CNVVF UAS team extends IMSI Catcher system for public safety and security

Egidio Accettulli[1], Luca Bellino[1] [0000-0002-4823-3589], Alessandro Spurio[1] and Onofrio Lorusso[1]

[1] Dipartimento dei Vigili del Fuoco, del Soccorso Pubblico e della Difesa Civile
Corpo Nazionale dei Vigili del Fuoco
egidio.accettulli@vigilfuoco.it, luca.bellino@vigilfuoco.it

Abstract. Italian National Fire Brigade (CNVVF - Corpo Nazionale dei Vigili del Fuoco), as the forefront for public safety and emergency response, actively employs drones technology through the UAS team. In this context, one of the most recent and innovative instruments equipped on drones is an IMSI Catcher system, capable of intercepting the phone signals through the IMSI Catcher technology, and thus of crucial importance in scenarios of search for missing person.

Keywords. UAS, CNVVF - Italian Fire Brigade, IMSI Catcher

1 - Introduction

In the last decade autonomously operating Unmanned Aerial Vehicles (UAVs), also referred as Unmanned Aerial Systems (UAS) or simply drones, have become a mass-market technology with a wide spectrum of applications [1]. Swarms and interactions with other cyber-physical systems, formation control and self-assembly methods, localizations and search approaches are just few examples investigated by academy and private or public companies [2].

The versatility, reliability, and ease of use of UAS make them a crucial asset for public safety and emergency response in a very wide range of scenarios, such as monitoring and control in emergency, search for a missing person, aerial photography and photogrammetry, georeferencing, landscape and aerial imaging also with the use of thermocameras or Lidar scanners or having access to impervious aerials [3,4]. In addition, drones equipped with cutting-edge measurement instruments are used as data acquisition platforms, also known as Mobile Sensing Platforms (MSPs), providing extremely precise data attained in almost every location such as prohibitive areas for manned vehicles or land teams as well as hostile environments that can put operators in danger.

In this context, the Italian National Fire Brigade (CNVVF - Corpo Nazionale dei Vigili del Fuoco) is at the forefront for public rescue and safety, too often threatened by extreme natural events, which in the recent years are increasing primarily due to climate change. Among the various resources the Brigade can deploy, the UAS team (called in CNVVF as SAPR team) is equipped with cutting-edge technologies and is one of the most advanced in terms of operational capacity. Indeed, the unmanned air fleet asset is of crucial importance not only in many scenarios where land team or helicopters cannot intervene, such as huge wildfires, nighttime operations, difficult weather conditions, or inaccessible areas, but also for gathering data and information that helps optimize the allocation of resources [5]. The data and information collected by these systems are linked to geographic coordinates, enabling the creation of mapping databases that can be shared among various agencies involved in managing the event.

Figure 1: *a) Example of IMSI Catcher technology equipped on UA DJI M600 of CNVVF. b) IMSI CAtcher system and main characteristics.*

The development of procedures and skills within the UAS team of CNVVF take places with the Central Italy Earthquake in 2016, where it was realized that obtaining in the shortest time imaging and data from the event to support the decision-making process was of paramount importance [6]. Since that moment, the advantages of employing drones have spread across various areas, allowing for the development of new systems and technologies as support for the many activities of the Italian fire

Brigade in terms of prevention, such as in the case of wildfires and structural collapses, 3D imaging thanks also to recent Lidar scanners [7,8,9] and river flood risk monitoring [10].

One of the most innovative equipment for drone technology is the IMSI Catcher systems, that can be equipped on machines of the CNVVF fleet and is of primary use in the scenario of search for missing person (See Fig. 1). Thanks to the IMSI Catcher technology (IMSI - International Mobile Subscriber Identity), it allows the location and connection to cell phones following the GSM, UMTS and LTE standard and to identify their terminals through their IMSI. The main goal of such a system is to locate phones in areas with no or poor signal and establish contact between victims and search teams.

Here we describe this innovative system, its features and capabilities when applied to public rescue operation in emergency scenarios, the main goal of CNVVF. Specifically, this paper presents the fundamental principles of the system's operation, examines its limitations, and explores the most effective techniques to maximize its potential. Additionally, it provides the analysis of statistics on search and rescue operations conducted with these tools, based on data from 2021 (the year of their implementation) to the present.

2 – UAS and CNVVF: recent developments and open challenges

The Italian Fire Department's drone service currently operates from 16 bases, with around 150 pilots and a fleet of over 60 drones, including both multirotor and fixed-wing types [11,12]. As a government organization, the Italian Fire Department follows specific rules for using drone in support of technical rescue operations such as having a minimum crew of two pilots, conducting pre-flight risk assessments and briefings, performing dynamic risk assessments during operations, holding post-flight debriefings, and keeping records of all activities. Depending on the area and airspace, additional mitigation measures may be required, such as using an airspace observer, monitoring aeronautical frequencies, and using thed-flight website, among others based on the risk assessment. Standard Operating Procedures (SOPs), recent Scenari di Soccorso Predefiniti (SSP)[1] and technical guidelines further outline the Unmanned Aircraft System (UAS) Operations Manual for the Italian Fire Department[2]. The drones are insured, hold airworthiness certifications, and are maintained according to the manufacturer's maintenance instructions and programs. As already mentioned, the applications of drones in supporting Italian Fire Department rescue operations are extensive following a continuous path of improvement and innovation. They are used in search and rescue missions, flood, landslide, avalanche emergencies, earthquakes,

[1] Currently undergoing final approval

[2] Currently under development according to ENAC and EASE Guide Lines.

hazardous substance incidents, and in both outdoor and indoor technical rescue operations, as well as forest firefighting [13,14].

EVENTO	Ore di Volo	Voli
Sisma CENTRO ITALIA 2016	422:50	1683
RIGOPIANO e Dissesti ABRUZZO 2017	11:11	45
Sisma ISCHIA 2017	16:39	95
Crollo Viadotto Polcevera GENOVA 2018	69:05	280
Sisma MOLISE 2018	29:48	75
Sisma CATANIA 2018	43:04	212
Maltempo VENETO 2018	16.57	61
Incendi Boschivi VARESE 2019	11:19	50
Sisma ALBANIA 2019	2:18	11
Incidente Ferroviario LODI 2020	3:10	13
Incendio Boschivo ABRUZZO 2020	28:41	86
Incendio Grattacielo MILANO 2021	7:57	31
Incendio Boschivo ORISTANO 2021	28:57	97
Incendio Boschivo Transfrontaliero TICINO 2022	16:00	27
Emergenza Alluvione MARCHE 2022	89:05	251
Emergenza Alluvione EMILIA ROMAGNA 2023	178:43	544
Emergenza Bradisismo Campi Flegrei NAPOLI 2024	83:00	117

***Table 1**: UAS Team hours of flights and number of flights for each major event in Italy since 2016.*

PERIODO	Ore di Volo	Missioni
dal 24.08.16	11917:13	40984
Anno 2017	334:11	1376
Anno 2018	1046:37	4248
Anno 2019	910:33	3721
Anno 2020	980:00	3670
Anno 2021	1595:21	5564
Anno 2022	2175:00	6838
Anno 2023	2437:36	7661
Dal 01.01.24	2164:17	6769

Dati estratti dal Log Voli dei Piloti e della Flotta UAS del CNVVF (agg. 23.10.24)

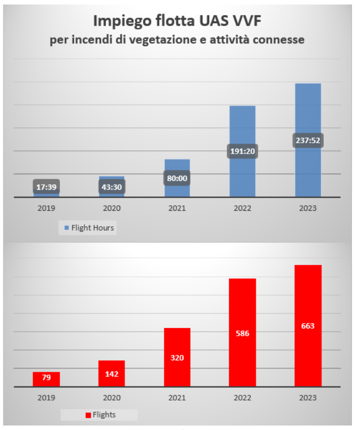


***Table 2**: UAS Team flights and flight hours in rescue scenarios and wildfire events since 2016.*

Indeed, since the establishment of the UAS Team of the CNNVF thousands of flight hours and flights have been performed in the major catastrophic and dangerous events in Italy (See Table 1) and in rescue operations or wildfire monitoring (See Table 2).

2.1 - The CNVVF UAS Team fleet

The Italian Fire Department's drone fleet consists of fixed-wing drones (primarily used for large area mapping) and multirotor drones of various sizes. The fleet includes small drones with a Maximum Take Off Mass (MTOM) of up to 2 kg equipped with EO/IR payloads (up to 20MP/640x512) for local inspections, and larger drones (MTOM up to 9.2 kg) that feature different plug-and-play payloads such as EO/IR (20MP/640x512), LiDAR, photogrammetry cameras (45MP), night vision cameras, laser telemeters up to 1000 meters, and searchlights of 10,000 lumens. These drones are ready to use and can be rapidly deployed in emergencies. However, they must be launched close to the scenario, and the operational time is affected by the distance between the base and the emergency location.

3 - IMSI Catcher

The main feature of IMSI Catcher systems is the ability to capture signals from mobile phones, even in the absence of network coverage, turning mobile devices into localization ``beacon''. The key technologies are the IMSI Catcher, which transforms phones into beacons to pinpoint the location of missing persons, is the IMSI Catcher that capture mobile signals, aiding in SAR efforts without network coverage.

These technologies are applied not only in traditional rescue scenarios in mountainous or urban areas affected by disasters but also in environments where communication infrastructures are compromised. The IMSI Catcher system, allows precise localization of a mobile phone even in areas without a cell signal. This is a critical aspect in SAR operations where time is of the essence to ensure the survival of those in danger.

3.1 - Technical features and operating principles

The system has two main components. The first one is the sensor, as the one in Fig. 1b, equipped on the UA. This sensor is capable of capturing different type of signals, ranging from 2G to 4G technology, thus GSM, UMTS and LTE. This recent sensor also is capable of capturing 5G signals but only of NSA type (Non Stand Alone). The sensor also identifies phones thanks to their IMSI or IMEI code, a unique identifier of the phone company or the phone itself. The other fundamental component is the control console, from where the operator can monitor all the activity of the sensor and the geographical information of the mission.

This system is thus capable of performing four operations: detect the signal of the phone, identify through the IMSI the specific device, establish a connection and communicate with it, and consequently geolocate the position of the phone with a standard geographical trilateration procedure. All these operations can be carried out without the collaboration of the owner of the phone, without any particular software or app on the device, keeping the level of battery up and without any help of other network operators. The only requirement is that the phone to be searched must be turned on.

Depending on the technology of the signal, the accuracy of the position ranges from around 550m with a 2G to a approximately 80m with a 4G. Moreover, an optimum average height of flight is of about 80-100m above ground allowing a quite precise localization of the phone in rescue operations.

3.2 - Concept of the Operations

Here we describe the main functioning of the IMSI Catcher system. First, when a request for the UAS team is received the UAS team is sent to the scenario and usually operations for missing person start from the last lookout point. Then, the drones are deployed equipped with the IMSI Catcher and some overflights trying to detect the phone cell by scanning the radio spectrum in order to find ARFCN channels used by phone operators in that area. Then the system evaluates the best configuration to catch the searched phone, which means that it searches for the best channels where to transmit and detect the identity of the phone by means of a standard protocol. In this phase it is important to perform a wide flight over the searching area concentrating efforts where the air space is free of obstacles, in order to catch as much signals as possible. Following, if the signal is detected the phone ask for connection to the IMSI Catcher. Once the mobile phone is connected, the geolocation process starts, according to the logic of trilateration (See Fig. 2a).

We may then point out some important considerations about the operation above described. First, the Line of Sight (LOS) is necessary for radio communication in 2G, 3G and 4G. If there a big obstacle between the receiver and the transmitter the signal is very attenuated whereas there is a medium attenuation in case of fog, rain, or wooded areas. Also, if the phone is on the ground floor, as in the case of a person who is sleeping or is fainted, instead of being, for instance, in the pocket of the person it is subject to more attenuation but when large rocks, mountains, or cliffs obstruct the seeker and the phone signal, the communication is completely lost.

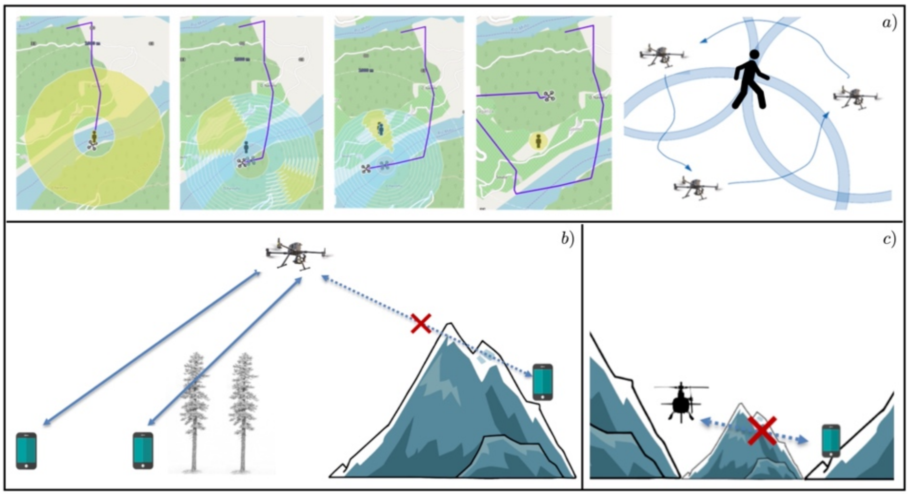


***Figure 2**: a) Concept of Operation. Identification of the area and trilateration of the signal. b) Signal loss due to obstacles. c) Height of flight too low.*

During flight there are also some important consideration to be outlined. If the flight is too high the signals will hit ground with low power and the cell phone to be searched will not be able to connect to the IMSI Catcher. On the other hand, if the flight is too low, there is the possibility of losing the line of sight due to obstacles and the previous problems may occur.

Some difficulties arise also in densely populated areas. Indeed, the system is designed to perform accurate selection. In rugged environments, for which it was originally developed, its operation is particularly effective due to the limited number of detectable devices. However, in urban setting where thousands of phones may be present, there are many base transceiver stations (BTS), and phones are close to them with a high quality of signal. Thus, the BTS have usually high priority in intercepting the signal making difficult the competition with the IMSI Catcher system that faces a greater challenge in identifying the target device among a larger number of phones. Consequently, the probability of finding a phone in such an area is much lower.

To this point a correct planning of the operations is fundamental. Indeed, it has been proved that coordination with the TAS team, employed to provide geographical analysis of the scenario and possible paths/obstacles, cooperation with telephone operators and a fast, targeted response in terms of flight task may lead to a quicker resolution of the operation and the finding of the missing person. This technology is based on the principle that when a phone attempts to connect to the network, the network responds by granting access and assigning a time slot. It is essential to maintain synchronization with this slot otherwise, if the assigned timing is lost, communication is interrupted. This process is governed by a standard protocol known as Timing Advance, which is implemented across all mobile networks to help maintain synchronization.

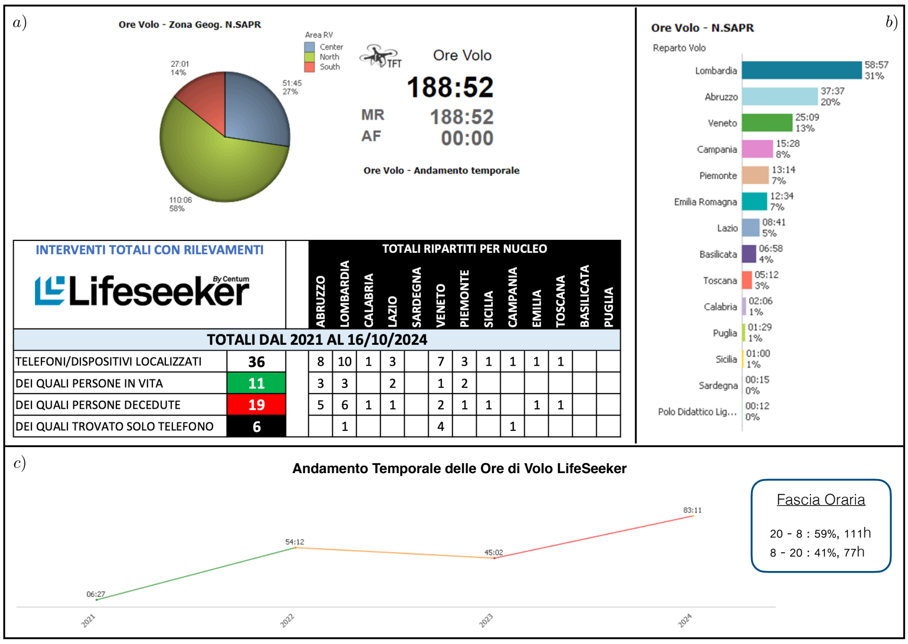
The process of triangulation is based on measuring the distance from three or more reference points-specifically, the location of the drone and the estimated position of the mobile phone signal. By calculating the distance from multiple drones or signal detection points, the system can accurately pinpoint the position of a missing person. In practical terms, the drone emits a signal that the mobile phone picks up. The phone then responds, allowing the drone to measure the time it takes for the signal to travel to the device and back. This time measurement is crucial for calculating the distance, which can be used to create a triangulation model.

Once the distances to at least three drones are calculated, the system applies trilateration techniques to determine the exact coordinates of the mobile phone. This is accomplished by solving a system of equations based on the distances calculated from each drone, allowing for an accurate determination of the user's location. Thus, the first phase focuses on identifying the phone. After the device has been located, the second phase, dedicated to geolocation, is activated. Using 4G technology, it is possible to narrow down the target area to a confidence radius of approximately 60 meters in less than one minute. This process facilitates the delineation of an increasingly confined area until a precise circle is established. The coordinates of the center of this area serve as the initial reference point. However, the target may be located anywhere within the defined boundaries.

4 - Statistics of the operations

Since the introduction of the first IMSI Catcher system in 2021 many operations have been performed in different scenarios. Mainly, this system is applied to search and find the phone of a missing person but the event, the environment, and the context of the cause of the disappearance can be of different nature. In
Fig. 3 we can see the main statistics of the operation with IMSI Catcher since their introduction in the fleet of the UAS Team.

From data, we can see that the regions Lombardia, Abruzzo and Veneto have the most flight hours performed. Even if it is true that these regions have the greatest number of instruments (See Fig. 3a), this is out of necessity. Indeed, due to the large geographical areas and the presence of mountains and woods, an increased number of disappearances of people has been detected. This can be addressed mainly to the trekking and trail activity, too often practiced by not prepared or trained people. Also, other research for missing persons are dictated by people of lost themselves in the woods during activities such as mushroom picking or hunting. Another important data is that the findings through IMSI Catcher system are for about 60% during night hours. This is a crucial data addressing that the quick activation of this instrument is of paramount importance in the first hours of the research, where land teams can have difficulties due to the night and is support in the research.



INTERVENTI TOTALI CON RILEVAMENTI — Lifeseeker By Centum — TOTALI RIPARTITI PER NUCLEO

TOTALI DAL 2021 AL 16/10/2024		ABRUZZO	LOMBARDIA	CALABRIA	LAZIO	SARDEGNA	VENETO	PIEMONTE	SICILIA	CAMPANIA	EMILIA	TOSCANA	BASILICATA	PUGLIA
TELEFONI/DISPOSITIVI LOCALIZZATI	36	8	10	1	3		7	3	1	1	1	1		
DEI QUALI PERSONE IN VITA	11	3	3		2		1	2						
DEI QUALI PERSONE DECEDUTE	19	5	6	1	1		2	1	1		1	1		
DEI QUALI TROVATO SOLO TELEFONO	6		1				4			1				

***Figure** 3: a) Number of flight hours divided for geographical area. Statistics of the missing persons found alive, dead or only their phone. b) Flight hours divided per region. c) Flight hours divided per years and time.*

5 - Conclusions and open challenges

In conclusion, the integration of UAS technologies such as the IMSI Catcher system significantly enhances the capabilities of public safety operations, particularly in search and rescue (SAR) missions. The ability to localize mobile phones in remote or signal-deprived areas offers a critical advantage in life-saving operations. Moreover, the flexibility and speed of deployment of drones make them invaluable tools in scenarios where time is of the essence, such as natural disasters or large-scale emergencies. The technical innovations in drone payloads, from LiDAR to night-vision cameras, ensure that these tools can function in diverse environmental conditions and provide real-time, actionable data to operators.

However, challenges remain in optimizing drone operations, particularly in urban areas where signal interference is high, or where geographical obstacles like mountains and dense forests impede radio communication. In critical air safety scenarios, it would be useful to install a radar system to enhance separation from ground obstacles. Additionally, a software approach can be employed to manage this separation by integrating elevation data (DEM) relevant to the flight area into the flight plan. By utilizing DEMs, the drone can automatically adjust its altitude to follow the terrain profile. Consequently, once the mission is set and the DEMs are uploaded, the system can alert the pilot if the drone approaches too closely to the obstacles, ensuring continuous monitoring of the situation.

Further advancements in algorithmic coordination, machine learning for object recognition, and signal processing will be crucial to overcoming these hurdles. The continued evolution of UAS systems and their integration with public safety services is expected to reduce response times, increase the accuracy of SAR missions, and ultimately save more lives.

Main International and National Regulation

- ICAO Chicago convention - Art. 8, Unmanned Aircrafts
- EASA Regulation (UE) 1139/2018
- EASA Regulation (UE) 947/2019
- EASA Regulation (UE) 945/2019
- D.Lgs. 151/2006 - Codice della Navigazione, Art. 743, Art. 744, Art. 748

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