DEVELOPMENT OF SYSTEM FOR REGISTRATION AND MONITORING OF UAVS USING 5G CELLULAR NETWORKS

[1,2]Roman Odarchenko[0000-0002-7130-1375], [1]Yaroslav Horban,[0000-0002-5880-5800] [3]Oleksandr Volkov[0000-0002-5418-6723], [3]Mykola Komar[0000-0001-9194-2850], [3]Dmytro Voloshenyuk[]0000-0003-3793-7801

[1]National aviation university, Kyiv, Ukraine, odarchenko.r.s@bundleslab.com

[2]Bundleslab KFT, Budapest, Hungary

[3]International Research and Training Center for Information Technologies and Systems of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

Abstract. The uncontrolled distribution and usage of unmanned aerial vehicles (UAVs) in the world, in combination with the risks associated with aircraft, other property, people's lives, privacy, violation of secure territories, and overall security, require the creation of a UAV registration and monitoring system. This work aimed to analyze the current state of the UAV registry in Ukraine, to identify the main weak points, and to develop an architecture for the UAV registration and monitoring system. The following tasks were solved to achieve the goal: analysis of the current state of the UAV registry in Ukraine; identifying the main weaknesses of UAV registration and monitoring in Ukraine and determining the directions for their solutions; development of a UAV registration and monitoring method; development of a model for the registration and monitoring of UAVs using 5G cellular networks; development of software for UAVs' registration and monitoring. As a result of the work, a system was developed that allows registering UAVs when they are turned on and monitoring the current coordinates of the UAVs which are using this system.

Introduction

Analysis of the UAVs' usage dynamics. More than 150 years have passed since the first UAV was created in 1849, but only since the beginning of World War I, the development of UAVs actively began and until the beginning of the twenty-first century, most of the UAVs were created for military purposes. The main milestones in the history of UAV development are [1, 2]:

- August 22, 1849 – the first usage of unmanned aerostat;
- 1924 – the first full-controlled flight;
- 1960 – a US reconnaissance aircraft was shot down with the capture of a pilot, which stimulated the development of UAVs;

– 1990s – the rapid development of UAVs associated with the development of global positioning system (GPS);
– 1995 – “G.A. MQ Predator” - the world’s first military “hunter-killer” aircraft without a human on board was created;
– 2014 – “X 47B” - first unmanned (remotely piloted) aircraft to launch and land on the aircraft carrier.

The dominant leader in the UAV market for the last years is the Chinese company DJI, accounting for more than 70% of the world market and more than 80% of the Ukrainian market [3]. According to recent data, the UAV market in Ukraine reached a value of $1 million per month. While in the world, the value will reach $185 billion in 2019 [4].

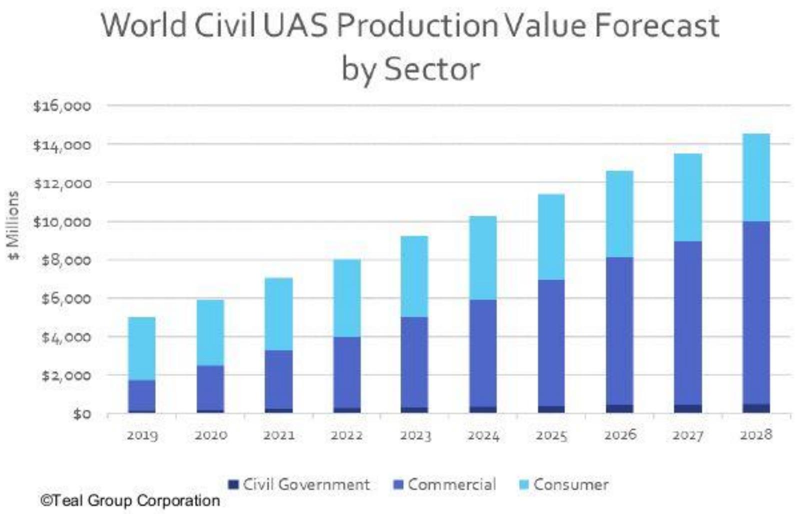


Fig. 1. UAVs world market [5]

Figure 1 shows that the Total UAVs’ market cost is increasing by about 15% every year. Analysts say that at this rate it will reach 2.8 trillion in 2030. USD.
In terms of UAVs’ diversity, Ukraine ranks 27th in the world, but most of the produced UAVs by Ukraine are rather outdated and inefficient. However, UAVs of domestic production make up only 7% of the total number of UAVs in Ukraine. Almost 90% of the total number are purchased in the USA, China, Israel, and Russia [6].
In recent years, we have seen an impressive growth in the use of Unmanned Aerial Vehicles (UAV, also commonly referred as drones) for a wide range of applications, spanning from military to commercial domains. Several successful applications of drones already available in the market include surveillance, reconnaissance, remote sensing, search and rescue, aerial photography, crop surveys, on-demand emergency communications, traffic control, monitoring natural resources like oil or gas exploration etc.

With the growing appearance of unmanned aerial vehicles (UAVs) both in business and people's daily lives one of the most important tasks that need to be addressed is to ensure the safe use of UAVs. At the same time, the introduction of promising information technologies plays a significant role.

In Ukraine, the priorities in the UAVs' development strategy include the creation of a unified registry and the direct registration of every UAV. For each of them, the information about the owner, place, date, and time of registration. In addition, the complete monitoring of UAV movements is planned, which means that all UAVs can be tracked at any point in time. For citizens, this will guarantee safety, since today the airspace of Ukraine is relatively empty, but it will gradually fill up with the development of UAVs. In-air accidents that could lead to a crash and further casualties can be prevented with the M2M (machine-to-machine) communication technology [7]. The new opportunities for the developments in this technology, which includes communication between UAVs, are provided with the usage of 5G cellular networks.

One of the key issues when organizing UAV monitoring is communication between multiple objects. The task of transmitting information as fast as possible, i.e. with minimal delay and high data transfer speed, remains as well. In order to properly support radio access technologies, widespread coverage of modern cellular networks should be created in Ukraine. Mobile communication technologies should significantly improve the quality of the basic criteria required for UAV monitoring.

Background works analysis

The ICAO Statute is the ninth edition of the Convention on International Civil Aviation (also called the Chicago Convention), which includes amendments from 1948 to 2006 [8]. According to the definition, an aircraft is any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface [2]. An unmanned aerial vehicle is a pilotless aircraft, which is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place (ground, another aircraft, space) or programmed and fully autonomous. An unmanned aircraft, piloted from a remote piloting point, is called RPA (remotely piloted aircraft) [9]. All unmanned aircraft, regardless of whether they are remotely piloted, fully autonomous, or combined, are subject to the provisions of Article 8 of the Chicago Convention relating to obtaining special authorization. According to Article 31, every aircraft engaged in international navigation shall be provided with a certificate of airworthiness issued or rendered valid by the state's authority in which it is registered [10]. The system consisting of UAVs and a control system on the surface of the earth is called RPAS (remotely piloted aircraft system), while it does not have to be self-sufficient. According to ICAO documents, of the components included in the RPAS, only the RPA is recorded in the aircraft register [11].

UAVs present a wide range of dangers for the civil aviation system [12]. These dangers must be identified and mitigated for safety risks [11, 42], as well as the introduction of airspace redesign, new equipment or procedures must be done. To achieve this, all countries, which are members of ICAO, must implement the relevant laws. Permission to use the airspace of European countries and the conditions for its use are granted by a joint civil-military air traffic management system based on an application for the use of airspace, except cases provided by the Air Codes. Regarding the Ukraine, currently, Ukraine as well does not have a registry created specifically for UAVs, that is, the use of UAVs is not defined by in the Air Code of Ukraine law [14]. That is why it is very necessary first to define the best rules for UAV registration and monitoring and afterwards development of novel architecture solutions for doing this.

Among various enabling technologies for UAV registration and monitoring, wireless communication is essential and has drawn significantly growing attention in recent years [15, 43]. Indeed, the standardization bodies are currently exploring possibilities for serving commercial UAVs with cellular networks. Industries are beginning to trial early prototypes of flying base stations or user equipment, while academia is in full swing researching mathematical and algorithmic solutions to address interesting new problems arising from flying nodes in cellular networks [16]. In [16] was provided a comprehensive survey of all of these developments promoting smooth integration of UAVs into cellular networks. Also, a large number of scientific works were devoted to the analysis of wireless technologies, new opportunities and challenges of these technologies if use them for drone communications [17 – 19], enhancements for LTE networks to support aerial vehicles [20, 21] and other open issues [22].

Thus, in order to optimize existing and build new 4G and 5G networks for drone communications to support remote registration and monitoring process, it is necessary to develop methods that will improve the performance of cellular communication networks so that they can meet a number of criteria in modern urban area: ensure the introduction of new mobile systems and support existing (saving of investments, that were made); meet the requirements of next-generation network architectures; have effective traffic management and quality assurance tools; provide convenient means for maintenance and operation. Therefore, to properly support new broadband radio access technologies in today's 5G cellular networks, the efficiency of data transmission should be improved while reducing the cost of delivering each megabyte of traffic and providing the quality of service (QoS) required by each type of traffic. In addition, new, more sophisticated network architectures for data transmission and management are emerging with the development of cellular networks. However, there are a number of unresolved tasks and issues that need to be addressed and resolved accordingly.

Research objectives statement

This chapter should analyze 5G network architectures for different UAV usage use cases. A gap analysis should be performed to evaluate which requirements are not met by other wireless technologies. After this will be developed the 5G network architecture for

Thus, the **object** of research is the process of registration and monitoring of unmanned aerial vehicles using cellular networks. The **subject** of research is the methods, architecture design and technologies for recording and monitoring unmanned aerial vehicles using 5G cellular networks. The **goal** of the work is to ensure the registration and monitoring of unmanned aerial vehicles. The following **scientific tasks** were solved to achieve this goal:

1. The current state of UAVs' usage regulation in European countries and in Ukraine is analyzed.
2. 5G network architecture for UAV registration and monitoring was developed.
3. A model for tracking UAV movements was developed.
4. Network-centric method for UAV registration and monitoring was developed.
5. Procedures for the registration and monitoring of UAVs were developed.

Research of cellular networks' characteristics to provide registration and continuous monitoring of UAVs

To ensure the communication needs of the UAV different cellular networks can be used in separate or even parallel way (multilink solution [23, 24]) (Fig. 2). Cellular networks can act as a control and/or data transmission channel between the drone and the operator or between drones (UAV networks). In this case, the "range" of the control channel is limited only by the cellular network's area of coverage in the city or country. After losing the network connection, the drone can return to the coverage area independently and choose a different route.

Moreover, the modern generation of cellular communication networks can provide most of the UAV needs [18]. Table 1 compares the data transfer rates of modern cellular communication networks generations.

Table 1. Comparison of cellular communication networks

Technology	Data transfer speed
1G	2.4 kbit/s
2G	63 kbit/s
3G	144 kbit/s - 2 Mbit/s
4G	100 Mbit/s - 1 Gbit/s
5G	1 Gbit/s – 35 Gbit/s

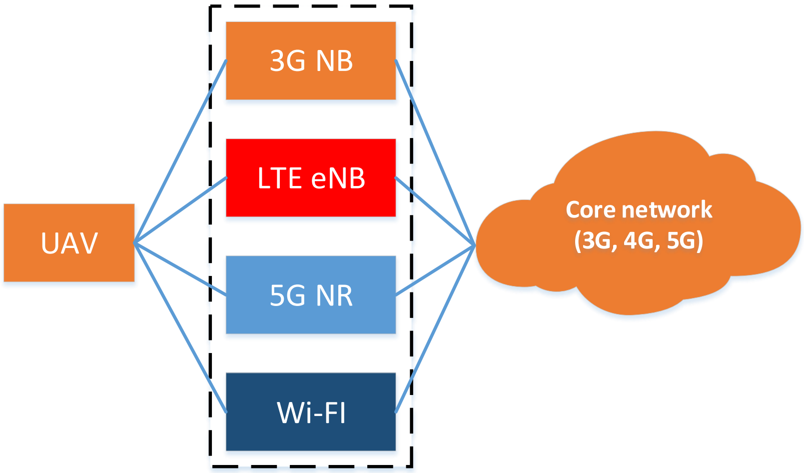


Fig. 2. Wireless networks for UAV communications

5G technology is more suited to provide drone communications because it has low power consumption, which is especially important for long UAV flights. The advantages of using this technology include the high range of the radio signal, up to 30 km in the open field and up to 8 km in the city. The unique bandwidth of the radio signal, which provides stable communication in difficult to reach areas, should be noted. The usage of this technology is most appropriate in this case.

During 2020 the final 5G standards will be set. In August 2019, more than 1 million people used 5G networks in South Korea [25]. 5G is evolutionary not only in data transfer rate but also in other important requirements. One of the main advantages is the delay time reduction from 5 ms to 1 ms. Reducing the delay to such a short time increases the possibility to develop new projects, such as [26, 27].

Along with this, 5G networks will use Massive MIMO technology – communication system with separate transmit and receive antennas [28]. Their use will allow spatial and temporal processing of signals, more efficient use of the power emitted by the transmitter, and reducing the interferences' negative impact. As a result, the number of antennas will be increased to 8-16 compared to conventional communication systems using single-element antennas.

Furthermore, 5G networks will support D2D (device-to-device) technology [29]. Device-to-device technology allows devices that are close to each other to communicate directly without the involvement of a 5G network. Only signaling traffic will pass through the core of the cellular network. The advantage of this technology is the ability to transfer data in the unlicensed part of the spectrum, which will further offload the network.

All these characteristics make it possible to create new original projects and appliances. One of them is the communication system for UAVs. 5G will allow unmanned aerial vehicles to operate at a qualitatively new level. 5G will allow UAVs to exchange data almost instantly, which will greatly assist in resolving airspace issues.

Development of UAV communication architecture using 5G networks

Today, one of the most important problems is the shortage of the radio frequency spectrum of the wireless networks supported by UAVs. This problem is affected by the factors, such as a large number and increasing usage of portable mobile devices (e.g. smartphones and tablets), various wireless networks (Bluetooth, WiFi, LTE, and cellular networks) coexist in UAVs' operating spectrum ranges. This leads to extremely intense competition for the spectrum usage, and thus UAV communication systems face a spectrum deficit. Therefore, it is necessary to obtain a further range of access through the dynamic use of existing frequency bands for the drones' communication. So far, many researchers and members of standardization groups have presented a concept of using UAV communication systems to increase the spectral capabilities, which are called cognitive UAV communications [36]. This concept is a promising network architecture that provides communication between UAVs and ground mobile devices operating in the same frequency band. In this case, UAV communications can cause strong interference with existing ground devices, since UAVs are usually located on LOS with ground users. Several articles could be found in the literature that studied the UAV cognitive communication system [36 - 38]. Joint optimization of the UAV trajectory and power transfer was performed to achieve the maximum impulse throughput of cognitive UAV communication, while simultaneously limiting the obstacles placed on the primary receivers below the acceptable level [36]. Recently, a method for distributing the contracting spectrum between an unmanned network cell and a traditional terrestrial cellular network with various scenarios was introduced, i.e., dividing the spectrum of single-tier unmanned cells in a 3D network and distributing the spectrum between an unmanned network cell and a traditional 2D cellular network. Using stochastic geometry, they obtained explicit expressions for the probability of drone cells' coverage and achieved the optimal density of UAVs to maximize throughput.

One of the main role in cognitive UAV networks belongs to 5G cellular networks. They are expected to be the foundation of the next generation UAV networks.

The first 3GPP release of 5G technology (Release 15) [30], also known as 5G NR (New Radio), was completed in 2018. Was introduced 5G NR to enhance the user plane performance and efficiency using dual connectivity across the LTE and NR bands [31]. During the second-half of 2018, the standalone (SA) version of 5G was

standardized, including the 5G core network (5GC), that enables deployments without any LTE infrastructure [32]. The 5G NR SA deployment can be also in combination with LTE but using only 5G NR for the user plane as in the early drop. The last drop of Release 15 specification was at the end of 2018, and it enables more architecture options for hybrid LTE and 5G NR deployments using the 5GC [31].
5G NR [33] should be used as a basis for UAV communications, and it has been acknowledged that diverse use cases from media, IoT, V2X and public safety should be considered when designing the architecture solution [31]. The subtask vision is to incorporate point-to-point, point-to-multipoint, multilink capabilities in 5G under one common framework and enabling dynamic use of different modes and network slices to maximize network and spectrum efficiency for more safe, reliable and cheaper UAV communications, registration and monitoring.
This section introduces the integrated space-air-to-ground network architecture in future 5G wireless communications (Fig. 3).

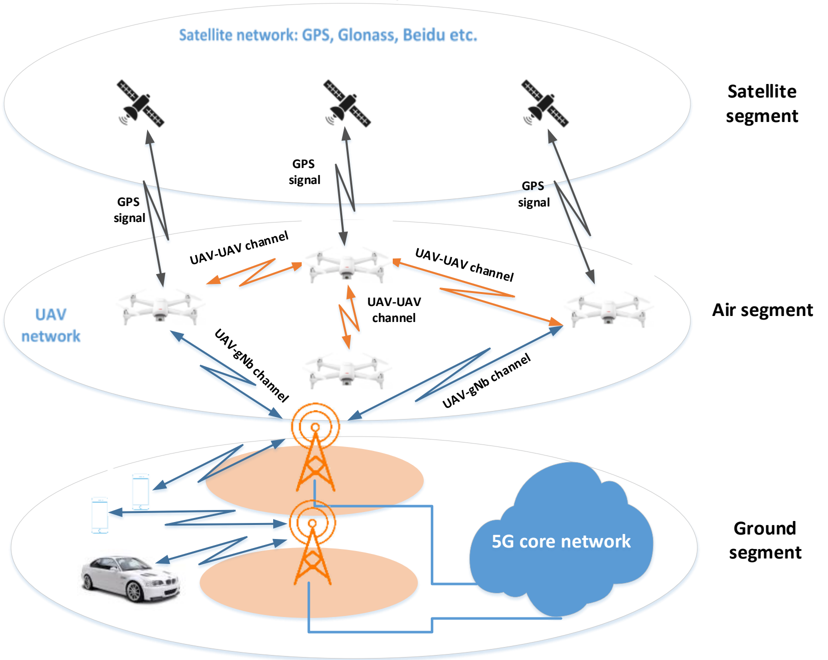


Fig. 3. Architecture of 5G networks

For example, densely deployed terrestrial networks in urban areas will be able to maintain access to high-speed data transmission, satellite communications systems can provide wide coverage and stable unhindered connection with the most remote and sparsely populated areas, while UAV communication can help existing cellular networks effectively manage very crowded areas. Currently, it is widely believed that an individually existing network cannot satisfy the need to process huge amounts of data and execute complex programs such as IoT (Internet of Things) applications. Therefore, there is a growing demand among scientific communities for the development of an integrated network architecture for space, air, and ground networks [34].

Such architecture will emphasize the need for communication between all devices that belong to the same category. In addition, the connection between satellite and UAVs is a key component in the formation of an integrated space-air-to-ground network. That is, for the regulation of airspace is necessary a high-quality data transmission [35].

For the architecture (Fig. 3) common IP packet format for UAV registration and monitoring system can be presented as follows:

IP header	UAV Serial number	Current coordinates of the UAV	Additional information

Each such packet has to consist of the information regarding the UAV identification number (ID) in the registry. It can be i.e. UAV serial number, which is given by the certified manufacturer in accordance with the state rules. Also, current coordinates of the UAV have to be transmitted in such packets. Additional information may carry special commands, requests etc. and the different types of additional payload have to be agreed on the layer of state regulatory bodies in the field of aviation.

Registration and monitoring system should build upon the 3GPP 5G network architecture [30]. This 5G network architecture should provide some key principles and concepts as follows [31]:

- Separate the User Plane (UP) functions from the Control Plane (CP) functions, allowing independent scalability, evolution and flexible deployments, for e.g. centralized location or distributed (remote) location of remote registration and monitoring system.
- Modularize the function design.
- Wherever applicable, define procedures (i.e. the set of interactions between network functions) as services, so that their re-use is possible.
- Enable each Network Function to interact with other NF directly if required.
- Support a unified authentication framework.
- Support concurrent access to local and centralized services. To support low latency services and access to local data networks, UP functions can be deployed close to the Access Network.
- The main design principles for the novel architecture are aligned with 3GPP direction.

The 5G system architecture for remote UAV registration and monitoring system is shown in Figure 4. Figure 4 shows how UAVs data IP packets will be transferred using 5G network architecture.

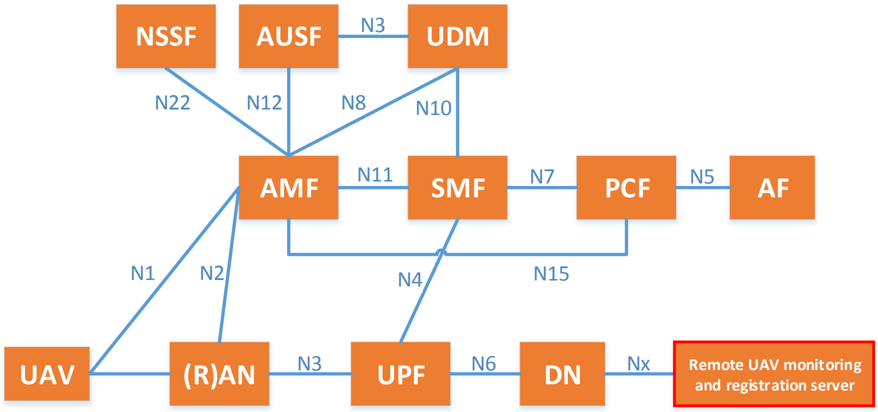


Fig. 4. 5G network architecture for UAV remote registration and monitoring

In this architecture functionality as it exists is concentrated in "Remote UAV monitoring and registration server" (RUMRS). The RUMRS is placed between the external users or regulatory bodies and the DN so the RUMRS would contain specific functionality for the user plane:

- registration of the UAV in 5G network;
- real-time monitoring of the current coordinates of UAV;
- restricted area approach tracking;
- emergency messaging to the UAV users/owners and regulatory bodies.

Control of the registration and monitoring session is performed by the RUMRS. Session control (Start, Update and Stop) messages are sent (via the service-based interface) to the AMF through the SMF which distributes them (over the N2 reference point) to the (R)AN.
The user plane session is managed by the SMF and the N4 reference point.

Development of network-centric method for UAV registration and monitoring

Countering the occurrence and elimination of the consequences of violations using UAVs includes:

- continuous computer monitoring of potentially dangerous locations and objects to determine the necessary measures to eliminate the consequences of each type of possible violations;
- the implementation of the necessary measures to prepare to deal with the consequences of possible violations;

- the implementation of a quick response to violations involving UAVs and the interaction of all used resources;
- organizing a possible set of parallel operational measures, dispatching, synchronizing and maneuvering resources in the dynamics of control [9].

In a broad sense, monitoring is understood as the systematic accumulation and processing of data on the state and dynamics of changes in the parameters of the object or process under consideration and the presentation of the results in a form convenient for the manager or expert [39, 45]. In dynamics, this is the collection and analysis of data on losses from violations. The monitoring system (Fig. 5) combines the monitoring tools of all levels and areas of management into a single whole.

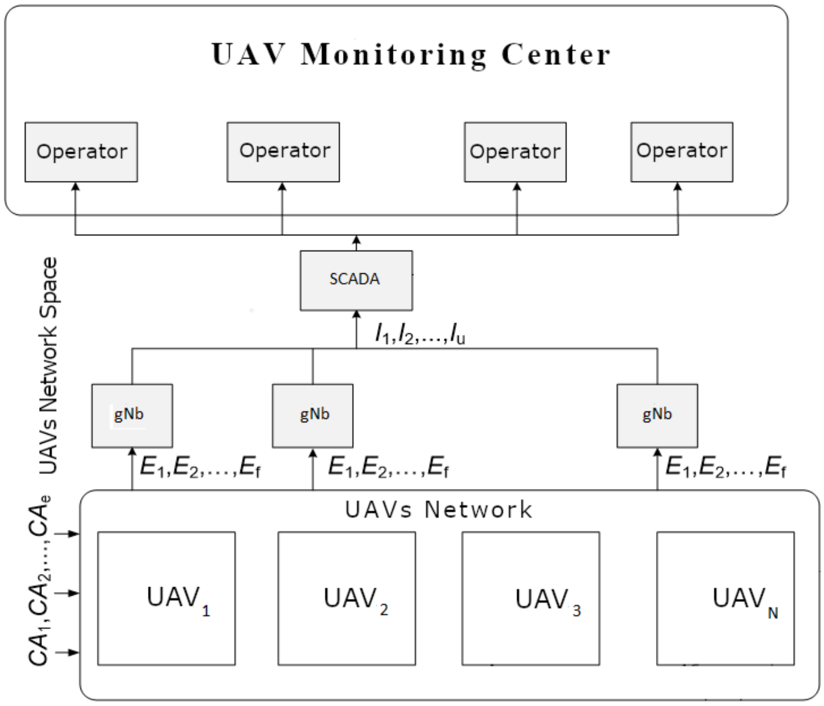


Fig. 5. Implementation of network-centric monitoring in the cellular network

The system must ensure delivery of all necessary information to the recipients in real-time or close to it as it is received and, very importantly, using the information for all levels and directions of management [46].
The following sequence of actions must be observed while operating such monitoring centers:

1. A certain security violation $E_1 \dots E_f$ occurs in the UAV network. It can be caused accidentally, or be a consequence, for example, of a certain type of terrorist attack $CA_1 \dots CA_e$.
2. Data on the security events are transmitted to specialized dedicated network sensors gNb. Each sensor can only be connected to a separate group of network devices.
3. Sensors compare the received information with the corresponding patterns, conditions, and flight zones. After that, the data on the occurred terrorist attacks $\mathrm{I}_1 \dots \mathrm{I}_\mathrm{u}$ is transmitted to SCADA (Supervisory Control And Data Acquisition).
4. Based on a set of rules for responding to terrorist attacks, SCADA decides how to respond.
5. After the violation is eliminated, SCADA exchanges information with operators and the SCADA system between operators.

Based on the above concept, the network-centric monitoring and response to violations in the UAV network are functioning as shown in Fig. 6.

The first step of the algorithm is to collect data from the network about the occurring violations from the set $E_1 \dots E_f$, caused by $CA_1 \dots CA_e$ – both intentional and unintentional actions – transmitted to the gNb sensors. Further, these violations $I_1 \dots I_u$ are identified by a specific set of their parameters through comparison with the corresponding patterns. This determines the type of known violation, or is identified as "not yet known."

After this, the identification of objects $O = \{\bigcup_{ac=1}^{ad} O_{ac}\} = \{O_1, O_2, \dots O_{ad}\}, (ac = \overline{1, ad})$ that are exposed to the violation takes place in parallel, and a set of extrapolation rules $R = \{\bigcup_{ab=1}^{ag} R_{ab}\} = \{R_1, R_2, \dots R_{ag}\}, (ab = \overline{1, ag})$ is formed that allows assessing the potential impact of the violation.

Determining the degree of violations' influence is carried out according to the formula:

$$IL_{bd} = \frac{Q_{bc}}{\sum_{bi=1}^{bc} Q_{bc}}, bi = \overline{1, bc},$$

where the assessment of comparative significance can be calculated by the formula:

$$Q_{bc} = \sum_{bi=1}^{bc} a_{bi}, x_{bibj}, bi = \overline{1, bc},$$

where x_{bibj} is the value of the bi-th criterion of the bj-th type of violation; a_{bi} is the "weight" of the bi-th criterion.

Violations response occurs according to the rules from the set $R = \{\bigcup_{i=1}^{n} R_i\} = \{R_1, R_2, \dots R_n\}$, followed by checking if the consequences of the violation have been eliminated. After a successful response, corresponding data on it is saved and a set $I = \{\bigcup_{ia=1}^{na} I_{ia}\} = \{I_1, I_2, \dots I_{na}\}$ is generated describing those violations. Data is transmitted and processed in the 5G radio interface secure unloading method and the reservation of network resources and load balancing methods. The requirements of the local and country laws must be taken into account.

Basing on the proposed algorithm it is possible to provide an implementation of the UAV monitoring and registration center to the network architecture (Figure 7).

In Fig. **7** the multi-access edge computing (MEC) was used as an additional functionality to provide closer access to the remote registration and monitoring services. MEC paradigm aims to explore the potential that could be achieved through the

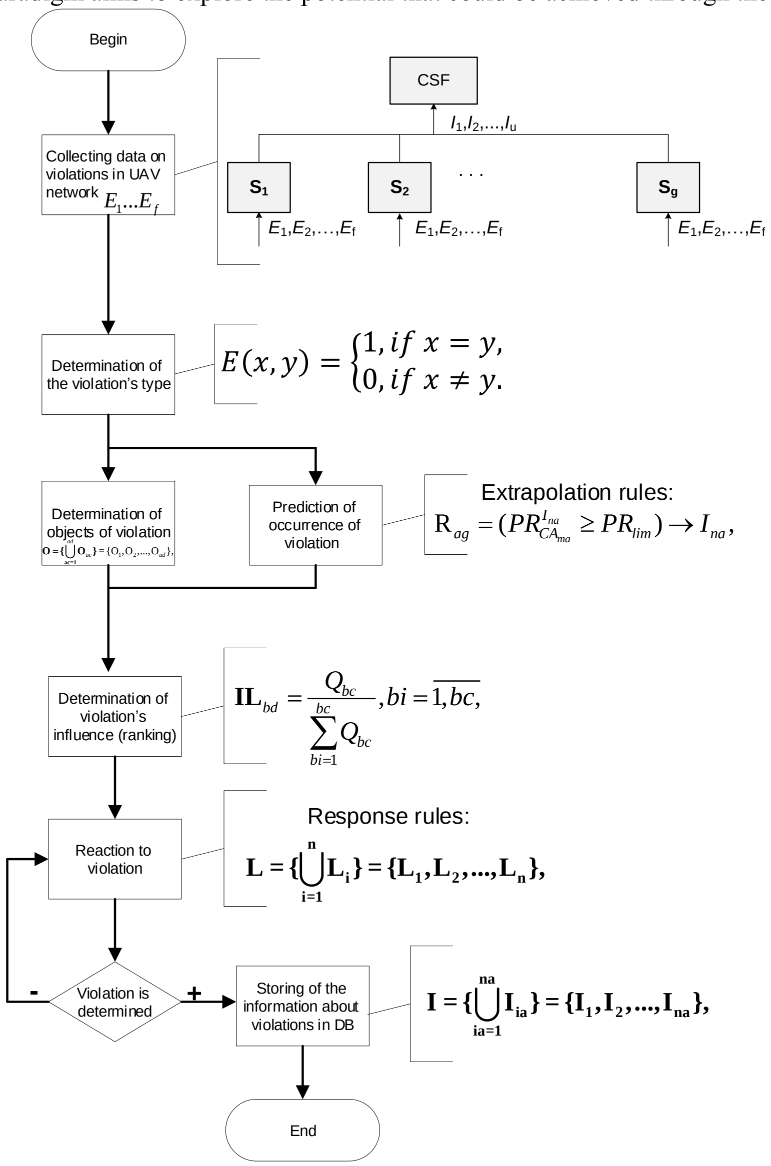


Fig. 6. Algorithm of the monitoring and response method

convergence of diverse fields such as communication and information technology (IT) [31, 42]. Such a convergence would help to the development of new applications for remote monitoring and registration enabled by the provisioning of cloud computing at the edge of the fixed and/or wireless access network. The overall mobile edge computing framework presented in [40], adapted to RUMRS is as shown in **Ошибка! Источник ссылки не найден.**. MEC could play a key role in hosting the low-latency UAV monitoring applications which could then be delivered to the UAVs using mobile access networks. The caching of frequently fetched content at the edge can enable MNOs to significantly optimize the transport network load, thereby minimizing deployment costs [31, 47].

One possible application of MEC from a RUMRS perspective, is as shown in **Ошибка! Источник ссылки не найден.**, where the remote UAV monitoring application and related high-capacity, low-latency content is hosted. The low-latency constraints for mentioned above traffic requires the content to be hosted closer to the access network, with possible dynamic update.

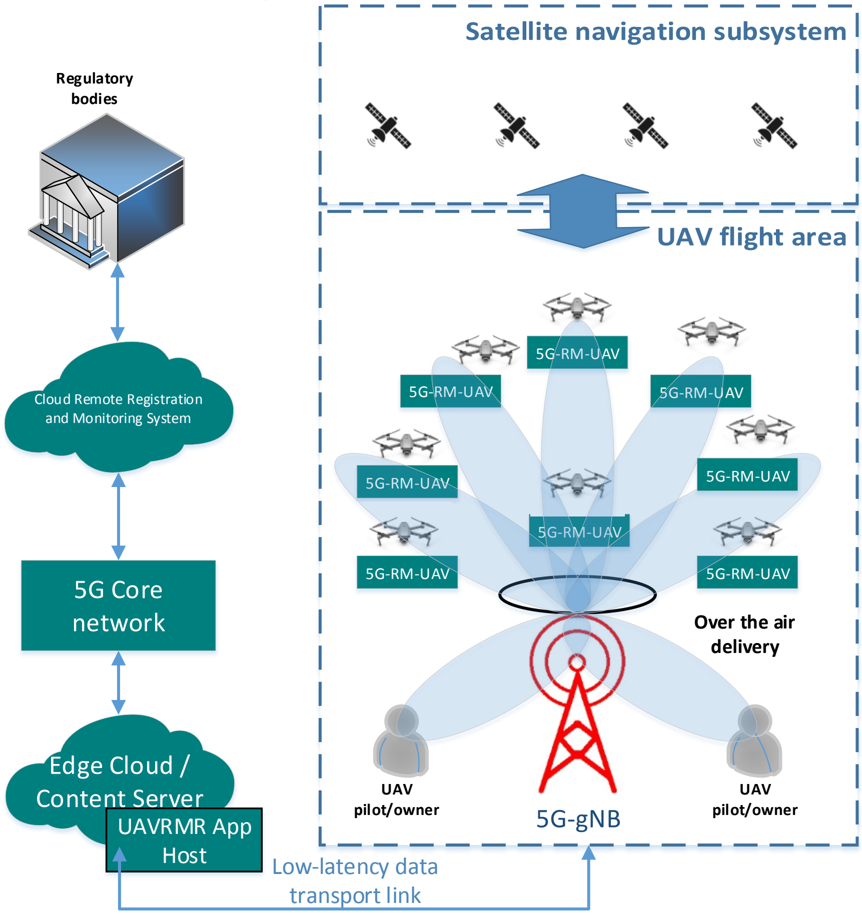


Fig. 7. Implementation of the UAV monitoring and registration center to the network architecture

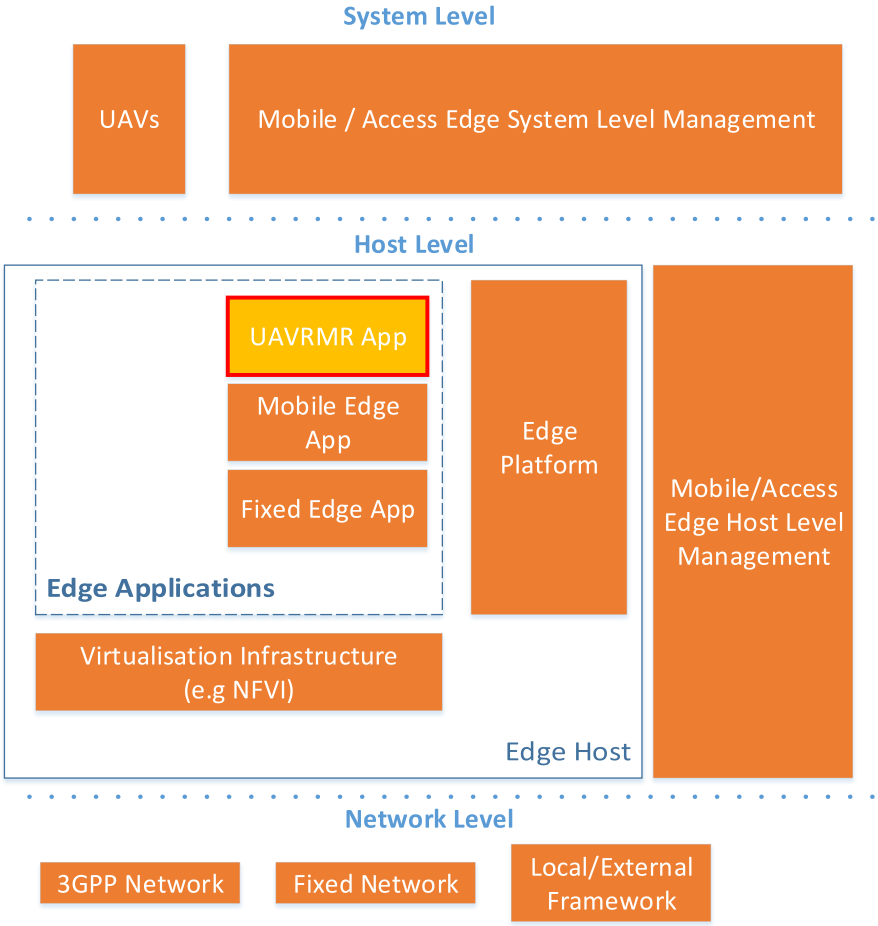


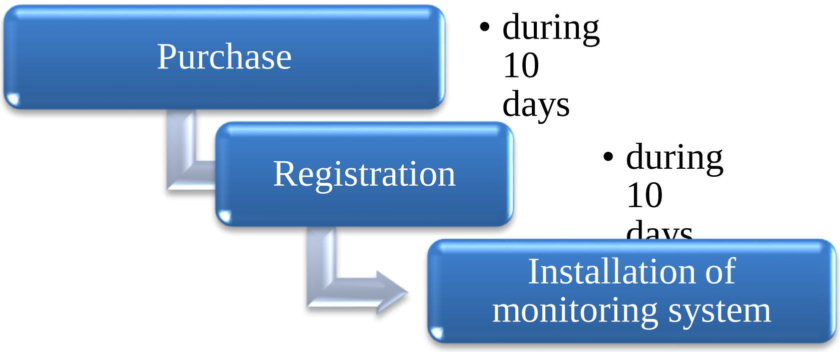
Fig. 8. MEC Architecture for RUMRS

UAVs' on-board registration and monitoring system architecture

After analyzing modern registration models of unmanned aerial vehicles in the world [3, 5, 41], there were made several conclusions. Thus, in many developed countries: China, Japan, Austria, Russia, UAVs' regulations are too strict and do not provide sufficient opportunity for the development of this area in the future.

From our point of view, the United States is an excellent example of the right policy with UAVs, which stimulates interest and development.
There are a lot of differences for different states on the moment of registration itself. Registration should be carried out directly with the purchase, that is, full control over the UAV market in the country. It is better, because everything is simple since when buying we can use it (so far no one sees it). However, when the registration takes place at the time of purchase, it is possible to establish the identity of the pilot. Along with this, another important issue of the time allotted for UAV registration disappears. The greater convenience and effectiveness of this system (Fig. 9a) compared to the existing one (Fig. 9b). This greatly facilitates the process of purchasing a UAV. Along with this, it will reduce the number of violations due to late registration.

(a)



(b)

Fig. 9. UAV registration and monitoring process (a- proposed procedures, b - existing procedures)

The UAV's registration and monitoring system usually is a small device that is attached to the UAV and connected directly to the battery, and it is polling from it (Fig. 10). Variations in which polling comes from batteries are possible.

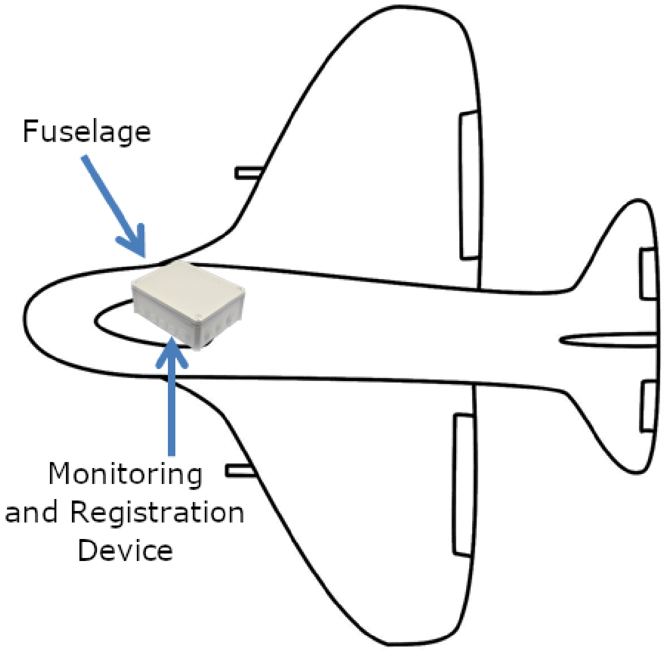


Fig. 10. Registration and monitoring system in UAV

At the first launch of the UAV, the registration and monitoring system is also started. Immediately after the first power-up, the first signal is sent to the server. This signal contains a regular UAV number and after the transmission is received by the server the number is linked to the device in the registry. The date and place of the registration are also determined at the same time. Thus, in the state register, information about the name and passport number of the owner is added to the UAV's number and model.

Physically, this concept can be implemented in the form of a Center for Monitoring and Responding to Violations (data processing center), which will receive data on the state of security, violations, etc. directly from various network nodes (Fig. 11).

Figure 12 shows the stages of signal transmission and processing according to the UAV monitoring model (Fig. 9). The UAV sends a signal that reaches the radio tower, where it immediately forwarded to the local center, and from that to the UAV monitoring center. The received signals are analyzed, reformatted, and stored in RUMRS (Fig.7).

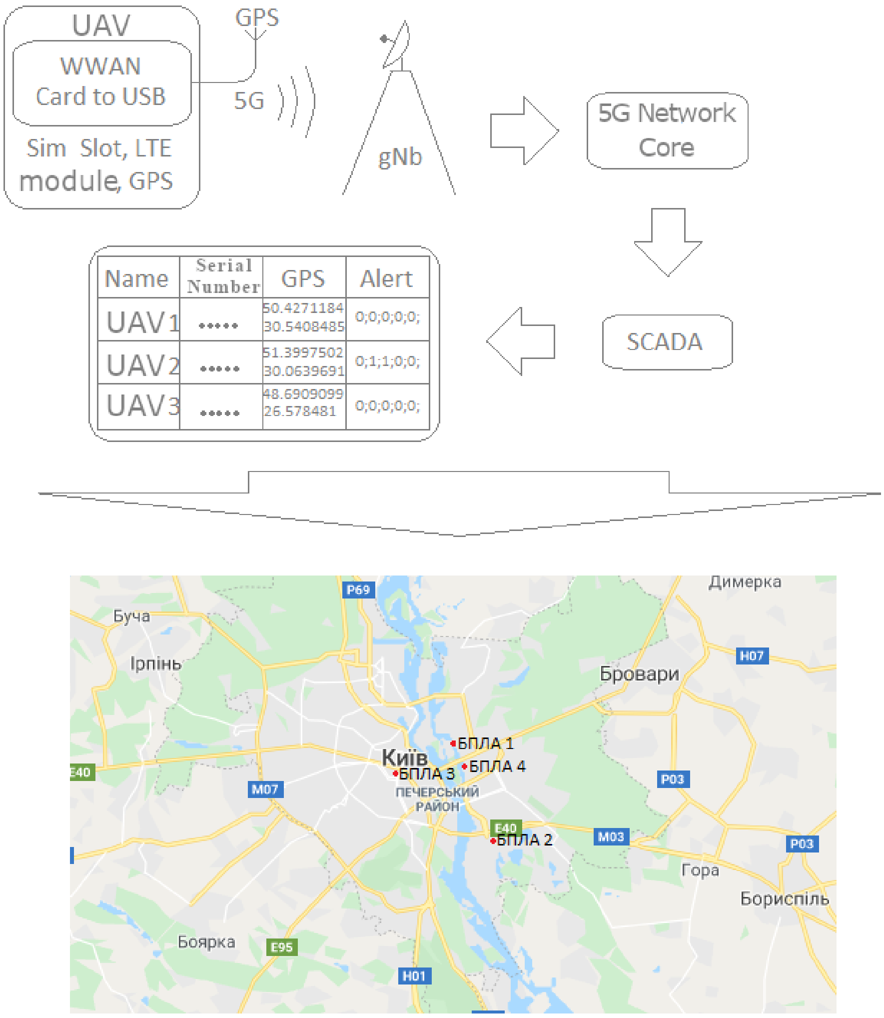


Fig. 11. Proposed model for UAVs' monitoring

Fig. 12. Signal path

The UAV's monitoring and registration system sends a signal with a frequency of 5 seconds. This interval is enough to track UAVs during the flight. In case of possible law violations, the UAV sends a normal signal, which is defined as a violation directly in the monitoring center, after which the signal is separately stored in the database. After the identification of violation, the following steps depend on the regulatory legal acts of the country/area in which the violation occurred. Possible options: penalization of the owner, UAV removal, calling the law enforcement officers.

Procedures for the registration and monitoring of UAVs

To register a UAV at purchase, a buyer must confirm its identity. After familiarization with the terms of UAVs' use in the airspace of a certain state, the drone passes the first stage of registration. The second stage occurs during the first turn-on of the drone. If a person disconnects the UAV registration and monitoring system on his own, this will cause various penalties, depending on the laws.

Since the signal is sent with a frequency of once per 5 seconds, so during a full flight, the monitoring and registration system spends 1000 times less charge than the average battery charge, that is, the monitoring and registration system reduces the flight time by 0.1%, which actually can be neglected. However, it would be more effective to have a monitoring and registration system built into the UAV directly.

This section describes how the proposed mobile core network (Fig. 4) can be enabled to provide multiple services in developed architecture. It was achieved through defining of the registration and monitoring sessions and their main call flows.

According to the above architecture (Fig. 4), it is assumed that UAV is already registered in 5G Core network.

After the UAV is coming to 5G coverage area in-built device should decide to create registration and monitoring session.

Session setup process shown on Fig. 13 is described below.

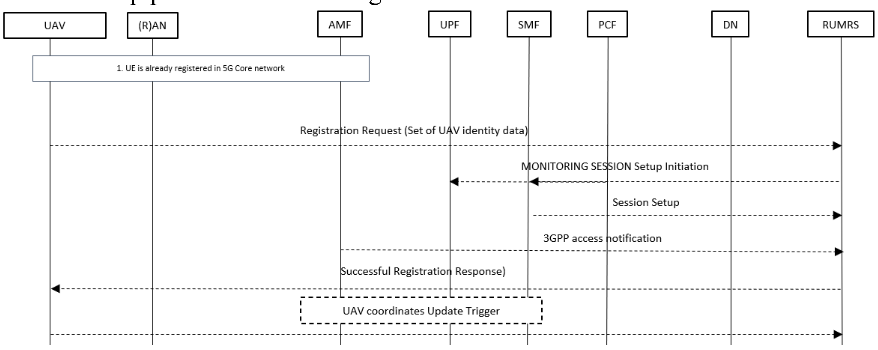


Fig. 13. Registration and monitoring session setup process

0. The UAV initiates a registration and monitoring connection (Registration Request).
1. RUMRS forwards the request to the SMF and AMF.
2. AMF forwards the request to the RAN (3GPP connection establishment).
3. AMF sends 3GPP access notification to the RUMRS.
4. RUMRS sends Session Setup Response to the UAV.
5. UAV sends UAV coordinates Update Trigger to the RUMRS.

Conclusions

The work is dedicated to solving the problem of monitoring and registration of UAVs. The regulation documents on unmanned aerial vehicles were examined and the conclusion was made that in these documents the problem of registration and tracking is at the initial stages of formation. This problem must be solved, since every year the use of UAVs is growing, i.e., drones are becoming increasingly popular among the population of the entire world. If the problem is not resolved, such aircraft can be used for criminal purposes and harm people.

To solve the problem of UAV administration, cellular networks were studied and compared. As a result, a modern 5G cellular network was chosen to develop a communication system. This network has a high data transfer rate with ultra-low latency and is the most progressive among all existing alternatives. This chapter describes in detail the main advantages and disadvantages of this technology.

A new UAV registration model was also proposed. This model can provide the highest level of safety when using UAVs.

This chapter examined the call flows within the Core Network that support the identified mechanisms. This level of evaluation and detail may be used as a solid basis for further 3GPP design and standardization in the direction of 5G usage for drones.

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