signal delays and degradation in overall communication performance. These effects are more severe as the higher carrier frequency is used for wireless communications. However, the higher operating frequency is required to ensure high bandwidth and throughput.

To overcome these limitations of the existing systems, First Responders implement careful planning, frequency selection, and antenna placement to ensure reliable communication during emergencies and other critical situations. However, these necessary measures require some time for the implementation at the actual fire location and delay the actions of “Golden Hour”. Therefore, significant challenges in establishing reliable, robust, broadband, secure communications during the “Golden Hour” of Forest Fires is an open and “burning” challenges.

In the context of SILVANUS, the deployment of Mesh in the sky, will take place to coordinate communication between the forward command centres who are expected to be separated by a distance and has been outlined in the D8.3, as the final architecture specification. The architecture specification is presented in Figure 1, for simplicity and easy reference. It is noted that the deployment of the Mesh in sky will also be used to enable communication from the forward command centre to the cloud based SILVANUS command centre.

This deliverable describes the overall innovation carried out in the project for deploying wireless communication systems during the forest fires. The solution, developed by SILVANUS, addresses all the shortcomings of the legacy wireless communication systems, and allows significant improvements compared to legacy solutions. The deliverable describes the overall system architecture, implementation and design characteristics and presents of results of both the laboratory and field trials prior to SILVANUS pilots. The report is structured as following: in Section 2 an introduction to the CONOPS and general architecture of the developed solution is presented, followed by results obtained from the laboratory and field trials of the developed solution as reported in Section 3. Subsequently, in Section 4 conclusions are provided with special emphasis on the developed solution that has been fully tested and validated in real forest fire conditions during the planned SILVANUS pilots that was carried out in 2023.

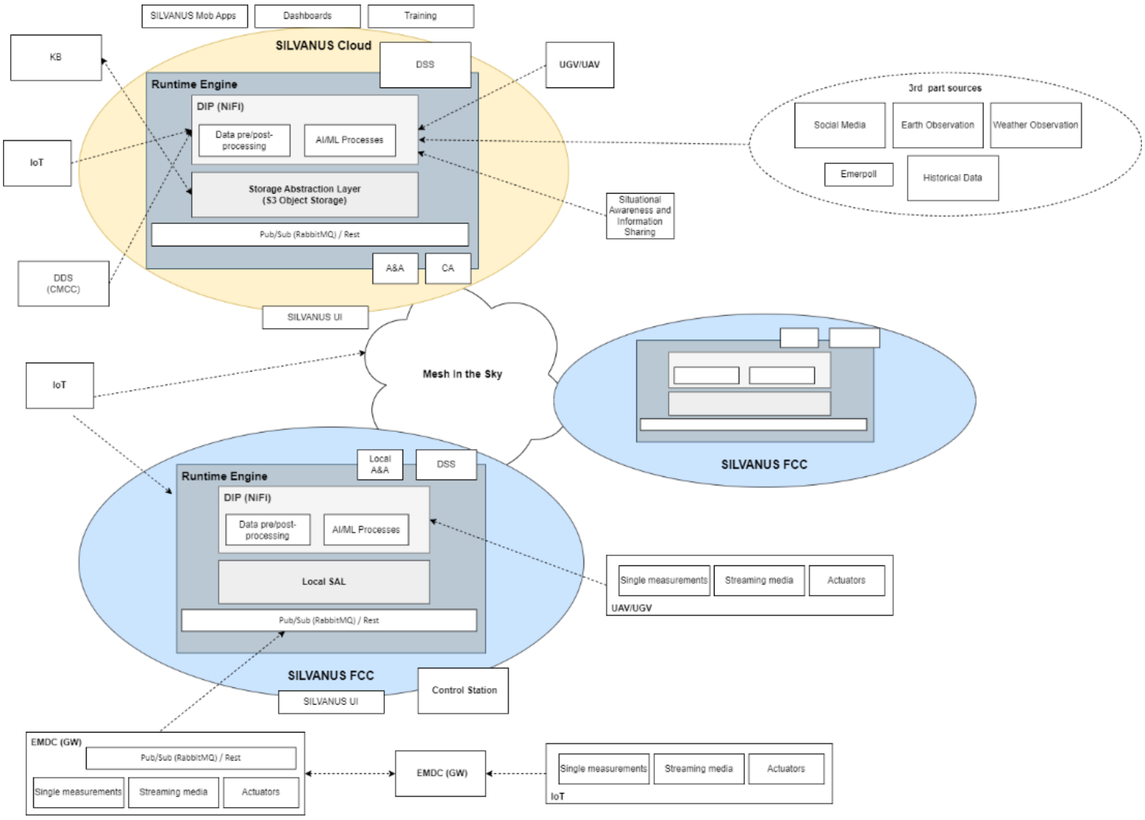

Figure 1 - SILVANUS architecture indicating the position of Mesh in the sky between the forward command centres and cloud command centre deployment

2 Secure Communication System for Forest Fires

2.1 Introduction to Mesh in the Sky

To address all the challenges associated with complex and diverse pilot scenarios the Unmanned Aerial Vehicles (UAVs) and Software Defined Radio (SDR) based ad-hoc broadband mesh communication from Rinicom, called RiniLink, will be used. Schematic diagram of the proposed solution, called "*Mesh-in-the-Sky*" is shown in Figure 2.

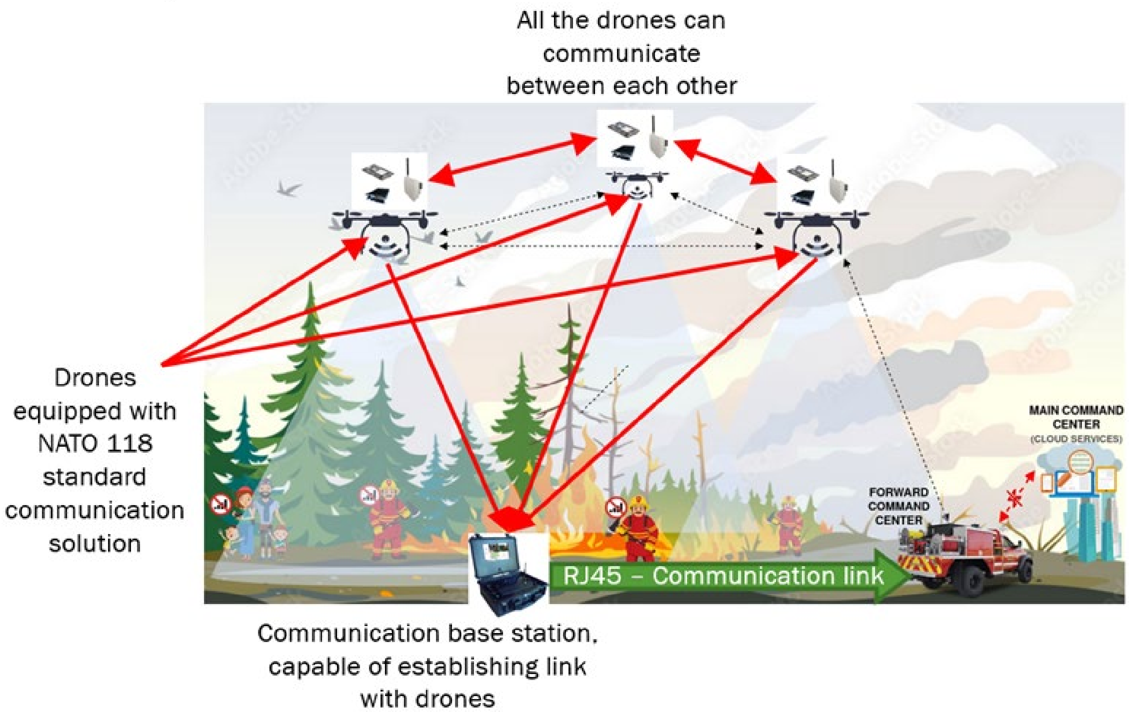

Figure 2 Schematic Diagram of Mesh in the Sky Solution

The advantage of using a SDR is that it can be readily adapted to different communications environments. The RiniLink SDR offers, in a single device, a database of waveforms to meet different customers' needs in a wide range of wireless applications and uses. Thus, the RiniLink SDR can be used in harsh environments and mobile applications.

The RiniLink SDRs can also be connected, on an ad-hoc basis, to form a network that lets each radio, automatically, connect to other RiniLinks; so, creating a self-healing, mobile and dynamic IP mesh network. Each RiniLink automatically routes data around the wireless network and may easily be configured to operate without user intervention. This makes the system ideal for rapid deployment scenarios.

2.2 Overall architecture

The concept of operation (CONOPS) of the proposed solution is explained in Figure 3. This CONOPS is developed utilising the overall SILVANUS aim to develop a suite of sensors that will be interconnected through a secure, robust wireless communication system and provide real time data required for efficient neutralisation of forest fires. It is assumed that the ground sensors provided by SILVANUS will have various communication interfaces and capabilities and these will be utilised when cellular or LoRa coverage is available in the area. The proposed solution will be implemented where no cellular or LoRa coverage exists, therefore, the proposed Mesh in the Sky will ensure seamless integration with all the sensors developed by SILVANUS Partners.

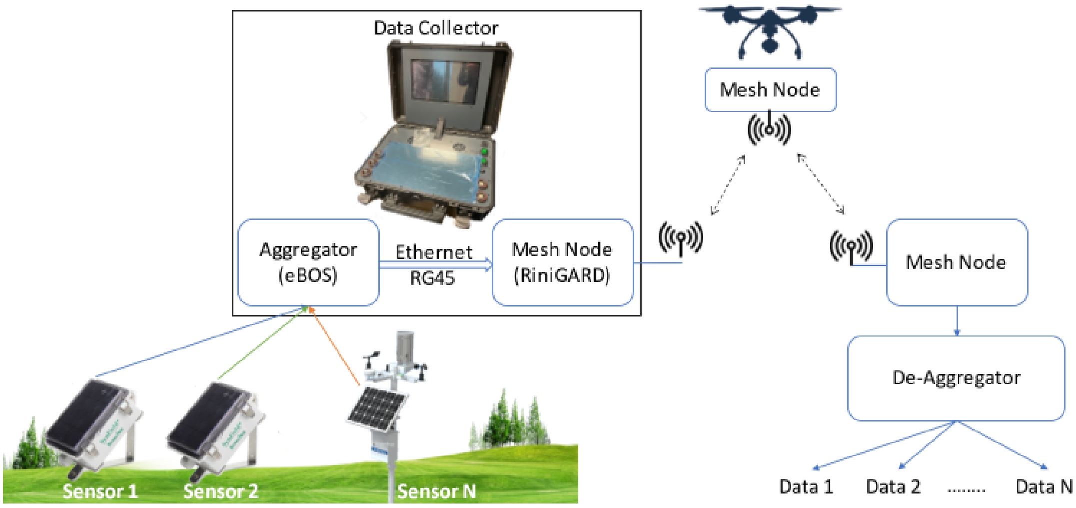

Figure 3 CONOPS of "Mesh in the Sky" in SILVANUS

More specifically, the proposed Data Collector (DC) will be installed in the area of no communication infrastructure and will be used to collect data from sensors. This aggregated data will be streamed via mesh network to a UAV which will be carrying another mesh node and acting as a relaying station in the sky. Information from the UAV will be finally received at a control centre which could be up to 70 km away. Picture of a SDR located on a drone is shown as an illustration of a possible solution in Figure 4.

Figure 4 UAV with integrated Mesh in the Sky node during laboratory testing

The implementation of the Mesh in the Sky node on a UAV was not a trivial task, as a number of constrained needed to be taken into consideration. These were:

- Weight of the node - ensuring that the payload is compliant with UAV take-off characteristics
- Physical dimensions of the node – ensuring that flight dynamics are not affected.
- Power consumption of the node – ensuring that UAV battery is not drown intensively.
- Antenna location and direction of the node – ensuring wide coverage area without unnecessary signal losses.

2.3 System characteristics

The *Mesh in the Sky* is an IP based system, operating using NATO IST 118 standard [2]. This standard is specifically developed for mesh communication in disadvantaged networks where ground infrastructure is poor or not available. It is a broadband mesh supporting up to 100 MB/s (depending upon the range) but with guaranteed connectivity of 20 MB/s at UAV ranges of 20 km from the Ground Station (GS). The system architecture is flexible enough to support multiple ground stations distributed upon the area of the forest fire.

The system will support multiple live High Definition (HD) video streams from the drones, proving situation awareness and real time video surveillance which could be used for analytics (detecting early fires, determining size of fires, etc) and a any other IoT sensors, plus flight related data (GPS coordinates, control signals, telemetry, etc).

The ground station could be connected to any Internet Protocol (IP) system, including IEEE802.11xx or LoRAN, making integration much easier and communication more reliable. This is due to the fact that in this case individual sensors do not need to be connected directly to the drone, but to the near-by GS, from where the aggregated traffic via MESH in the Sky will be transmitted to any control centre.

Furthermore, the proposed Mesh in the Sky system architecture allows the installation of various IoT sensors directly on the drone, providing real time sensory data from a wide area of surveillance. Correspondingly, these sensors could be wired directly into the Mesh in the Sky, dramatically simplifying overall networking architecture.

3 System Configuration and Laboratory Test Results

In preparation for the pilots and field trials, the proposed Mesh in the Sky was built and tested in Rinicom's test laboratory. To ensure accurate measurements of the system performance, Rinicom's test and measurement equipment were utilised during the trials in full compliance with ISO 9001 quality standard. These sections outline the results of these tests and provides more details on system configuration.

3.1 System Setup

To conduct the laboratory trials the 3 newly built Mesh in the Sky nodes and one IP camera were used. Their MAC and IP addresses are shown in Table 1.

Table 1 Configuration Parameters of Mesh in the Sky Nodes and IP Camera used in Laboratory Trials

	RADIO 1	RADIO 2	RADIO 3	IP CAMERA
MAC ADDRESS	00:11:6A:03:7F:57	00:11:6A:03:7E:C7	00:11:6A:03:7F:17	00:07:5F:C4:25:2E
NODE ID	1	2	3	MIC IP Starlight 7000i
IP ADDRESS	192.168.1.176	192.168.1.137	192.168.1.112	192.168.1.165

Figure 4 illustrates the fully assembled Mesh in the Sky node used during the laboratory trials.

Figure 5 SYLVANUS Mesh in the Sky Radio Node

3.2 Network Architecture During Laboratory Trials

During the laboratory trials conducted as an integral part of D5.2, it was tried to emulate a scenario which duplicates one of the most common operational scenarios for SILVANUS pilots – the scenario where 1 UAV will be hovering over the area of a pilot providing connectivity to all ground based IoT sensors, GSs, remote

Control Centres (C2) and authorised users. Figure 5 illustrates network architecture set up for all three mesh nodes, IP camera, server and network switch, together with their IP addresses. The test configuration of the Mesh wireless node is presented in Figure 6.

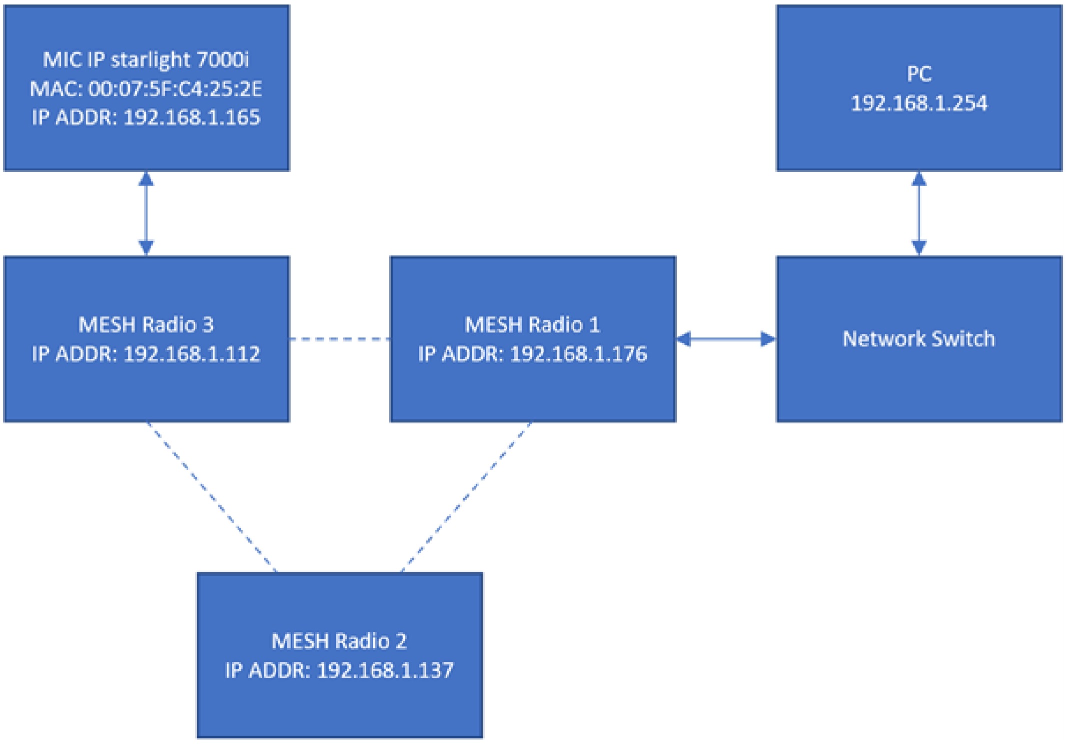

Figure 6 SILVANUS MESH Network Architecture During Laboratory Trials

3.3 Operation of Mesh Nodes

The use of the developed MESH-in-the-Sky system during SILVANUS pilots must be in full compliance with European and local regulations. Therefore, once the mesh network was developed, significant efforts were spent on ensuring their compliance with regulatory requirements, especially on spectral masks and signal emissions both within and outside operating frequency bandwidth. The results of these tests for all 3 mesh nodes are shown in Figure 7.

Figure 7 Spectrum Masks for Mesh Radio 1, Mesh Radio 2, and Mesh Radio 3

All the measurements spectral characteristics are in full compliance with the regulatory requirements.

In addition to spectral characteristics the developed solution was tested in drone operations, streaming video from the on-board camera on the UAV to 2 users on the ground and utilising a mesh node installed on the flying drone, as shown in Figure 7.

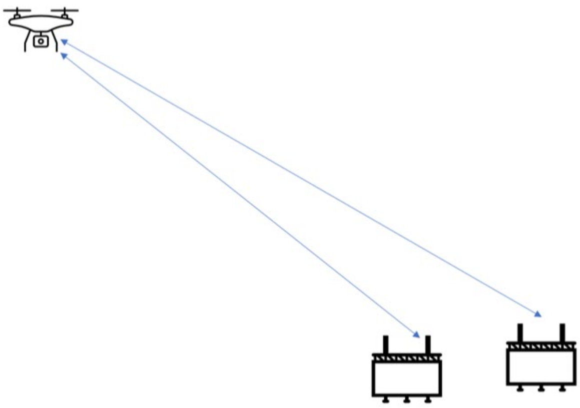

Figure 8 Mesh in the Sky Field Testing Configuration

The set-up parameters of the on-board IP camera of this test together with snapshot image received at one of the GS, are shown in Figure 8.

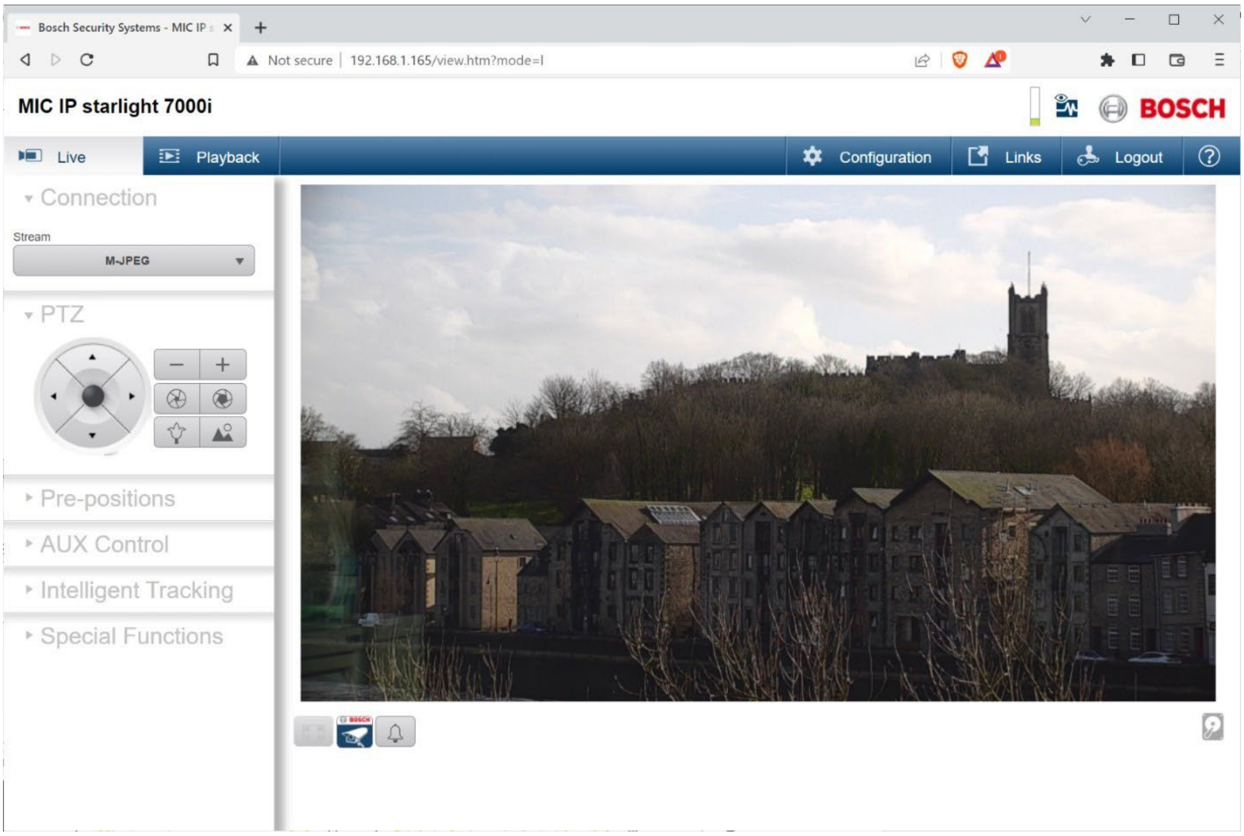

Figure 9 Screenshot of Video Streaming Utilising Mesh Node on a drone

Figure 9 below illustrates a few snapshots of the video recorded during the trials. Full video will be available on SILVANUS portal.

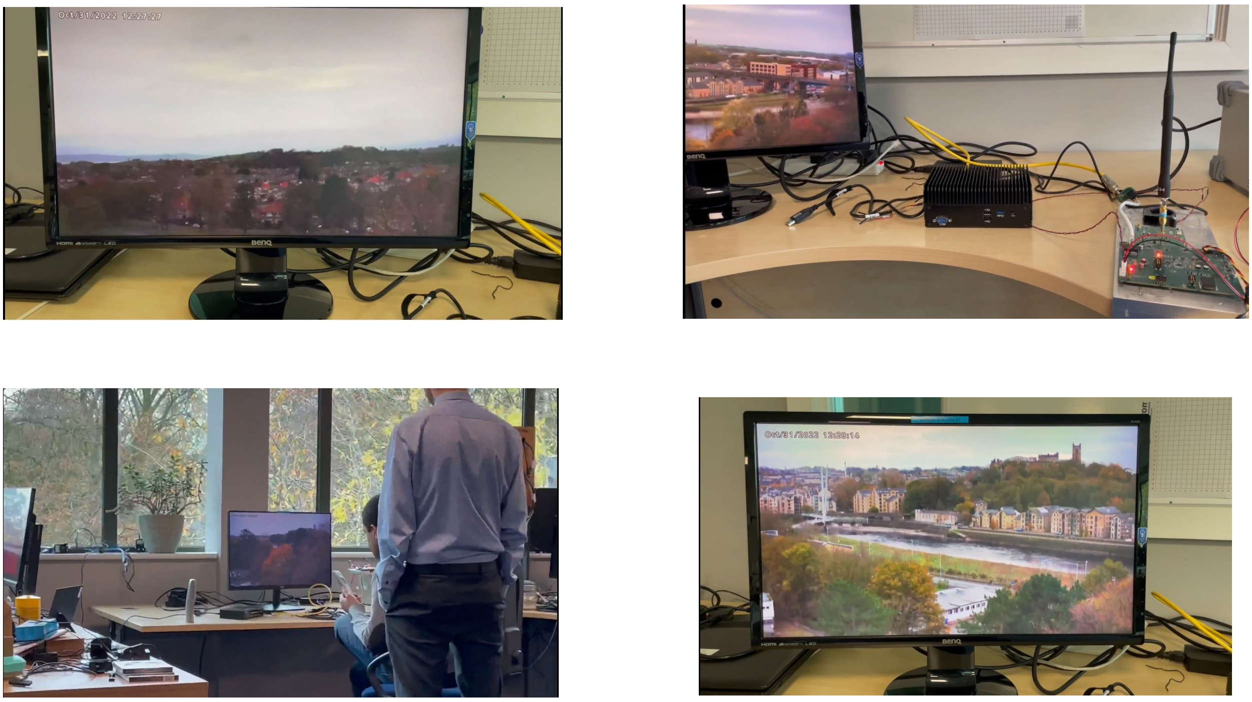

Figure 10 Screenshots from Video Recorded During Trials

The developed SILVANUS Mesh in the Sky radio system provided sufficient bandwidth which ensured uninterrupted transmission of HD video stream. The initial in-house trials and testing confirmed full compliance with the requirements and system readiness for the pilot trials in real forest environments.

The results of the completed tests and trials were summarised in the scientific paper, which is accepted for publication and presentation at *the 2024 IEEE International Geoscience and Remote Sensing Symposium (IGARS 2024)* in Athens in July 2024 [3].

3.4 Demonstration and configuration from field trials

During the April 2023 field exercise activity organised in Croatia by HVZ, RINICOM engineers, demonstrated the operational configuration of the Mesh in the sky wireless nodes. The configuration of the wireless nodes in the field is presented in Figure 11. The communication infrastructure was used to transport in-situ device data captured and generated from the IoT sensors that were deployed for the detection of smoke and fires. The installation of the sensor is presented in Figure 12. The IoT device communication was interfaced with the Wireless Mesh, which was further interfaced with the Internet through 5G router, thus enabling Internet access to the IoT sensor. The wireless mesh bandwidth was tested to be reliable for the transportation of the images and HD videos that were gathered from the field.

Figure 11 - RINICOM engineers setting up the mesh nodes in the field for creating communication infrastructure for transmitting IoT device data to the cloud

Figure 12 - In-situ device deployed by CTL in the field to interface with the Wireless mesh

4 Conclusions

In this report results obtained during the development, implementation, testing and verification of the SILVANUS Mesh in the Sky secure communication solution for Forest Fire Fighters are presented. The developed system eliminates the drawbacks of the legacy communication systems and allows rapid deployment during the Golden Hour while enabling seamless integration with both ground-based and on-board IoT sensors developed by SILVANUS Partners.

The system undergone comprehensive testing in the laboratory conditions, ensuring full compliance with regulatory requirements. In addition, system was tested in live conditions, utilising a UAV in conditions emulating the most common operational scenario of SILVANUS pilots. Detailed results of these trials, including snapshots of video demonstrating performance of the received HD video, are presented in in this report.

Finally, it is concluded that the developed SYILVANS Mesh in the Sky radio system provided sufficient bandwidth which ensured uninterrupted transmission of HD video stream, is in full compliance with the requirements and is ready for the pilot trials in real forest environments.

The video demonstration of the Mesh in the sky has been published in the SILVANUS YouTube Channel[3].

[3] https://www.youtube.com/@silvanusproject4671

5 References

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