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DATA TRANSMISSION STRATEGIES FOR UAV: AN OVERVIEW AND FUTURE PERSPECTIVES

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ABSTRACT

This paper presents a literature review on strategies for data transmission from small-sized Unmanned Aerial Vehicle (UAV). It is part of a preliminary investigation for further research on data transmission from UAV, which will help us to identify history and present state of this area. Some basic concepts of UAV are introduced in this literature review, and different applications are identified through surveys on this area. Through analysis of these applications, corresponding data are classified into three distinct types: radio control (RC) data, telemetry data and application sensor data. They are transmitted through different data links. The specifications of different data transmission strategies are compared on this paper. The most popular wireless network: Wi-Fi, 4G LTE and Bluetooth are also addressed on this paper, their features are measured on UAV data transmission scenes. The multi-UAV communication strategies are also discussed and the Flying Ad-Hoc Network (FANET) is introduced. At last a hypothesis about unified data transmission link is raised.

INTRODUCTION

This paper is a literature review on the art of data transmission from Unmanned Aerial Vehicle (UAV). Its purposes are exploring the UAV data transmission scope, extracting critical conceptions on this area, conducting comparisons to data transmission strategies, summarizing current circumstances, and raising hypothesis for further research. It also helps beginners or people who are interested in UAV data transmission have a glance on this field.

UAVs have become more and more popular on both military and civil fields. For distinct applications, different data transmission strategies are used. Some of these technologies have issues like instability, high coast, obsoleteness, complexity, etc. On the other hand, many wireless network communication technologies are updated in recent years. We claim that it is possible using wireless networks improve traditional strategies of data transmission from UAV.

This paper shows the process to verify this claim. First, we provide background and motivation behind the survey on the area of data transmission from UAV, including some basic knowledge on UAV and its applications on different domains. Some wireless network data transmission technologies are mentioned. We also discuss the motivation behind the idea of using wireless networks as an alternative to traditional UAV data transmission technologies. Then the discussion part will depict the details of three kinds of data links, which are classed by the type of data they transmit. Finally, a comparison between data transmission strategies from UAV is carried out. On the next section, three kinds of main stream wireless network technologies are introduced, and comparison between them on UAV data transmission scenes are conducted. We also introduce the multi-UAV communication strategies, especially Flying Ad-Hoc Network (FANET). The paper concludes with a summary and a hypothesis for future work.

BACKGROUND AND MOTIVATION

UAV, as abbreviation of Unmanned Aerial Vehicle or Uninhabited Aerial Vehicle, is referred to as “Drone” in daily life. They are aircrafts with no human pilot or passengers, whereas many sensors like altimeter, GPS receiver, camera, etc. With the help of data acquired by these sensors, the flight of a UAV can be controlled autonomously by onboard computers (e.g., programmed flight plans), operated by remote control of a pilot at ground control station (GCS), or manipulated by combination of former two methods (e.g., onboard autopilot combine radio control). The power supply of a drone can be jet, piston, or electric engine. Classified by construction, there are three major types of UAVs: fixed-wing, rotary-wing, and multi-rotor.

UAVs are utilized in both military and civil areas. The military role of UAVs has grown fast in the last ten years. Various countries are developing or have already released their own military UAVs, US military has implemented many drone strikes on the war to ISIS. Except using UAV directly as attack weapon, there are many other applications for drones in the battlefield, e.g., military network relay (Orfanus, Freitas, & Eliassen, 2016), battlefield circumstance surveillance (Ma'sum et al., 2013), even used as a cyber power (Hartmann & Giles, 2016) in the future. For civilian use, fixed-wing UAVs like aviation models are very popular among amateurs at first; they are normally used on agriculture and mapping. With the rise of multi-copter, more applications are explored based on its stable, easy control, and high payload, e.g., aerial photography, disaster victims rescue (Wolfe, Frobe, Shrinivasan, & Hsieh, 2015), cellular network reinforce (Afonso et al., 2016; Galkin, Kibilda, &

DaSilva, 2016; Merwaday & Guvenc, 2015; Sharma, Sabatini, & Ramasamy, 2016), Wi-Fi internet access (Gu, Zhou, Fu, & Wan, 2015), video surveillance (Qazi, Siddiqui, & Wagan, 2015), sensor network data collection (Say, Inata, Liu, & Shimamoto, 2016), etc.

With the development of UAV applications and new wireless data transmission technologies like 802.11ay, 5G, Bluetooth 5, etc. appear, data transmission has become a hot topic on UAV field. It's very necessary to make a review of the data transmission strategies used by UAV and compare their differences to find their advantages and disadvantages. These surveys will help us to find out which part of this area can be improved for further investigation.

AN OVERVIEW OF DATA TRANSMISSION METHODS

This section will make discussions on data transmission strategies for UAV and GCS.

Based on the requirements of distance, bandwidth, cost, reliability, anti-interference, etc., different data transmission strategies, which are called data links, are used. In telecommunication, a data link is the means of connecting one location to another for transmitting and receiving information. To build a data link, a set of electronic assemblies are needed, including transmitter, receiver and the interconnecting data telecommunication circuit. The data transmissions are governed by specific link protocol on a data link.

(Rochus & ULM, 2000) introduced UAV data link selection criteria, which help us to measure existing UAV data links. Based on these criteria and requirements of UAV applications, three kinds of data link are classified: Radio Control (RC) data link, telemetry data link, application data link.

Radio control data link

Fig. 1. RC controlled aviation model.

Normally, the flight path of a UAV is controlled from the GCS remotely. The commands, which are used to control direction, altitude, flying modes of UAV, are called flight control data. A wireless remote control data link for UAV should be dependable, fast, supporting long-rang communication, complying with radio regulations, etc. Radio frequency can totally meet these requirements, so it is widely used on small to middle-sized UAV remote control, this kind of data link is commonly referred as RC. Figure 1 show RC controlled aviation model.

For radio control, frequency band is a very important attribute, which will decide control range and bandwidth. Hertz (Hz), megahertz (MHz) and Gigahertz (GHz) are the units used to measure frequency. Each frequency band is divided in several channels. There are serval frequency bands allocated for RC depending on the country. Each frequency band is divided in serval channels. For European, most countries choose 35MHz as the frequency band for model aircraft ("Radio Control Frequencies," 2011), channels 55 to 90. In north America, the frequency band for model aircraft devices is 72MHz ("Radio Control (R/C) Radio Service," 2016), channels 11 to 60 with 20KHz separation. 2.4GHz "Spread Spectrum" technology is a new technology which can be used globally, it can scientifically eliminate interference.

There are various data encoding/decoding protocols for RC. Pulse Width Modulation (PWM) is a classic protocol used in early ages, the receivers are used to control the servos directly with standard PWM signal, providing one channel for each servo. Pulse Position Modulation (PPM) needs only one signal wire for several channels. A PPM signal is basically a series of PWM signals sent on the stream wire, so it is called "analog signal in time domain". Pulse Code Modulation (PCM) needs one signal wire as well, but its signal is digital, which gives it the potential of signal error detection even error correction. Serial protocol of RC is a group of protocols requires serial port on the flight controller. They are designed by different radio manufacturers, the widely used serial protocols are SBUS, IBUS, XBUS, DSM2 etc.

Recently, a new technology called "Spread Spectrum" become popular(S. x. Chen & Lv, 2009; Holubnychyi & Konakhovych, 2013; Yuan Jun, Jian Ming, & Xing Yun, 2016), which is likely to become part of the future of RC. On traditional RC systems as mentioned before, they need a frequency all to themselves if they are going to avoid interference with each other, because they are easily to be disrupted. A noisy thermostat or electric drill can often cause massive amounts of electrical interference. Whereas a 2.4GHz spread spectrum radio system can avoid these interferences, even all 2.4GHz systems can get along in harmony, despite apparently using the same frequency.

Telemetry data link

During the flight of a UAV, lots of flight status data are created by different sensors inside UAV. These data are very important and normally will be transmitted back to GCS to help the operator aware the flight status, so the data link transmitting flight status is also called telemetry data. UAV with autopilot controller often include the flight statues data into autopilot processing. So there are a variety of data acquisition system and flight control systems that log and process sensor data (Or D. Dantsker, 2014). We surveyed commonly used sensors on UAV and Table 1 shows these sensors and corresponding data collected from UAV. These data will be transmitted back to GCS through specific telemetry data link.

Table 1 Sensors and data of UAV

Sensor	Data	Unit
Inertial Measurement Unit	Attitude	degree
	Acceleration	m/sec^2
	Rotation Rate	rad/sec
	Magnetic Field	arb
GPS	Position	m
	Ground Speed	m/sec
	Velocity	m/sec
Magnetometers	Magnetic Field	arb
Altimeter	Altitude	m
Pitot probe	Airspeed	m/sec
Digital inputs	PWM signal	µsec
Analog inputs	Voltage divider	v

The industrial, scientific and medical (ISM) radio bands are radio bands reserved internationally for the use of radio frequency on industrial, scientific and medical purposes other than telecommunications. ITU Radio Regulations ("ITU Radio Regulation," 2012) defines radio bands can be used by ISM. ISM compatible devices bands have to tolerate interference from other ISM devices. In recent years, ISM bands like 915MHz (US), 433MHz (EU), 2.45GHz (International) have been widely used for telemetry data transmission from UAV.

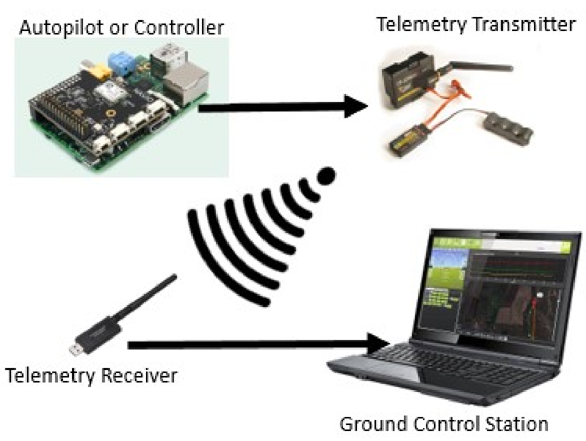

Fig. 2. Telemetry data link.

Figure 2 shows an integral telemetry data transmission process. At the beginning, the UAV controller or autopilot collects data from different sensors, the data will be formatted following specifically communication protocol, then the data stream will be sent to RF transmitter, which will transmit data to the GCS. The GCS consists of a RF receiver and a computer with professional telemetry software. Telemetry data will be decoded and displayed on the screen.

The most popular telemetry protocol nowadays is MAVLink which is a very lightweight, header-only message marshaling library for small size UAV. Since it is open source and free to use, it has been utilized by most of the commercial or open source autopilots and GCS software. MAVLink can transmit control data, telemetry sensor data and even live video stream.

QControl Ground Station (QGC) is one widely used open source GCS. It provides full flight control and mission planning for any MAVLink enabled UAV. QGC can run on Windows, OSX, Linux, iOS and android devices. On QGC, there is one flight map display showing telemetry information from MAVLink capable vehicle.

Application data link

As a floating platform on the sky, many applications, e.g., live onboard video stream, Wi-Fi access, cellular network reinforcement, are implemented on a UAV. Transmitting application data from UAV has become a hot topic. Except traditional radio frequency transmission, package-switch based wireless networks have become the best solution for small-sized UAV application data transmission. Wi-Fi, Bluetooth, Cellular network are options on this list.

Many regulations should be measured before choosing a proper data link for a UAV application (Rochus & ULM, 2000). Normally a new data link will be set specially for a specific application except the RC data link and telemetry data link. To build an application data link, many requirements need to be satisfied. The application data link radio frequencies should be different for RC and telemetry data link, which would help to avoid interference or even destruction. Also, range, bandwidth and latency should be considered. The environment and expense will decide which strategies should be used for application data transmission.

In applications, such as UAV racing, surveillance (Qazi et al., 2015), target search(Kingston, Rasmussen, & Humphrey, 2016), photography (X. Li & Yang, 2012), etc., a typical function, transmitting live video stream from onboard camera to ground station is needed. This system is called first-person view (FPV) (Mhatre et al., 2015). FPV system contains an onboard camera connected with an analogue video transmitter, a video receiver like monitor or goggles on the ground. The signal is totally analogy to make sure there is no latency, then user can have a truly immersive, first-person experience. Some application use Wi-Fi to stream video, which will lead into latency because of the video compress process and Internet protocol. It's acceptable when the latency is well controlled. Also, the digital video stream is easy to be stored or processed.

Another popular application of UAV is providing temporary Internet or cellular network access (Afonso et al., 2016; Galkin et al., 2016; Gu et al., 2015; Merwaday & Guvenc, 2015; Sharma et al., 2016).This is very important for disaster rescue, big even, ceremony, etc.

Since the application data link highly depends on the data type it translates and there are so much options, it is very hard to choose a proper data link for a specific application. As we mentioned before, MAVlink is an open source protocol that can package and transmit telemetry data. It can also be extended to other kinds of data, even digital video stream. So, it is feasible to build a general platform based on MAVLink protocol. But for some time and bandwidth sensitive applications like live video stream, the wireless network will be bottleneck. Next section depicts possible wireless networks can be used for UAV data link.

Comparison between UAV data links

The International Telecommunication Union (ITU), specifies which parts of the radio spectrum are to be used for different radio transmission technologies and applications ("ITU Radio Regulation," 2012). However, different countries and areas many have different regulations regarding radio frequency allocation. Considering the distance and bandwidth, RC link prefer to choose lower frequencies, because it do not need much data to transmit (just serval channel control signals). Whereas telemetry data link and application data link the normally used higher frequency because the bigger of the frequency, the bigger the bandwidth can be, so higher data transfer rate will be supported. For the radio transmission range, it is decided by both maximum transmit power, the receiver sensitivity, environment, antenna length, etc. But on the same situation, the smaller the radio frequency, the longer distance it will be transmitted.

Table 2 UAV data link comparison

	RC Data Link	Telemetry Data Link	Application Data Link
Frequency	35MHz (EU)	433MHz (EU)	See Table 3.
	72MHz (US)	915MHz (US)	
	2.4GHz (Global)	2.45GHz (Global)	
Bandwidth	Slow	Medium	Fast
Distance	Long	Medium	Vary with solutions

We made a brief comparison for three types of UAV data links. Table 2 shows details about this comparison. Three criteria are measured on this table: frequencies, bandwidth and distance. RC data link and telemetry data link are more mature than application data link, they have been used for a long time as UAV datalink. Application data link is based on wireless networks, which provide more options for different applications.

WIRELESS NETWORKS

Wireless network uses wireless data connection for connecting network nodes. There are a handful of different wireless networks like WPAN, WLAN, WMAN, etc. Every kind of wireless network has their unique definition on both Physical and Data link layers. Wireless networks are good options for UAV application data transmission. On this section, Wi-Fi, Bluetooth and Cellular network are discussed for small-sized civilian UAV data transmission scenes.

WLAN connects devices using a wireless distribution method. It can just cover a limited area such restaurant, home, museum. A WLAN users can move around inside the coverage area and keep connecting with network. WLAN can also provide users accessibility to the Internet.

Most WLANs used today are based on IEEE 802.11 standards and are marketed under the Wi-Fi brand name. It is a technology that allows electronic devices to connect to a wireless LAN (WLAN) network, mainly using the 2.4GHz UHF and 5GHz SHF ISM radio bands. Wi-Fi family consists of a series of standards; 802.11b was the first widely accepted one, followed by 802.11a, 802.11g, 802.11n and 802.11ac. 802.11n can use either the 2.4GHz or the 5GHz band. It operates at a maximum net data rate from 54Mbit/s to 600Mbit/s. 802.11ac builds on 802.11n and uses only the 5GHz band. It adds more spatial streams, higher-order modulation, and Multi-user MIMO technology, yielding a data rate of up to 433.3 Mbit/s per spatial stream, 1300 Mbit/s total. They are the latest two standards, which has become main stream in the Wi-Fi products market.

Cellular network provides both voice and data transmission service through the wireless link between base station and user mobile device. Telecommunication providers have deployed cellular networks over most urban and rural area where people live. Cellular network has experienced 1G-Analogue cellular, 2G-Digital cellular, 3G-Mobile broadband and 4G-Native IP networks for now. 5G should be rolled out by 2020 to meet business and consumer demands.

Long-Term Evolution (LTE) is the most popular 4G standard used in the word by now. The LTE 4G cellular network can provide 300 Mbit/s peak downlink rate and 75 Mbit/s uplink peak rates. It can manage high mobility connection and support multi-cast and broadcast stream. LTE supports a wide range of carrier bandwidths (1.4MHz to 20MHz) and both frequency division duplexing (FDD) and time-division duplexing (TDD) spectrum technologies. Its Evolved Packet Core (EPC) is an IP-based network architecture, which results in lower cost on operation.

Bluetooth is a wireless communication technology designed for connecting devices over a certain distance, e.g. phone and headset, PC and speaker. The Bluetooth Special Interest Group (SIG) in charge of the development and licensing of Bluetooth. Bluetooth uses frequency hopping spread spectrum technology, it is a packet-based communication protocol based on a master-slave structure. One master can communicate with up to seven slaves at the same time.

On June 2016, The Bluetooth Special Interest Group (SIG) announced Bluetooth 5. It will provide four times longer communication range, doubled speed and eight times increase on broadcast messaging capacity. Extending range will deliver robust, reliable Internet of Things (IoT) connections that make full-home and building and outdoor use cases a reality. Bluetooth 5 supports 50Mbits/s maximum speed and 800 feet (243.84m) maximum range.

Quality of Service (QoS) is the overall performance of a telephony or computer network. To compare the performance of wireless networks, several aspects about QoS should be considered, such as throughput, latency, bit rate, error rate, jitter, etc.

We collected WiFi, Blutooth, and 4G-LTE specifications, because they are the mostly used wireless network today. Table 3 shows a comparison between them.

Table 3 Wireless network data link comparison

	802.11n	802.11ac	Bluetooth 4	4G-LTE
Frequency	2.4GHz, 5GHz	5GHz	2.4GHz	2-8GHz
Bandwidth (theoretical)	150Mbps	450Mbps	25Mbps	1 Gbps
Distance (max)	250m	250m	60.96m	3-5km
Latency (average)	200ms	200ms	100ms	5ms
Power Consumption	High	High	Low	Medium
Security	Medium	Medium	Low	High

These wireless networks have been very mature and widely used in our daily life, but they all have some disadvantages for UAV data transmission. Wi-Fi can be the first choice of UAV data transmission, since it provides a proper link distance, fast speed and medium cost, but it needs more power to work and the latency is not small enough. There are still many popular products using optimized Wi-Fi wireless network. Since Bluetooth is designed for data transmission between two or devices that are near each other when speed is not an issue, its designing requirements are totally different with UAV data transmission high speed, long distance requirement, so it is not fit to be used as UAV datalink. 4G cellular network seems to be the best choice for small-sized UAV data transmission. It can provide both high speed and longer distance for data transmission. Also, the QoS make sure low latency for time sensitive data transmission. Since cellular network highly depends on the base station coverage, its application for UAV data transmission is limited in urban or rural area where cellular network has covered. Also, the price for access to 4G is higher, the 4G equipment and data expense will cost more than Wi-Fi and Bluetooth.

MULTI-UAV COMMUNICATION STRATEGIES

The data links introduced on former sections are in the scenario of one single UAV communicates with its GCS. In some scenarios, such as mapping (Mahdoui, Natalizio, & Fremont, 2016), battlefield (Orfanus et al., 2016), disaster (Erdelj & Natalizio, 2016), the cooperation of multiple UAVs is needed. They can jointly conduct missions such as surveying, reconnaissance, monitoring, detection, search and rescue while enjoying the reduced cost and increased reliability of multi-UAV communication. Multi-UAV will provide better solution and play an important role.

There are many advantages of implementing multiple UAVs rather than a single powerful one on some specific tasks. The execution time will be dramatically decreased when use multiple UAVs simultaneously; The whole system is more robust and redundant, and fault tolerance and flexibility can be improved, one failure of individual vehicle can be replaced by other UAVs; Sometimes, using one high performance UAV could be an expensive solution, but a cheaper solution using a team of low cost UAVs can easily face the constraints imposed on individual UAVs such as power consumption, weight, size and range. The features of multi-UAV communication make it a focus on UAV research.

One of the hot topic of multi-UAV is its communication strategy. Numerous researches have been done on multi-UAV communication strategies of different scenarios. Li et al. (B. Li, Jiang, Sun, Cai, & Wen, 2016) developed and tested a two-UAV communication Relay system, which can extend the communication range and build communication over obstacles; Cesare et al. (Cesare, Skeele, Soo-Hyun, Yawei, & Hollinger, 2015) made an algorithm for multi-UAV system to maximize the efficiency of exploring and mapping an unknown environment when a team is faced with unreliable communication and limited battery life. (J. Chen, Fei, & Geng, 2012) shows the data link design for GCS and multi-UAVs.

There are also lots of research focus on FANET (Bekmezci, Sen, & Erkalkan, 2015; Temel & Bekmezci, 2014). A wireless ad hoc network is the decentralized wireless network which does not rely on an existed infrastructure such as a router or base station. Each node on this network participates in routing by forward data for other nodes. Mobile Ad-Hoc Network (MANET) and Vehicular Ad-Hoc Network (VANET) are two popular ad hoc networks for mobile phones and cars, so FANET is basically ad hoc network between UAVs. Figure 3 shows a typical FANET of UAVs. The traditional communication between UAVs is provided by the GCS through satellite or infrastructure. But these kinds of communication architectures restrict coordination and collaboration of UAVs. FANET is a distributed wireless network structure that allows communication among nodes without the need for infrastructure, which can properly solve these problems.

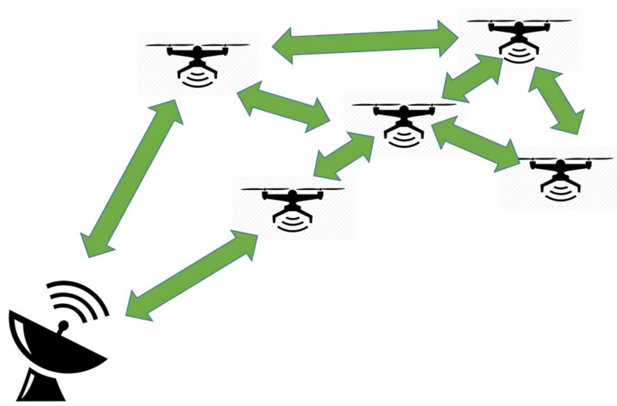

Fig. 3. A typical FANET of multi-UAVs.

CONCLUSION

The strategies of data transmission from small-sized Unmanned Aerial Vehicle (UAV) have been researched on this paper. Some basic concepts of UAV are introduced at this literature review, and different applications are identified through surveys on this area. Through analysis of these applications, corresponding data link are classified into three distinct types: RC data link, Telemetry data link and application data link. The specifications of different data transmission strategies are compared. To choose proper application data link, three most popular wireless networks: Wi-Fi, 4G LTE and Bluetooth are introduced on this paper, their features are measured on UAV data transmission scenes. And an introduction about multi-UAV communication strategies is also introduced at last.

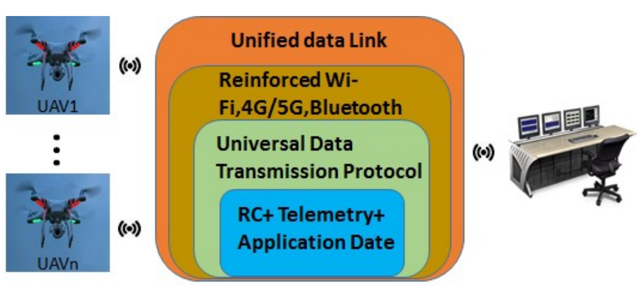

Fig. 4. Unified data link.

Based on the former research, some trends can be identified on the UAV data transmission area: RC data link and Telemetry data link can be substituted by Application data link if it can support a stable, low latency data transmission service even at low speed; Application data link as a general data transmission link could be implemented on a universal data transmission protocol e.g., TCP/IP, UDP, MAVLink. The enhanced Wi-Fi based application data link will be main stream on market and more 4G or 5G based data link will be used for time-sensitive, large data flow, long distance applications using UAV. One hypothesis is raised for future study on this area: A general UAV data transmission framework that can transmit both RC data, telemetry data and general application data. Wi-Fi, cellular network and Bluetooth will be chosen depending on specific mission. Figure 4 shows the structure of this hypothesis.

It should be declared that this framework is not mean to build a UAV data transmission system that fits all airborne applications, since different applications have their special requirements i.e. cost, range, throughout, interference etc. In contrast, it is just a framework, which is optional on data links and using FANETs or not, compared with a fixed and unchangeable system. This framework will help airborne applications quickly find out their UAV data transmission strategies according to their specific requirements.

REFERENCES

Afonso, L., Souto, N., Sebastiao, P., Ribeiro, M., Tavares, T., & Marinheiro, R. (2016). Cellular for the skies: Exploiting mobile network infrastructure for low altitude air-to-ground communications. *IEEE Aerospace and Electronic Systems Magazine, 31*(8), 4-11. doi:10.1109/MAES.2016.150170

Bekmezci, I., Sen, I., & Erkalkan, E. (2015, 16-19 June 2015). *Flying ad hoc networks (FANET) test bed implementation.* Paper presented at the Recent Advances in Space Technologies (RAST), 2015 7th International Conference on.

Cesare, K., Skeele, R., Soo-Hyun, Y., Yawei, Z., & Hollinger, G. (2015, 26-30 May 2015). *Multi-UAV exploration with limited communication and battery.* Paper presented at the 2015 IEEE International Conference on Robotics and Automation (ICRA).

Chen, J., Fei, Q., & Geng, Q. (2012, 26-27 Aug. 2012). *The Design of Data Link for Multi-UAVs.* Paper presented at the Intelligent Human-Machine Systems and Cybernetics (IHMSC), 2012 4th International Conference on.

Chen, S. x., & Lv, J. l. (2009, 26-28 Dec. 2009). *A Study of the Performance of Hybrid DS/FH Spread Spectrum Systems under UAV Fading Channel.* Paper presented at the 2009 First International Conference on Information Science and Engineering.

Erdelj, M., & Natalizio, E. (2016, 15-18 Feb. 2016). *UAV-assisted disaster management: Applications and open issues.* Paper presented at the 2016 International Conference on Computing, Networking and Communications (ICNC).

Galkin, B., Kibilda, J., & DaSilva, L. A. (2016, 23-25 March 2016). *Deployment of UAV-mounted access points according to spatial user locations in two-tier* *cellular networks.* Paper presented at the 2016 Wireless Days (WD).

Gu, Y., Zhou, M., Fu, S., & Wan, Y. (2015, 9-12 March 2015). *Airborne WiFi networks through directional antennae: An experimental study.* Paper presented at the 2015 IEEE Wireless Communications and Networking Conference (WCNC).

Hartmann, K., & Giles, K. (2016, May 31 2016-June 3 2016). *UAV exploitation: A new domain for cyber power.* Paper presented at the 2016 8th International Conference on Cyber Conflict (CyCon).

Holubnychyi, A. G., & Konakhovych, G. F. (2013, 15-17 Oct. 2013). *Spread-spectrum control channels for UAV based on the generalized binary Barker sequences.* Paper presented at the Actual Problems of Unmanned Air Vehicles Developments Proceedings (APUAVD), 2013 IEEE 2nd International Conference.

ITU Radio Regulation, (2012).

Kingston, D., Rasmussen, S., & Humphrey, L. (2016, 19-22 Sept. 2016). *Automated UAV tasks for search and surveillance.* Paper presented at the 2016 IEEE Conference on Control Applications (CCA).

Li, B., Jiang, Y., Sun, J., Cai, L., & Wen, C.-Y. (2016). Development and Testing of a Two-UAV Communication Relay System. *Sensors, 16*(10), 1696.

Li, X., & Yang, L. (2012, 26-27 Aug. 2012). *Design and Implementation of UAV Intelligent Aerial Photography System.* Paper presented at the Intelligent Human-Machine Systems and Cybernetics (IHMSC), 2012 4th International Conference on.

Ma'sum, M. A., Arrofi, M. K., Jati, G., Arifin, F., Kurniawan, M. N., Mursanto, P., & Jatmiko, W. (2013, 28-29 Sept. 2013). *Simulation of intelligent Unmanned Aerial Vehicle (UAV) For military surveillance.* Paper presented at the Advanced Computer Science and Information Systems (ICACSIS), 2013 International Conference on.

Mahdoui, N., Natalizio, E., & Fremont, V. (2016, 15-18 Feb. 2016). *Multi-UAVs network communication study for distributed visual simultaneous localization and mapping.* Paper presented at the 2016 International Conference on Computing, Networking and Communications (ICNC).

Merwaday, A., & Guvenc, I. (2015, 9-12 March 2015). *UAV assisted heterogeneous networks for public safety communications.* Paper presented at the Wireless Communications and Networking Conference Workshops (WCNCW), 2015 IEEE.

Mhatre, V., Chavan, S., Samuel, A., Patil, A., Chittimilla, A., & Kumar, N. (2015, 2-3 Nov. 2015). *Embedded video processing and data acquisition for unmanned aerial vehicle.* Paper presented at the 2015 International Conference on Computers, Communications, and Systems (ICCCS).

Or D. Dantsker, R. M., Michael S. Selig, Marco Caccamo. (2014). High-Frequency Sensor Data Acquisition System (SDAC) for Flight Control and Aerodynamic Data Collection Research on Small to Mid-Sized UAVs. *AIAA Paper*(2014-2565), 16.

Orfanus, D., Freitas, E. P. d., & Eliassen, F. (2016). Self-Organization as a Supporting Paradigm for Military UAV Relay Networks. *IEEE Communications Letters, 20*(4), 804-807. doi:10.1109/LCOMM.2016.2524405

Qazi, S., Siddiqui, A. S., & Wagan, A. I. (2015, 17-19 Dec. 2015). *UAV based real time video surveillance over 4G LTE.* Paper presented at the 2015 International Conference on Open Source Systems & Technologies (ICOSST).

Radio Control (R/C) Radio Service, (2016).

Radio Control Frequencies, (2011).

Rochus, W. W., & ULM, D. C. A. (2000). *UAV Data-Links: Tasks, Types, Technologies and Examples*: Defense Technical Information Center.

Say, S., Inata, H., Liu, J., & Shimamoto, S. (2016). Priority-Based Data Gathering Framework in UAV-Assisted Wireless Sensor Networks. *IEEE Sensors Journal, 16*(14), 5785-5794. doi:10.1109/JSEN.2016.2568260

Sharma, V., Sabatini, R., & Ramasamy, S. (2016). UAVs Assisted Delay Optimization in Heterogeneous Wireless Networks. *IEEE Communications Letters, PP*(99), 1-1. doi:10.1109/LCOMM.2016.2609900

Temel, S., & Bekmezci, I. (2014, 27-30 May 2014). *Scalability analysis of Flying Ad Hoc Networks (FANETs): A directional antenna approach.* Paper presented at the Communications and Networking (BlackSeaCom), 2014 IEEE International Black Sea Conference on.

Wolfe, V., Frobe, W., Shrinivasan, V., & Hsieh, T. Y. (2015, 9-12 June 2015). *Detecting and locating cell phone signals from avalanche victims using unmanned aerial vehicles.* Paper presented at the Unmanned Aircraft Systems (ICUAS), 2015 International Conference on.

Yuan Jun, Z., Jian Ming, Z., & Xing Yun, Z. (2016, 8-11 Aug. 2016). *Application of a new spread spectrum method based on M-sequence in airborne data-link.* Paper presented at the 2016 Progress in Electromagnetic Research Symposium (PIERS).