Communications and Networking Standards for UASs: The 3GPP Perspective and Research Drivers

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Abstract—The unmanned aircraft system (UAS) is becoming increasingly popular for a myriad of applications, including commercial, public safety, and mission critical. A UAS consists of an unmanned aerial vehicle (UAV) and the UAV controller which use radios to communicate. While the controller is traditionally a human operator who is maintaining line of sight with the UAV it controls, the trend is moving towards long-range control and autonomous operation. To enable this, reliable and omnipresent wireless connectivity is indispensable as it is the only way to control or take control of the UAV flight. This paper surveys the ongoing 3GPP standardization activities for enabling networked UAsVs. In particular, we discuss the requirements, envisaged architecture and services to be offered to UAVs and to remote controllers, which will communicate with one another and the UAS Traffic Management (UTM) through cellular networks. Global research and major R&D platforms are presented as those that will drive future standards.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) have been successfully used for the delivery of goods in humanitarian, medical and commercial contexts and show huge potential for smart delivery solutions at scale, adding an additional degree of freedom for improving transportation logistics and use of resources [1]. UAVs are also considered critical to support public safety missions in different domains, including search and rescue operations and disaster management [2]. Another valuable use case for UAVs is precision agriculture where UAVs can be used to manage and monitor crops, detect weed, and collect ground sensors data (moisture, soil, etc.) in areas where there is no network or no business case for deploying one [3]. The low deployment cost, high maneuverability, and ability to operate in dangerous or hostile environments are some of the reasons for considering UAVs over other technologies and human missions [4].

An unmanned aircraft system, or UAS, is commonly considered as a UAV and its controller. The UAV controller can directly control the UAV from a nearby operator using a remote controller (RC), or indirectly through a terrestrial or satellite network. The growing market for commercial UAVs has led to global research and development (R&D) on communications and networking technology and protocols supporting UAV operations. Industry has started to plan and design the integration of UAVs into 4G and 5G networks. Studies and data collection have been conducted over the past decade by companies defining next generation communications and networking standards.

The Third Generation Partnership Project (3GPP), an industry-driven consortium that is standardizing cellular networks, has been active in identifying the requirements, technologies and protocols for aerial communications. Fig. [1] provides an overview of the recently completed and ongoing 3GPP standardization efforts for UAS/UAV communications and their progress to date. The 3GPP study to use enhanced long-term evolution (LTE) support for aerial vehicles successfully concluded at the 3GPP RAN#76 meeting in 2017 and the report RP-171050 is publicly available. It led to the 3GPP Release 15 (Rel-15) Technical Report (TR) 36.777. This report identifies the necessary enhancements to LTE to optimize the network performance when serving UAVs. The first item that is discussed to enable efficient UAV operation is that of developing a robust communications framework for UAV services that sustain high levels of safety and authorized use, and that embody the requirements and dynamics of the airspace regulation. These factors will enable UAV operations to safely coexist with pedestrian, vehicular and commercial air traffic activities. As a result, 3GPP Technical Specification (TS) 22.125 discuss the requirements to enable and integrate UAV services into 3GPP networks.

The 3GPP TR 22.829, published in 2019, identifies several UAV-enabled applications and use cases that shall be supported by 5G networks and consequently points to the necessary communications and networking performance improvements. During 2020, the work items related to UAS communications and networking standards in Rel-17 focus on two main aspects: The first is to support the connectivity, identification, and tracking of UAVs (TR 23.754). The second is the application architecture to support efficient UAV operations (TR 23.755). Both are expected to complete in 2021.

The objective of this paper is to present the recent 3GPP standardization efforts for the UAS integration into emerging cellular networks in a way that explains the motivation behind the requirements and proposed solutions and allows identifying the remaining challenges and opportunities. We therefore introduce the main standardization items, the envisaged applications, their requirements and challenges. The main standardization items are the remote identification of UAS nodes, command and control (C2) and other UAS-enabled wireless applications and services. The requirements are discussed in Section II. In Section III we describe the corresponding solutions as envisaged by the 3GPP. Section IV introduces three major emerging R&D platform projects, which are developed by large consortia through public-private partnerships and which will enable experimental research and field trials to spur innovation and facilitate the transition.
Section V identifies important challenges for future research, development, and standardization and an outlook on emerging use cases and technology. Section VI provides the concluding remarks.

II. UAS Identification, Control and Wireless Service Requirements

The 3GPP has established certain requirements for effective communications with UAVs. First, the UAS nodes need to register and authenticate with the network and provide regular status notifications. This is done by remote identification. Then the main functions, such as C2 and other services can be facilitated through the terrestrial cellular network. This includes remote control of the UAV from the UAV controller through the network, as well as common applications such as video streaming and surveillance. We describe the requirements here and the proposed technological solutions in Section III. The presented information is based on the 3GPP documents presented in Fig. 1.

A. Remote Identification of UAS Nodes

For awareness, safety and efficient management or airspace operations, an aircraft needs to provide identification and regular presence updates to the control towers and airspace management system. For UASs this means that both the UAV and the controller need to register and regularly confirm their presence to the supporting network, which facilitates this information to the UAS Traffic Management (UTM). The UTM is a centralized flight management system developed and maintained by governmental authorities. The identification requirements are:

1) The UAS nodes should register to the network and provide information that allows associating the UAV and its controller as UAS node pairs to the UTM.

2) The transport network should be able to forward the UAV originating data to the UTM. This data contain the UAV identity, its capability as a user equipment (UE), make and model, serial number, take-off weight, position, owner information, take-off location, mission type, flight data, and operating status.

3) The transport network should be able to forward the UAV controller data to the UTM. The UAV controller is typically a ground control station or RC unit. The UAV controller data contain the UAV controller identity, its capability as a UE, controller position, owner, operator and pilot information, and flight plan.

4) The UAS nodes should be able to use the network to transfer any other data that may be relevant to the UTM after successful authentication and authorization.

5) The network should be able to forward live position information updates of the UAV and its controller to the UTM. The UAS nodes therefore need to transmit beacons at regular time intervals.

6) The network needs to gather the UAS identification and subscription information for discriminating between UAS-capable UEs and non-UAS-capable, or regular, UEs. A UAS-capable UE is a radio transceiver that supports the UAS communications features to effectively communicate with the UTM, but also with other network entities and application servers.

B. C2 Communications

There are different UAV flight operations that can be controlled through four C2 modes. These modes are described in continuation.

* Steer to waypoints: This control message is responsible for transferring the pre-scheduled waypoints or other flight declarations from the UAV controller or UTM to the UAV.
### TABLE I: KPIs for different C2 modes [5].

| Control Mode                                      | Message Interval | Max UAV Speed | Message Size  | Latency | Positive ACK |
|---------------------------------------------------|------------------|---------------|---------------|---------|--------------|
| Steer to waypoints (UAV terminated)               | < 1 s            | 300 km/h      | 100 byte      | 1 s     | Required     |
| Steer to waypoints (UAV originated)                | 1 s              | 300 km/h      | 84-140 byte   | 1 s     | Not required |
| Direct stick steering (UAV terminated)            | 40 ms            | 60 km/h       | 24 byte       | 40 ms   | Required     |
| Direct stick steering (UAV originated)             | 40 ms            | 60 km/h       | 84-140 byte   | 40 ms   | Not required |
| Automatic flight on UTM (UAV terminated)           | 1 s              | 300 km/h      | < 10K byte    | 5 s     | Required     |
| Automatic flight on UTM (UAV originated)           | 1 s              | 300 km/h      | 1500 byte     | 5 s     | Required     |
| Approaching Autonomous Navigation Infrastructure (UAV terminated) | 500 ms           | 50 km/h       | 4k byte       | 10 ms   | Required     |
| Approaching Autonomous Navigation Infrastructure (UAV originated) | 500 ms           | -             | 4k byte       | 140 ms  | Required     |

- **Direct stick steering**: Control messages are transmitted from the UAV controller directly to the UAV to provide flight directions through waypoints. The direct stick steering packets are often adjusted as a result of the video traffic feedback from the UAV to the controller.

- **Automatic flight by UTM**: This control type is associated with the autonomous flight option that is provided by the UTM through an array of predefined 4D polygons that constitutes the flight plan. The UAV feeds back periodic position reports for a full tracking of the UAV during the entire flight.

- **Approaching autonomous navigation infrastructure**: This control type is activated for autonomous UAV flights where the infrastructure may provide updated UAV flight instructions, for example, the next waypoints, altitudes and speeds. It can also help with autonomous departing and landing operations.

Each one of these modes has specific requirements in terms of packet interval, message size, and end-to-end latency, among others. These are captured in Table I. The control links are bi-directional where messages are exchanged between the UAV controller, the UTM, and the UAV. Packet reception feedback, or acknowledgment (ACK), is required for all UAV terminated transmissions which may contain critical UAV flight control instructions. Acknowledged communications mode is not required for certain C2 packets originating at the UAV. The switch between C2 modes during a UAV operation needs to be supported by the network within the specified latency figure. For the direct stick steering mode, the 3GPP recommends using video feedback. The requirements for video feedback are a function of the type of control:

- **Visual line of sight (VLOS) operation**: 2 Mbps data rate at 480p video with 30 frames per second (fps) and 1 s latency.

- **Beyond VLOS (BVLOS) operation**: 4 Mbps data rate at 720p video with 30 fps and 140 ms latency.

The BVLOS operation has more stringent video feedback requirements because the pilot does not see the UAV directly.

### C. Other Wireless Applications and Services

For the full integration of the UAS into cellular networks, the 3GPP standardization is expected to support various UAV-assisted applications or services. Most of these services are defined around video and photos delivery from the UAV that provide environmental/situational awareness, surveillance or entertainment services. Table II contains the distinguished KPIs for various uplink and downlink services that are envisaged to be delivered through wireless networks for network-connected UAVs. The services mentioned in Table II are related to the payload data, as opposed to C2 type of data, that are collected by the on-board sensors during the UAV operation. The different data types and services require different quality of service (QoS) which are captured as throughput and latency figures.

### III. 3GPP Communications and Networking Solutions for Supporting UAS

The UAS communications applications include both the C2 and radio access services provided through the UAVs. Correspondingly, the communications network needs to support robust communications and networking services to UAVs.
TABLE II: KPIs for UAV-assisted wireless services [5].

| Services                                      | Uplink Data rate | Uplink Latency | Downlink Data rate | Downlink Latency | Height | service area         |
|-----------------------------------------------|------------------|---------------|-------------------|------------------|--------|----------------------|
| 8K video live broadcast                      | 100 Mbps         | 200 ms        | 600 Kbps          | 20 ms            | < 100 m | Urban, scenic area   |
| 4K*4K AI surveillance                        | 120 Mbps         | 20 ms         | 50 Mbps           | 20 ms            | < 200 m | Urban, rural area    |
| Remote UAV controller through HD video       | ≥ 25 Mbps        | 100 ms        | 300 Kbps          | 20 ms            | < 300 m | Urban, rural area    |
| Real-Time Video                              | 0.06 Mbps        | 100 ms        | -                 | -                | -      | Urban, rural, countryside |
| Video streaming                              | 4 Mbps → 720p video | 100 ms | -                 | -                | -      | Urban, rural, countryside |
|                                             | 9 Mbps → 1080p video | -     | -                 | -                | -      | Urban, rural, countryside |
| Periodic still photos                        | 1 Mbps           | 1 s           | -                 | -                | < 120 m | Urban, rural, countryside |

Fig. 2: UAS authorization procedure.

The cellular network that can offer such services can then support safe and efficient UAS operations, as well as added functionalities and more flexible operation enabled by the broad coverage that cellular networks provide.

A. Remote Identification of UAS

The 3GPP standards rely on the UTM entity that receives the UAS node authentication and credential information through the mobile network operator (MNO) that serves the UAS nodes. The authentication and credentials information is defined by the vendors and may be associated with the status of the aerial node or its operator, or with the intended operation. All required authorization and credential checks for the UAV node and its operator to gain access to the network and specific services will be performed by the UTM. The main mechanisms for authorization and identification of UAS nodes from the point of view of the 3GPP is through the aerial communications subscription information and the radio capability.

Fig. 2 shows the authorization procedure for the UAV and its operator to be registered and authorized by the 3GPP network. After the UAS nodes get approval to use the network for UAV control and other applications and to connect to the UTM, additional authentication mechanisms at the application layer must be triggered to activate the UTM services, such as UAV collision avoidance system and live position tracking. If the incoming attach request to the UTM does not match the aerial communications subscription, the request will be declined and the operation will be terminated. The operation request of a UAV may also be rejected when operating in a prohibited area, which is known as the no-fly zone, even if the identities or credentials are verified. The remote identification of UAS nodes can be used to supplement flight operation enforcement with the help of the collected information about the deployed UAVs, active operators, the specific geographical area, and so forth, which can aid in detecting suspicious behavior or prevent nuisance complaints.

B. C2 Communications

C2 data mainly carries the control commands from the ground station to the UAV for operating the flight. It also carries telemetry data from the UAV to the ground controller to facilitate efficient control. The UAV has a number of distinct flight functions that can be managed by a ground operator through the UAV controller. In addition, C2 links can be established between the UAV and the UTM for other air traffic management operations.

The UTM plays a vital role in the air traffic management and its deployment through the 3GPP network can be classified into centralized or decentralized UTM. The UTM should be able to transmit the path information and flight clearance to the UAV during the entire flight. The communications system should maintain a latency below 500 ms to deliver any route modification notification from the UTM to the UAV. The integration of 3GPP and UTM systems shall be capable of avoiding aerial vehicle collisions by enabling short-range broadcasts from the UAV.

The cellular network can be used to assist different UAS communications services as a transport network. For the sake of reliability and service quality, more than one connection can be established adding redundant C2 data links. Fig. 3 illustrates the C2 and UTM support through the cellular network. It shows three paths:
• **Direct C2 communications**: This link directly connects the UAV with the UAV controller. This connection will be activated only if both nodes, the endpoints of the direct C2 link, are authenticated and registered to the network. The control commands will be carried over the resource that may be configured and scheduled by the network, taking into consideration the C2 communications requirements.

• **Network-assisted C2 communications**: The unicast C2 communication links will be created between the cellular network and the UAV as well as between the network and the UAV controller. The UAV and its controller do not need to be close to each other and may register to the network through the same or different radio access networks (RANs).

• **UTM-navigated C2 communications**: This type of connection is used to connect the UTM ground node with the UAV. Typically, most of the UTM-navigated C2 links will be established indirectly over a 3GPP network server. This type of communications is used for monitoring the UAV’s flight status, for verifying that it adheres with the regulations, for delivering flight path updates, for keeping track of the UAV navigation, and for providing flight navigation orders whenever needed, among others [6].

It should be noted that the steer to waypoints and the direct stick steering packets can be delivered via the direct or the network-assisted C2 communications link, whereas the other two fundamental C2 modes described in Section II.B are to be provided by the UTM-navigated C2 communications system.

### C. RAN Support Roles of UAVs

The deployment of modern radios as UAV payloads, specifically for the UAVs that fly at low-altitudes, has been widely considered by the R&D community. The goal of these radios is to establish broadband data links for numerous applications, including aerial support nodes for terrestrial RANs. The motivation for this is the ability of UAVs to navigate in the three-dimensional space and hover in place with minimum restrictions as well as low deployment and maintenance costs. Such use of UAVs can support the different generations of cellular networks. The 3GPP calls such an aerial radio node the on-board radio access node (UxNB). The UxNB can be used to extend the coverage or increase the capacity of the cellular systems. It allows rapid deployment in disaster and emergency use cases, e.g. for supporting evacuation where communications infrastructure may be lost, or for providing capacity on demand at crowded events, such as concerts or sports events. The UxNB node can implement an aerial base station (ABS), an aerial relay (AR), or an isolated Evolved Universal Terrestrial RAN (E-UTRAN) solution, as illustrated in Fig. 4. The UxNB flies to the designated area where wireless services are needed and then hovers there while enabling wireless connectivity to ground users. Depending on the service requirement, a backhaul may need to be established.

Before the UxNB starts its base station functionality, it needs to be authorized by the network management system and its configuration adjusted based on the specific operation, objectives and internal and external parameters. The UxNB can then serve a specific geographical area for a given time, using certain spectral resources. The flight time of the UxNB is effected by various factors that can shorten its operation. Some of those factors are the UxNB size, on-board battery, cargo, aerodynamics, and authorized airspace regulations. Therefore, it has been recommended that the 3GPP systems assisting the aerial missions of the UxNB nodes support the close monitoring and reporting of the UxNB status. This includes the UAV’s power consumption, position, trajectory and mission, and the environmental condition. This continuous monitoring and reporting will facilitate achieving the required QoS for the given mission for a longer period, which can be accomplished by managing dynamic UxNB replacements.

Another emerging application of the UxNB is to provide local routing and proximity-based services (ProSe), as introduced in the 3GPP TS 24.334. UxNB can, for example, establish ProSe group communications among ground users located in remote areas without network coverage. For such a scenario, the deployed UxNB will act as an ABS and provide a RAN with or without a backhaul connection. In the latter case, the UxNB will allows communications among the UEis in the areas served by the UxNB by establishing an internal IP network. On the other hand, the isolated E-UTRAN offered by the UxNB with a backhaul link can support external routing of selected IP traffic from the local network to external IP networks, such as the Internet. The 3GPP standardization currently limit this application to LTE’s E-UTRAN, but there is interest to support next generation RANs in the future.

The huge potentials and benefits of deploying UxNB nodes...
in the sky motivated researchers and industry to define and standardize a set of services. Those services will provide the means to minimize the power consumption of the UxNB by optimizing the operational parameters, UxNB path planning, and service delivery. In addition, it is important to consider and monitor the radio frequency interference among the deployed UxNB nodes and terrestrial cellular users for effective network operation. This is important because of the generally strong line-of-sight conditions and the fact that the deployment of a UAV at a specific location may not have extensive field data collected beforehand.

As has been mentioned before, the UxNB’s greatest weakness is its short operational time and, therefore, it is important to optimize the management of UxNB node replacement for uninterrupted service provisioning. Another major challenge that needs to be considered in the future design of next generation cellular network infrastructures is the placement and orientation of antenna systems to provide coverage for aerial UEs that fly at different altitudes. As there will be different types of UEs—specifically, UAS-capable and non-UAS-capable UEs—with different specifications and characteristics, the network needs to be able to handle them simultaneously and ensure that it can meet the required QoS agreements.

IV. RESEARCH CHALLENGES AND OPPORTUNITIES

Fundamental challenges are still to be tackled for the full integration of UAVs into emerging cellular networks. In what follows, we identify what we believe are among the most compelling research directions to follow.

- **Accurate Localization Services:** The use of UAVs in the cellular systems introduces a new category of devices that need to be supported through the network. As a result, there will be a distinct subscriptions including differentiated services offered and different charging policies. The UAV nodes will be differentiated from the default UEs by the height parameter which 3GPP includes to distinguish UAV-UEs from ground UEs. Recently, the UAV localization problem has received great attention from the research community. The ongoing research solutions that can be used to tackle this problem can be classified based on the measurements to three groups: vision-based, inertial navigation system (INS)-based, and wireless signal-based solutions. The vision-based techniques utilize the on-board cameras to provide the required information for UAV localization and navigation. The real time localization of vision-based solution can be achieved by the support of combinations of simultaneous localization and mapping and iterative closest point techniques [7]. The INS-based solutions aim to monitor the orientation, location and velocity of the devices by utilizing the inertial measurement unit, however its performance on the UAV degraded after a certain flight time [8]. The wireless signal localization mechanisms rely on the use of the RF characteristics to enhance the localization and navigation services. Typical RF parameters that are currently used in the localization techniques are: received signal strength indicator, time difference of arrival, round-trip time, direction or angle of arrival, and ultra-wide band [9]. The robust use of these techniques will likely require a combination of sensor data and signal processing approaches and needs fundamental and experimental research and standardization.

- **Multi-UAV Management:** The short battery life and limited payload capacity of small UAVs are major their weakness. This limits their practical uses. As a result, most of the current or proposed deployments of UAVs are anchoring on the use of multiple vehicles or UAVs swarms, so that they can replace each other without degrading the service performance. Therefore, it is essential to have a low-latency, proactive, and scalable management system to control the handover of missions and transition of roles. Also, the special characteristics of the UAVs such as the wide mobility pattern and dynamic trajectories can be seen as crucial task regarding the network management. Therefore, certain 5G enabling technologies, such as slicing and network softwarization offered by software-defined networking and network function virtualization, can be seen as promising solutions for single or multi-UAV management [10]. While these technologies allow flexible network use and custom network services, how to ensure isolation and resource availability and QoS guarantees for UAV control and data communications will be an important R&D theme for the next years.

- **Security:** As the UAVs show huge potentials to support various use cases in different application domains, it becomes of critical concern to strengthen the security of those nodes while allowing them to efficiently performing their task. The aerial nodes are vulnerable to attacks, such as unauthorized access and control, eavesdropping of data transferred between UAVs and ground control stations, jamming of GPS signals or UAV communications links, and location and identity spoofing attacks [11]. Therefore, providing secure and reliable wireless links and different levels of integrity and privacy protection mechanism must be sustained by the standards as mandatory features and enforced in practice. The research community has investigated various options to provide a secure, resilient and self-configurable framework for UAV communications. These options include blockchain solutions as a defense system against UAV network softwarization attacks. Cross-layer authentication and mutual authentication mechanisms have been proposed for improving the confidentiality and integrity of UAV communications, specifically at the application layer. In addition, physical layer security techniques, such as artificial noise transmission and relaying, can be leveraged with UAVs to assist terrestrial networks [12].

V. R&D PLATFORMS

While UAS communications research and standardization are still in their early stages, important R&D projects and testbeds are being established. These are necessary to study the performance requirements of UAVs and evaluate the technology and protocol solutions to support the various use cases
in real-life scenarios. Repeatable experimental results obtained in controlled, yet production-like environments, will in return accelerate advancing communications standards.

- **AERPAW**: The Aerial Experimentation and Research Platform for Advanced Wireless (AERPAW) is being built in the US since 2019 under the Platforms for Advanced Wireless Research (PAWR) program. AERPAW is a unique large-scale testbed enabling experimentation with advanced wireless technology and systems for UAVs. The goal of AERPAW is to support global 5G and Beyond 5G wireless research on connected 3D mobility, spectrum agility and security, and 3D network topology, among others. AERPAW will therefore offer access to commercial-grade 5G technology and networks as well as to software radios that can be programmed to implement many different waveforms and protocols. These radios will be deployed on several fixed nodes and be available as payloads for UAVs. An emulator and sandbox will enable development and pre-testbed deployment of new radios, networks and experiments [13].

- **5G!Drones**: In June 2019, a three-year European project named 5G!Drones [14] has kicked off. Academia has joined forces with industry and includes network operators and research centers for testing UAV use cases over 5G networks. The use cases that are considered in this project includes: UAV traffic management, public safety, and situational awareness. The trials aim to validate the ability to support aerial services and provide feedback that can be used to improve the performance of 5G systems for the selected use cases. 5G!Drones is part of Phase 3 of the 5G Public Private Partnership (5GPPP) projects funded by the European Commission.

- **5G-DIVE**: In October 2019, a collaboration of vendors, service providers, network operators, small or medium-sized enterprises (SMEs), academic and research centers from the EU and Taiwan established the 5G-DIVE project [15]. 5G-DIVE plans to perform field and real-life tests of different 5G technologies to ensure technical merits and business value proposition are fulfilled, before advancing those technologies to higher levels. The trials mainly focus on Industry 4.0 use cases, such as digital twin app and real time video analysis for zero defect manufacturing. The second trials focus on autonomous drone scouting involving drone fleet navigation and intelligent processing of images captured by the drones. 5G-DIVE is funded by the European Union through the H2020 Program.

VI. CONCLUSIONS

UAS technology is providing innovative solutions to support various applications in the public, private, and military sectors. The benefits come not only from their mission-oriented use, but also as a general platform for a number of different purposes, including network support. This has been realized by the 3GPP that is refining the terrestrial cellular network for supporting 3D mobile users and networks. This article surveys the 3GPP standardization efforts for networking UAS nodes and integrating them into cellular networks as end users or RAN support nodes. We introduce the initial 3GPP work items meant for 4G LTE and cover the recent standardization activities for 5G networks until mid 2020. We discuss the UAS node registration, C2, and wireless services requirements for UAVs. The paper moreover discusses the emerging and future use cases of UAS, as well as experimentation and field trials for closing the gap between fundamental research, standardization, development, and deployment. Finally, we elaborate three important lines of research and discuss the opportunities, challenges, and ongoing efforts. This research, when demonstrated on an experimental platform in a production like environment, will enable future standardization studies and drive new use cases for advanced wireless technology to spur innovation at the intersection of communications/networking, control, and applications.

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REFERENCES

[1] G. Oh, Y. Kim, J. Ahn, and H.-L. Choi, “Task allocation of multiple UAVs for cooperative parcel delivery,” in Advances in Aerospace Guidance, Navigation and Control, G. Oh, Y. Kim, J. Ahn, and H.-L. Choi, Eds. Cham: Springer International Publishing, 2018, pp. 443–454.
[2] M. Silvagni, A. Tonoli, E. Zenerino, and M. Chiaberge, “Multipurpose UAV for search and rescue operations in mountain avalanche events,” Geomatics, Natural Hazards and Risk, vol. 8, no. 1, pp. 18–33, 2017. [Online]. Available: https://doi.org/10.1080/19475705.2016.1238852
[3] P. Mathur, R. H. Nielsen, N. R. Prasad, and R. Prasad, “Data collection using miniature aerial vehicles in wireless sensor networks,” IEEE Wireless Sensor Systems, vol. 6, no. 1, pp. 17–25, 2016.
[4] K. P. Valavanis and G. J. Vachtsevanos, Handbook of Unmanned Aerial Vehicles. Springer, 2015, vol. 1.
[5] 3GPP, “Unmanned Aerial System (UAS) support in 3GPP,” 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 22.125, 12 2019, version 17.1.0.
[6] A. S. Abdalla and V. Marojevic, “Machine learning-assisted UAV operations with the UTM: requirements, challenges, and solutions,” in IEEE VTS Workshop on Urban Air Mobility, IEEE Veh. Technol. Conf. (VTC-Fall 2020), 4-7 October 2020, pp. 1–5.
[7] J. C. Trujillo, R. Munguia, I. Urzua, E. Guerra, and A. Grau, “Monocular visual SLAM based on a cooperative UAV-target system,” Sensors, vol. 20, 06 2020.
[8] A. Nourelldin, T. B. Karamat, M. D. Eberts, and A. El-Shafie, “Performance enhancement of MEMS-based INS/GPS integration for low-cost navigation applications,” IEEE Trans. Veh. Technol., vol. 58, no. 3, pp. 1077–1096, 2009.
[9] J. A. del Peral-Rosado, R. Raulefs, J. A. Lopez-Salcedo, and G. Seco-Granados, “Survey of cellular mobile radio localization methods: from 1G to 5G,” IEEE Commun. Surveys Tuts., vol. 20, no. 2, pp. 1124–1148, 2018.
[10] O. Sami Oubbati, M. Atiquzzaman, T. Ahamed Ahanger, and A. Ibrahim, “Softwarization of UAV networks: A survey of applications and future trends,” IEEE Access, vol. 8. pp. 98 073–98 125, 2020.
[11] Q. Wu, W. Mei, and R. Zhang, “Safeguarding wireless network with UAVs: a physical layer security perspective,” IEEE Wireless Commun., vol. 26, no. 5, pp. 12–18, 2019.
[12] A. S. Abdalla, K. Powell, V. Marojevic, and G. Geraci, “UAV-assisted attack prevention, detection, and recovery of 5G networks,” IEEE Wireless Commun., vol. 27, no. 4, pp. 40–47, 2020.
[13] V. Marojevic, I. Guevenc, R. Dutta, and M. Sichitiu, “Aerial experimentation and research platform for mobile communications and computing,” in 2019 IEEE Globecom Workshops (GC Wkshps), 2019, pp. 1–6.
[14] “5G!Drones project,” [https://5gdrone.eu/ accessed July 2020].
[15] “5G-Dive Project,” [https://5g-dive.eu/ accessed July 2020].
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