International Conference KNOWLEDGE-BASED ORGANIZATION
Vol. XXX No 3 2024

COMMUNICATION TECHNOLOGIES AS A MEDIUM FOR CONTROL AND DATA TRANSFER IN THE UNMANNED AIRCRAFT SYSTEMS

Georgi STANCHEV

"Georgi Benkovski" Bulgarian Air Force Academy, Dolna Mitropolia, Bulgaria
gstanchev@af-acad.bg

Abstract: *The currently available communication technologies used as a medium between the main elements of unmanned aircraft systems – unmanned aerial vehicles and command centers – are discussed. The advantages and disadvantages of different types of communication technologies are analyzed, as well as the relationship between their technical parameters and the operational characteristics of the overall unmanned aerial system. General conclusions have been drawn regarding the correct selection of communication technology as a medium between the main elements of the unmanned aerial system and the tasks it solves.*

Keywords: communications, control, data transfer, unmanned aircraft systems

1. Introduction

In recent years, unmanned aircraft systems (UAS) have been increasingly used both for solving combat tasks and in civil affairs – aerial photography and mapping, hitting targets, search and rescue operations, delivery services, environmental and infrastructure monitoring, surveillance and policing, etc. One of the main components of these systems are unmanned aerial vehicles (UAVs), also commonly known as drones. These UAVs are remotely controlled by the other main element of the UAS – the command centre (CC). However, at certain stages of the task being solved UAVs can and should be able to work autonomously. A huge amount of widely variable data is transferred between UAS elements: still images and videos, sensor and telemetry data, control commands and relayed data traffic.

Communication technologies used as a means of control and data transfer between UAS elements play an essential role in the effective and safe operation of these systems. Each such communication technology, serving as a medium between UAS elements, has its own significant advantages and disadvantages [1].

In this article, the communication technologies most commonly used in UAS, in their capacity of media, are presented, together with their inherent technical parameters, as well as their crucial advantages and disadvantages.

2. Communication Technologies as Media between the Main Elements of Unmanned Aircraft Systems

The types of communication technologies most commonly used as media between UAS elements are as follows [2, 3]:

- Autonomous Radio Channels (ARC)
- Wi-Fi Network
- Mobile Cellular Network (MCN)
- Satellite Communication Network (SCN)

The main technical parameters that are determined by the communication medium in the UAS are the frequency range, the

DOI: 10.2478/kbo-2024-0096

transmitter power and the data rate in the transfer channels. In certain cases, the purposes and methods of encoding control signals and data are also taken into account.
In UAS, control commands and data are transmitted over radio channels that are susceptible to noise and interference, which can lead to errors in the transmitted information. For this reason the use of channel coding - Forward Error Correction (FEC) is required to increase the reliability of transmission of control commands and data transfer [4]. The choice of FEC type depends on both the specific requirements of the communication technology and the characteristics of the communication channel [5, 6]. In addition, in many cases, especially in military UAS, it is necessary to protect the information from unauthorized access by encrypting it.
These technical parameters and the organizational structure of the media determine the operational parameters – range of action, flight time of an individual UAV; quantity, quality and security of the transmitted information; latency of the control systems, etc. Below are detailed the key features of the main medium types.

2.1. Autonomous Radio Channels

The most common method used to control UAVs and transfer data between them and the CC is via ARC. In this method, a radio link is used between the transmitters and receivers, which are elements of the UAS. There are no other communications equipment or networks between them. The ground transmitter sends signals from the CC to the UAV's receiver to control its operation.
In this method, the UAV's camera and other sensors send data to the ground station using a radio channel similar to a radio control one, but the transmitter is in the UAV and the receiver is in the UAS's ground station. This data transfer on different frequencies, as it is shown on Figure 1, is referred as Frequency Division Duplex (FDD).
The RC method is characterized by limited range and is affected by obstacles such as buildings, trees and other terrain features. Therefore, it is best suited for UAS in which the UAVs are operated and transmitted in areas with relatively clear lines of sight and at a relatively short distance from the operator and CC.
In systems using ARC, radio signals have frequencies in the ranges of 27-28 MHz, through 35 MHz, 40-41 MHz to 433 MHz. Some systems operate at even higher frequencies, e.g. 5.8 GHz, which are used for communications with UAVs over very short distances [7].
In UAS using ARC, the power emitted by the transmitters depends on the particular radio system and operating frequency. In the lower frequency ranges, more power is required to transmit an equivalent amount of data, compared to the higher frequency ranges.
When using ARC, the transmitters emit radio signals with power ranging from a few milliwatts to several watts, depending on the control distance and the required data transfer rate.
Data transfer rates range from several kbps to several Mbps, which meets the requirements for transmission of telemetry data and low-quality video images. This is due to the narrow bandwidth, especially in the low-frequency ARCs. However, the latency of the control systems is extremely low due to the lack of other communication equipment and protocols between the main UAS components.
The encoding methods employed to protect data in ARC systems, both from noise and interference, and from unwanted access, in ARC systems can be quite flexible, tailored to the intended use and resource constraints of each particular UAS. Several types of FEC codes are suitable and most commonly used in UAS. These are:

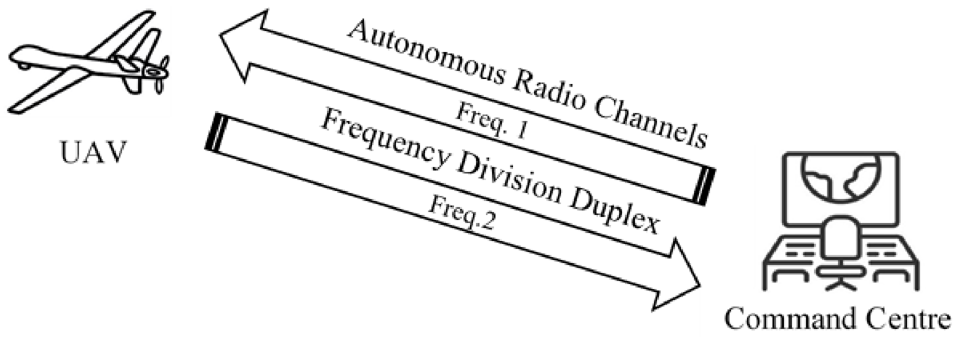

Figure 1: Autonomous Radio Channel as a medium between UAV and Control Centre

- Low Density Parity Check (LDPC) codes - a special case of the block linear codes with a parity check. Their check matrices contain a small number of significant elements (sparse matrices). This achieves simplicity of the encoding process and provides a relatively high net data rate while maintaining relatively good error correction capabilities.
- The Reed-Solomon codes are remarkable in their class in that, for a given ratio between information and check symbols, they can correct the maximum number of errors. These codes are particularly suitable and give good performance in communication channels with fading where packet errors are common.
- Convolutional (recurrent) codes are a type of inseparable, continuous codes, which, in combination with interleaving, are one of the most effective and most commonly used measures to combat packet errors resulting from fading. Even better results in channels with severe noise and interference are obtained if a convolutional encoding with an interleaving process is used as an inner error protection, and a Reed-Solomon encoding as an outer one. Of course, in this case too, the increased reliability of data transfer is at the expense of their net data rate and system latency.
- Turbo codes are a new class of FEC codes. They are the first practically usable codes that bring the actual channel capacity extremely close to the maximum channel capacity known as the Shannon limit [8]. Turbo codes are obtained as a result of the parallel operation of two or more convolutional coders, improving the overall efficiency of error detection and correction. In the turbo coding process, the output of one convolutional encoder is used to modify the input of another convolutional encoder. Turbo codes are used in 3G (UMTS) and 4G (LTE, IEEE 802.16 - WiMAX) mobile cellular communications, as well as in satellite communications and communications with objects in deep space.

2.2. Wi-Fi Network

Wi-Fi (IEEE 802.11) networks are also a widely used medium between the main elements of UAS. Moreover, with this approach, data can flow across the global Internet if the Wi-Fi network has such connectivity. The operator can control the movements of the UAV through a mobile device (smartphone or tablet) connected to the same Wi-Fi network – Figure 2. However, Wi-Fi communications have a limited range and may be affected by interference from other Wi-Fi networks [3]. In addition, two-way information exchange in the radio interface is organized by Time Division Duplex (TDD), which does not permit high-speed data exchange over long distances and with moving objects. This communication method is suitable for UAVs that operate in a limited range and in areas with a stable Wi-Fi network, which is not overloaded by other active users.

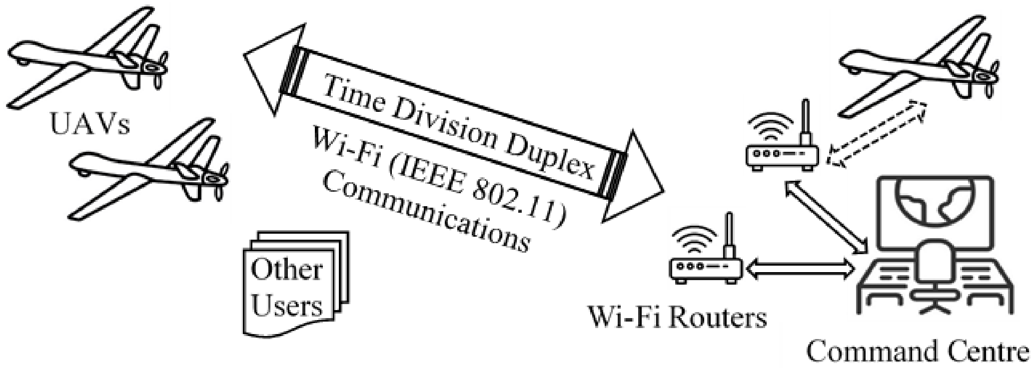

Figure 2: Wi-Fi Network as a medium between UAVs and Control Centre

The most commonly used frequency range is the license-free one - around 2.4 GHz (ISM band), 5 GHz (U-NII band) and even the newer standard Wi-Fi 6E (IEEE 802.11ax), which operates in the 6 GHz frequency band. However, the latter two ranges are highly absorbed by local objects and are only suitable for very short distances and assured line of sight. The power of the transmitted radio signals of Wi-Fi communication technologies is limited by local national and regional regulations and is usually in the range of 100mW to 1W. FEC coding at the physical level is convolutional with interleaving. There is no possibility to change the standardized radio interfaces. However, UAS using a Wi-Fi network, albeit at short distances, offer higher data rates compared to systems using ARC. Transfer rates range from a few Mbps to hundreds of Mbps, depending on the Wi-Fi standard used and the distance between the UAV and the ground CC, allowing the transfer of high-resolution images and video.

2.3. Mobile Cellular Network

MCNs are used in UAS that operate over long distances, e.g. within national borders. UAVs are equipped with communication modules to connect with a ground-based MCN that operate according to one of the established standards: GSM (2G), UMTS (3G), LTE (4G), 5G NR(5G) – Figure 3. The range of action can exceed the limits of a cellular system if there is technical and contractual connectivity (roaming) between neighbouring MCNs. Communications in UAVs using MCN can be affected by poor network coverage or congestion due to momentary peaks in the number of active users [9]. The response speed of UAVs in their control is low due to the delay of signals in the MCN. The latter is more pronounced in modern cellular communication systems using packet switching technology instead of the older channel switching technology. MCNs from 3G and above support asymmetric channels, which optimizes communication traffic to and from the UAVs. The data transfer rate can reach several hundred Mbps, for the new generations of MSC, but this depends a lot on the coverage of the area in which the UAVs operate. The frequencies used in these UASs are in the ranges around 400 MHz, 850 MHz, 900 MHz, 1800 MHz, 1900 MHz and 2600 MHz. In systems using MCM as media, the power emitted by radio transmitters is also limited by local regulations and standards, with maximum power limits typically ranging from 200 mW to 2 W, depending on the frequency band and cellular network used. An advantage is that the radio interface standard requires the base station to regulate the power emitted by the mobile communication equipment.

2.4. Satellite Communication Network

Satellite communication networks are used as media in a system whose UAVs operate in very remote areas from the CC or outside the range of MCNs. The UAV is equipped with a transceiver for satellite communications, through which it connects to the network of a specific satellite communications system – Figure 4.

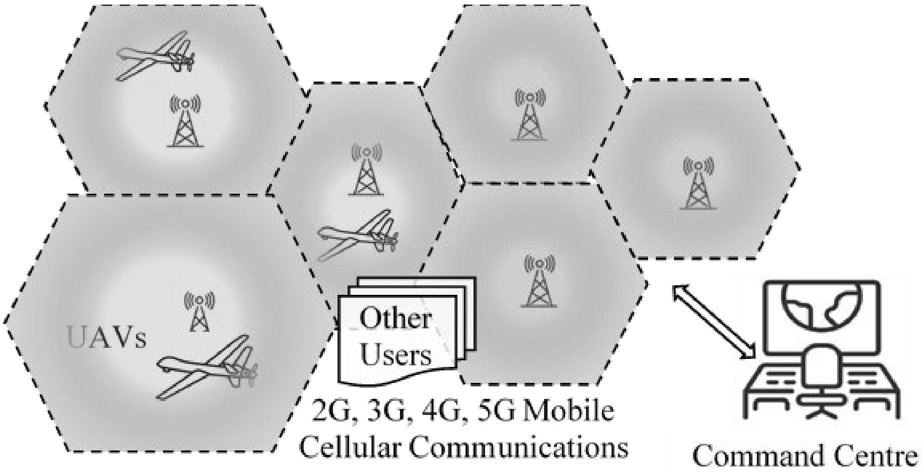

Figure 3: Mobile Cellular Network as a medium between UAVs and Control Centre

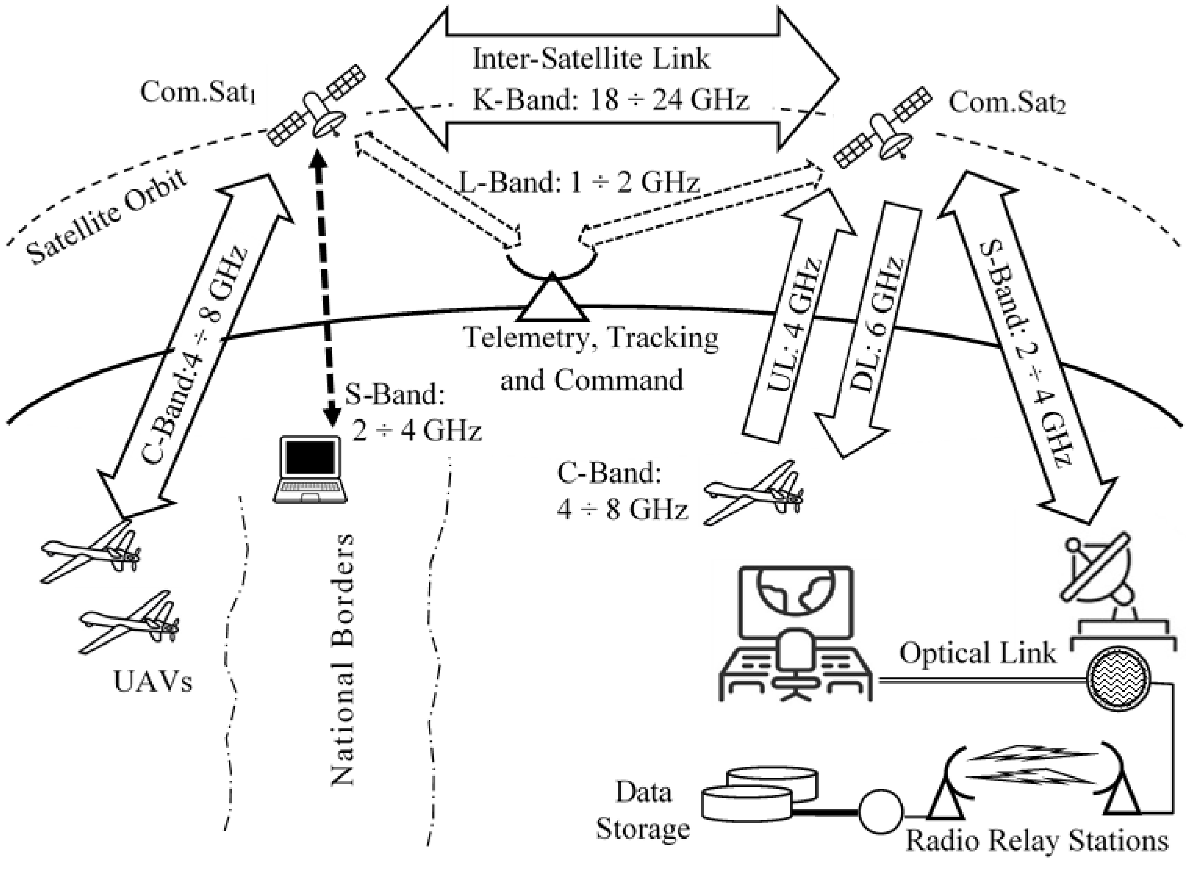

Figure 4: Satellite communication network as a medium between UAVs and Control Centre

The operator controls the UAV via a satellite communication terminal. Such equipment is also needed for the centres, responsible for the collection, storage, processing and analysis of the data obtained from the video and sensor equipment of the UAVs. Satellite communications work globally and are ideal for missions where UAVs operate in remote or hard-to-reach areas such as forests, deserts or mountains. Satellite communications are also very reliable as they are not susceptible to noise and interference compared to other communication methods. However, they require more transmitted power and are expensive, and UASs that use them as media are characterized by high latency. This means that control commands to the UAVs and data from them arrive at their destinations with a noticeable time delay. In UAS using communication satellites, frequencies range from 1 GHz to 40 GHz, in different frequency bands for the uplinks and the downlinks. Here, as with MCN, the principle of assigning the higher frequency transmission range to the equipment with more energy is applied. For inter-satellite links, the range around 22.5 GHz is most commonly used. The latter two conditions are related to the molecular absorption frequency dependence and peaks in it because of oxygen and water vapour in the Earth's atmosphere. Here it is relevant to note that any UAV, regardless of which system it belongs to, can have a GPS receiver on board, which significantly improves its operational characteristics.

3. Conclusions

Based on the considerations highlighted so far, some general conclusions can be drawn regarding the utility of communication technologies as media between the main elements of the UAS.

- The efficient performance of tasks by UASs requires a correct choice of a medium between its main elements – CC and UAVs. This is achieved through in-depth understanding of the strengths and weaknesses of the communication technologies used as such media.
- Strict compliance with local, national and regional regulations is required in the territories and airspace where UAS elements operate. This includes the frequency ranges and radiated power levels used, as well as with aviation safety requirements.
- Data transfer between CC and UAV is affected by many factors – noise and interference, signal strength, atmospheric conditions, etc. Choosing a suitable communication method and system is needed to provide an optimal balance between speed and reliability of this transfer.
- In-depth knowledge and research is also required for finding a practical balance between the probability of error in information flows and the latency of the system. This is achieved by properly estimating the maximum acceptable error probability for each data type and selecting an appropriate error correction method and code.

References List

[1] U.S. Department of Defense. *Unmanned Aircraft Systems (UAS). DoD Purpose and Operational Use.* 16 Feb. 2024. Available from https://dod.defense.gov/UAS/.

[2] Namuduri K., et al. UAV Networks and Communications. Cambridge University Press; 2018. pp. 26 – 57.

[3] Saad W., et al. *Wireless Communications and Networking for Unmanned Aerial Vehicles*. Cambridge University Press; 2020. pp. 123-144, 207 – 239.

[4] Rappaport T.S. *Wireless Communications: Principles and Practice*. Prentice Hall; 2002.

[5] Lin S., Costello D.J.Jr. *Error Control Coding*. Second Edition. London: Pearson; 2004.

[6] Sklar B. Digital Communications: Fundamentals and Applications. Second Edition. Moscow: Williams Publishing; 2004. pp. 331 – 543.

[7] Georgiev N.L.,et al. Main Means of Remote Control of Unmanned Aerial Vehicles with a Small Radius of Action, *International Journal “NDT Days”*. 2018. ISSN: 2603-4018.

[8] Vicetic B., Yuan J., Turbo Codes: *Principles and Applications*. New York: Springer; 2012. pp. 73–78.

[9] Tse D., Viswanath P. *Fundamentals of Wireless Communication*, Cambridge University Press; 2005. pp. 266 – 324.