Navigation and Communication of UAS Operating in BVLOS

Subjects: Transportation

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Unmanned Aerial Systems (UAS) have rapidly gained attraction in recent years as a promising solution to revolutionize numerous applications and meet the growing demand for efficient and timely delivery services due to their highly automated operation framework. Beyond Visual Line of Sight (BVLOS) operations, in particular, offer new means of delivering added-value services via a wide range of applications.

Keywords: UAS ; UAVs ; BVLOS ; communication systems ; autonomous navigation

1. Introduction

UAS are currently conquering the skies due to their autonomous capabilities, high mobility, and fast and flexible deployment. Typically, the more general term of UAS consists of the unmanned aircraft, namely Unmanned Aerial Vehicles (UAV), a Data Link, and the Remote Pilot Station (RPS) [1]. With the emergence of new technological advancements in communication and sensor technologies, these systems have gained the potential to catalyze equivalent fundamental change in our mobility infrastructure. Particularly, BVLOS operations are playing a pivotal role in unlocking the full potential of unmanned systems due to their extended intelligence and autonomy. BVLOS refers to the capability of an unmanned vehicle to operate where humans cannot reach, following a predefined route, while any onboard information is obtained using advanced sensing instrumentation, such as on-board cameras and detect and avoid technologies. In such a highly automated operation framework, the aircraft is able to conduct its own mission, make its own decisions during the mission, and react to unforeseen events without the pilot's intervention [2]. What is more, the integration of technical components and subsystems that are optimized for specific UAS applications becomes paramount. These application-optimized components capitalize on the wealth of expertise garnered from diverse domains, with a special emphasis on Electronic Components and Systems (ECS), while the the continuous technological advances in the field open the gates for more versatile applications. Indicatively, UAS can alleviate humans from exposure to hazardous environments, perform frequent and efficient inspections, provide dynamic security, ensure access to high-frequency aerial data, utilize edge computing in an efficient manner, enable rapid response during emergencies, as well as enable object building maintenance and consumer market [3][4]. Over the past few years, drone industry investments have been progressively reaching new records, while the relevant business use cases of commercial UAS have expanded significantly [5]. In addition, technology advancements in sensors and communication technologies have opened the way for new applications that will further boost their use in sectors

2. Enabling Technologies for the Navigation and Communication of UAS Operating in the Context of BVLOS

Nowadays BVLOS flights open a myriad of applications revolutionizing various industries, from goods delivery to safety and security, through surveying, crowd management, as well as search and rescue [6]. Drones can make a significantly positive impact on customer satisfaction by enhancing the quality of delivery services. In recent years, many leading retail companies, such as Amazon, Google, and Walmart, were introducing drone delivery services [7]. "Amazon Prime Air" was initiated by Amazon to deliver packages of 2.3 kg within thirty minutes at a distance of 16 km from click to delivery [8]. After introducing innovative sensor technologies and communication systems to their UAS delivery services, the company aspired to reduce noise pollution, eliminate their carbon footprint, and facilitate safer and more reliable services. In 2019, DHL launched its first fully automated, intelligent drone delivery solution in China which reduces one-way delivery time from 40 min to only eight minutes and can save costs of up to 80% per delivery, with reduced energy consumption and carbon footprint compared to road transportation [9].

The key to unlock the potential of UAS, and allow various related applications to bloom, is to develop components, systems, and architectures for autonomous, intelligent, and safe UAS use, beginning from the industrial domain(s) for components, over system design and development, with cross-domain contributions to system architectures for resilience, robustness, and collaboration air-to-ground. SESAR (Single European Sky Air Traffic Management Research) has already started work on regulatory and procedural structures for drone co-existence with crewed traffic with the U-space architecture and has defined levels of implementation of that architecture U1–U4, covering the period from 2019 to 2035 [10].

2.1. Detect and Avoid Technologies

Detect and Avoid (DAA) technologies are key to unlocking commercially viable BVLOS operations, as they allow a safe and efficient integration into civilian airspace, by helping UAS to avoid collisions with other aircraft, buildings, and other obstacles. The growing number of UAS applications has made a necessity for sophisticated and highly dependable collision avoidance systems, as evident and incontestable from the public safety perspective [11]. Such systems are based on the use of sensors to detect and position obstacles to subsequently establish maneuvers to guarantee the safety of the aircraft. Many recent works implement LiDAR (Light Detecting And Ranging), vision cameras, or thermal or infrared cameras for collision avoidance of UAS [12][13].

The detection of possible objects in the navigation space can be also realized using pattern recognition technology, which includes methods for identifying relevant characteristic features of an object via image processing algorithms. Deep learning algorithms for object detection with high sensitivity to data restructuring are the most common approaches in object detection and classification [14].

2.2. Communication Technologies

The reliability of UAS communication technology is essential for their wider deployment. The commercialization of fifth-generation networks (5G) technology provides UAS communication with ultra-high speed, very low latency, high data rate transmissions, and other capabilities, which effectively solve the problem of the UAS communication quality [15], at least when the operational volume is within the coverage of the mobile network. However, current UAS communication systems still face several limitations in terms of UAV aerial base station (BS) deployments, spectrum utilization, and energy consumption of UAV communication [16]. Extensive research has been conducted regarding UAV groups, categories, sorting, charging, and adjustment. In the last few years, the European Telecommunications Standards Institute (ETSI) defined a new concept called “Multi-access Edge Computing” (MEC) which refers to the deployment of cloud computing services at the edge of the cellular network. UAVs can be integrated into MEC networks as users that execute various computing tasks [17]. Such systems can significantly decrease network congestion and increase the network performance in applications related to task allocation [18].

Future UAS applications have stricter demand for latency, data rates, and reliability and channel variations introduced by their mobility, which in turn relocates research interest beyond fifth-generation (B5G) mobile communications. Emerging UAS scenarios include drones that can act as mobile roadside units (RSUs), gathering data from an area and transmitting that data to terrestrial vehicles, stationary RSUs, and other nearby drones. UAS networks can be deployed faster than any other stable network infrastructure system; thus, it is better to use them as the basis of mobile infrastructure networks for remote locations [19]. To enhance network and performance in UAS communication, the existing literature has explored various emerging wireless communication technologies, such as non-orthogonal multiple access (NOMA), which prevails over the traditional orthogonal frequency-division multiple access (OFDMA) schemes due to its unique characteristics, such as enhanced spectrum efficiency (SE) and reduced traffic latency with high reliability [20].

Towards protocols for the UAV to ground control communication, only related work dealing with non-military approaches is discussed in the following. There are several protocols applicable to the commercial drone use case which can be utilized in the mobile network context. One widely used protocol is the Micro Air Vehicle Link (MAVLink) protocol, which is applicable to wireless radio communications. It is lightweight and its reliability is ensured by double checksum. Kosuda et al. [21] discuss the potential of using it for UTM communication, such as identification or traffic monitoring. One drawback is the lack of security mechanisms, such as message encryption. However, when deployed on a cellular network, the data is encrypted when sent over the wireless link by the mechanisms implemented in the mobile network [21]. Furthermore, there are other open-source and lightweight protocols, such as the UranusLink protocol and the UAVCan protocol, although they are less commonly used. Similar to MAVLink, both protocols lack security mechanisms. However, the UAVCan protocol provides limited encryption ability [22].

2.3. Autonomous Navigation

Awareness of the UAS surroundings is a key aspect of BVLOS operations, particularly in large-scale and complex environments. Drone navigation is characterized by two fundamental components: path planning and obstacle detection and avoidance. Path planning involves determining an optimal trajectory for the drone and defining parameters such as the velocity and turns over time, to achieve optimality in the trajectory generation. As such, each autonomous flight is characterized by an objective, either being the arrival to a certain target point, or the aim of maximizing the information coverage [23]. With regards to UAS navigation, different path-planning alternatives can be used depending on the specific requirements of the application [24]. These methods can be classified into two categories: those that are based on a sampling of the search space, and those that employ artificial intelligence (AI) to find a solution with respect to the representation of the environment [25]. There exist various different sampling based UAS navigation techniques, for example, graph-based shortest-path-finding algorithms, such as Dijkstra's algorithm [26] and its variations [27], the A* path search algorithm [28], or the Fast Marching (FM) [29] Potential Fields [30] and Rapidly exploring Random Tree [31] methods. Genetic algorithms and other bio-inspired techniques have also been employed for UAV path planning [32]. These methods avoid constructing complex environment models and search for a near optimal path based on stochastic approaches, so they provide efficient solutions to NP-hard problems with many variables and non-linear objective functions [33]. Finally, Reinforcement learning (RL) methods allow for UAV navigation in highly dynamic environments as the aircraft is able to learn from the results of past actions and uses environmental feedback as the input for path planning. The use of DRL techniques to train neural networks through a Reinforcement Learning (RL) strategy are becoming popular in the field of UAV navigation [34].

Recent works on autonomous UAV navigation have mainly focused on the creation of a 3D map of the surrounding environment. This 3D deployment and resource utilization has been addressed by powerful optimization methods such as convex optimization [35] or game theory [36]. In addition, various path-planning methods have been deployed for obtaining optimal paths, including graph-based methods such as the A* algorithm [37][38], or evolutionary methods such as the Particle Swarm Optimization (PSO) [39][40]. The observation that UAS navigation can be treated as a sequential decision-making problem has led more and more researchers to the use of learning-based methods for solving complex navigation problems and intelligently managing onboard resources [41]. AI and ML models play a vital role to all these tasks as the main part of the processing pipeline, which begins with data collection and pre-processing and ends with inference and decision making in real time. The models for some tasks are continuously or periodically trained in order to adapt to new conditions and environments and this process can be carried out either online or offline. Recent works have implemented the Deep Reinforcement Learning (DRL) algorithm for solving UAVs' reactive navigation problems in a simulated environment [42] or in real-world conditions [43].

The Mounted Mobile Edge Computing Network (MEC) can provide more flexible and reliable UAVs' connectivity with affordable infrastructure investment. Some interesting studies focused on UAVs' path planning and obstacle avoidance in MEC networks using a DRL-based algorithm [44][45]. Additionally, UAV-supported wireless communication systems have been implemented to enhance robustness and optimize network performance via the utilization of a deep Q-network (DQN) framework [46].

Although autonomous navigation methods are continuously evolving, driven by technological advancements, BVLOS can only be successful if carried out in concert with other roadmaps for regulatory development and operating standards and procedures. Initiatives to unify European regulatory standards for commercial drone operation have been introduced by EASA and a Specific Operations Risk Assessment (SORA) can be conducted that aids safety and compliance for operations in urban environments. Moreover, if the planned operation reaches into airspace where the drone may come into contact with traditional (manned) aviation, the upcoming regulations around U-space come into play, of which it is currently being developed by SESAR [47].

2.4. UAS Emerging Use Cases

Recent technological developments, trends, and societal needs have opened the way for an unparalleled expansion in the use of UAS for a great number of applications, where humans cannot reach or are unable to perform in a timely and efficient manner. The following section presents some emerging UAS use cases.

2.4.1. Logistics and Delivery of Goods

The existing logistics domain could benefit by integrating UAS technologies to achieve a more sustainable distribution of goods. For example, package delivery, the carrying of critical medical supplies to remote or inaccessible areas, or even aerotaxis capable of carrying passengers are some of the application areas where UAS offer great potential. Overall, UAS can provide advanced features against conventional solutions in logistics services, such as simultaneous delivery at several locations, reduced operational costs, environmental benefits, reduced traffic congestion and risk for accidents within large cities, and accessibility to remote areas or areas without infrastructures [48].

2.4.2. Forestry and Agriculture

In forestry and agriculture, autonomous, intelligent, and safe systems have received substantial attention in recent years. Technological advancements are rapidly adopted and pave the way for an operational UAV-supported forest monitoring system and boost further adoption among stakeholders. What is more, UAS can be used for various agricultural activities, such as the collection of weather data, the monitoring of crop growth, the early detection of crop diseases, the prevention of crop wastage due to the effective harvesting of crops, the monitoring of livestock behavioral patterns, animal location within and outside the farms, and an increase in production for both crops and livestock with the aim to boost farm productivity [49].

2.4.3. Infrastructure Maintenance

In recent years, the introduction of UAS technology as an additional remote, non-destructive method for infrastructure inspection and maintenance is increasingly attracting interest. UAS equipped with different camera and sensor technologies may represent an efficient and cost-effective support for improving the quality of infrastructure inspections [50]. UAS can also enhance the automation of monitoring activities of the infrastructure and allows for gathering crucial data needed for decision-making policies on the maintenance, repair, retrofit, or rebuild of bridges, thus increasing the resilience of the infrastructure network. UAS can carry out these activities and also promise a quicker and more cost-effective turnaround preparation of maintenance, resulting in lower overall maintenance costs and lower impacts on the traffic that is using the superstructure [51].

2.4.4. Search and Rescue Operations

UAS offer great potential is the search and rescue domain. Beneficially envisioned and applied applications in recent years extend to forest health monitoring, fire mapping applications, forest inventory, disaster prevention, and disaster management. UAS equipped with enhanced sensory abilities and novel control systems, as well as the capability of sophisticated mapping in unknown environments, prove beneficial for operating in harsh or difficult-to-access remote areas [52].

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