A survey for UAV open-source telemetry protocols

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ABSTRACT

One of the most important sections on UAV technologies is the telemetry communication. Due to the growing needs of UAV applications a number of telemetry protocols are available. Different telemetry protocols can be used in several applications. In this paper we adduce the most important open-source telemetry protocols and their main features. For the most critical UAV application domains we present the most significant telemetry protocols and their characteristics. Afterwards, we compare and classify the telemetry protocols, depending the needs of the UAV application domains. Finally, we propose the most suitable telemetry protocol for each UAV application domain.

KEYWORDS

Telemetry protocols, UAVs, application domains

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1 INTRODUCTION

In recent times the Unmanned Aerial Vehicles (UAVs), have become an integral part of everyday life. UAV applications are rapidly emerging, resulting in high investments and increment of job positions. Applications in health sectors, military operations, vehicle speed monitoring, construction of small buildings and mapping of agricultural areas, are few examples of how UAVs contribute in our daily routine. Also, UAVs have important participation in critical situations such as flood and fire rescues, delivery essentials and network coverage in remote areas. The main domains that include UAV applications are: Search and Rescue (SAR), construction, delivery of goods, monitoring and mapping, visual tracking and surveillance and network coverage provisioning. Hence, the UAVs demanding expectations must be supported by new ideas and revolutionary design implementations. The UAVs are now the most considerable systems for several application domains. This fact motivates the researchers to constantly develop and find solutions to meet the contemporary demands. Especially, in the field of UAV communication there are many different approaches and implementations. The UAVs' communication function is based on the telemetry technologies and protocols. Telemetry on the UAVs' implementations is the configuration and data exchanged between the flight controller of the vehicle and the ground station. Nowadays, there are several protocols which provide different kind of services. For instance, there many protocols that can be used for applications that require long distance, security, low cost etc. However, there is no clear path for the designer to decide which protocol is the more beneficial one according the requirements of a specific application. This fact leads to multiple choices and complexity. Choosing a telemetry protocol is crucial for meeting the UAV applications requirements and for efficient operation in terms of performance and power consumption.

Existing scientific publications [1, 2], point to the characteristics of one or more protocols, but they don't provide a solution to this problem.

In this paper, the characteristics of the most important UAV communication protocols are presented according to the requirements of the most significant application domains. Then, the most suitable protocol is recommended for each domain. We focus on opensource protocols, as they are more advantageous than the commercial ones. They are less expensive, easy to configure and modify and they also operate with other systems and modules without the commitment to any vendors. Therefore, they are increasingly used at telemetry applications.

The rest of paper is structured as follows: In section 2, the main telemetry protocols are presented and analyzed. In section 3, the domain applications are analyzed according to their telemetry needs. Then, for each application domain the protocols are evaluated. The features of each protocol are the key factors for fulfilling the needs of the requirements of each application domain. The most well-suited protocols are presented at the end of this section. Finally, section 4 concludes this paper.

2 RELATED WORK

The UAV telemetry protocols are very important for the communication and the control of the UAV systems. These protocols can be opensource e.g., MAVink or closed DJI (Da-Jiang innovations) Lightbridge [3]. In this research we focus on the open-source telemetry

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protocols. Opensource protocols are more advantageous compared to the commercial protocols. More details on the most significant open-source protocols will be given bellow.

MAVlink (Micro Air Vehicle Link) is a very lightweight messaging protocol for bidirectional [4] communication between drones and onboard drone components. It is built for hybrid networks where high-rate data streams drones flow to ground stations, but are mixed with transfers requiring guaranteed delivery. The maximum data rate can reach 250 kbps, and the maximum range is typically expected to be 500m, but highly dependent on the environment and level of noise and antenna setup. MAVLink is deployed in two major versions: v1.0 and v2.0, which is backwards-compatible. Telemetry data streams are sent in a multicast design while protocol aspects that change the system configuration and require guaranteed delivery like the mission protocol or parameter protocol are point-to-point with retransmission [5]. MAVlink can support swarms of drones with mesh topology using the MAVproxy ground control unit feature [6]. As for authentication MAVlink supports no authentication mechanism (nor authorization) which leads to a variety of attacks.

ZigBee is a telemetry technology based on a number of nodes that consist of smart objects and provide different functions. It is a short-range telemetry protocol and is ideal for applications with requirements bounded by 10 meters as minimum distance and 100 meters as maximum distance. It supports applications with operating frequency at 816MHz, 915MHz and 2,4GHz (typically). The transmission rate is depended by the frequency band, the maximum transmission rate is 250Kbps at 2,4 GHz [7, 8]. Additionally, the combination of anti-interference and high reliability features that are supported, makes it efficient in areas with poor GPS signal, such as places where obstacles (e.g., buildings) are blocking the signal transmission [9]. The main advantage of ZigBee is the low complexity technology protocol with low energy requirements. ZigBee modules can have batteries that last for more than a half year, due to the sleep mode that ZigBee becomes active when it is not working. In addition, ZigBee protocol supports low-cost modules but with high sensitivity and flexibility [10]. The most common network topology that ZigBee can apply is mess topology but it can also apply on star, hybrid and ad-hoc topologies [11]. As for safety [12], ZigBee offers high secure data transmission services. The section of Data encryption consists of a symmetric key and 128-bit Encryption Standard algorithms (AES) [13] and data integrity section, secures the instant data transfer due to the message integrity code (MIC) [14].

LoRaWAN (Long Range Wide Area Network) [15] is a telemetry communication protocol based on LoRa [16] modulation for long-range distance network applications. It can be used for urban and suburban areas and covers long distances from 5 km (urban) to 15km (suburban). Additionally, it is a low frequency band protocol (868 and 900 MHz) that can operate on projects based on Industrial and Medical [17] frequency band. LoRaWAN is developed to support technologies like Low Power Wide Area Networks (LPWAN) [18] that are power efficient, but they perform on bidirectional low speed communication (between 0.3 and 50 Kbps). Hence, it isn't recommended for high-speed applications and real time data [17]. The supported network topology is star [19], it is composed of a Network Server that proceed as main controller, Gateways that collect and transmit data and end devices that operate as relays between the Network Server and Gateways.

According to [20] LoRaWAN topology allows the operation on systems that ground station can detect UAVs and communicate at long ranges using the minimal possible infrastructure. Therefore, the cost for purchasing such systems is extremely low. Additionally, it is suitable for developing swarm systems up to 72 drones. Security for transmitted data is provided using AES for encryption and authentication [21].

MQTT (Message Queuing Telemetry Transport) [22] is a publish/subscribe protocol that allows edge-of-network devices (clients) to publish or to subscribe/consume to a broker (server). A client sends and receives data and the broker exchanges integral data. This motivates the ability of data sharing as well as to control and manage the system devices. It operates on top of TCP/IP level and has slow throughput on high or low latency and on high bandwidth network. It is a telemetry protocol that commonly supports short-range communication [23]. MQTT is a high reliability technology since it maintains stateful session awareness. The lightweight and efficiency of MQTT makes it possible to significantly increase the amount of data being monitored or controlled. Concerning security, MQTT provides authentication of every user who intends to publish or subscribe to particular data. The supported topology is mess [24].

Open Long-Term Evolution (Open-LTE) [25] is an open-source implementation of the 3GPP LTE specifications, which is a standard for wireless broadband communication for mobile devices and data terminals. The main goal of Open-LTE is to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments. Moreover, its network architecture has been designed with the goal to support packet-switched traffic with seamless mobility and Quality of Service (QoS) [26]. Open-LTE architecture supports hard QoS, with end-to-end quality of service and guaranteed bit rate (GBR) for radio bearers. Open-LTE protocol offers two-way communication. The supported network topology for Open-LTE is the mesh topology [27]. Concerning performance, Open-LTE covers the entire range of minimum download speeds from 3G's 20 Mbps to 4G's 100 Mbps, giving it a massive range of potential speeds. However, it requires subscription to operate, which increases the cost [28].

3 EVALUATION OF TELEMETRY PROTOCOLS

UAVs have a great number of applications that the latest years are utilized. This research focuses on specific application domains that are more common and critical. These are search and rescue (SAR), construction, delivery of goods, monitoring and mapping, visual tracking and surveillance, network coverage provisioning.

Figure 1. Presents the main civil application domains that UAVs commonly performs. These application domains will be analyzed and correlated with the features of the telemetric protocol that have been mentioned in the previous chapter.

- Search and rescue (SAR).

The effects caused by the dangerous climate changes (earthquakes, floods), or human caused disasters, (fires) affect thousands of people all over the world. Hence, one of the most important and life-valued UAVs missions is the SAR. More specific, SAR is the

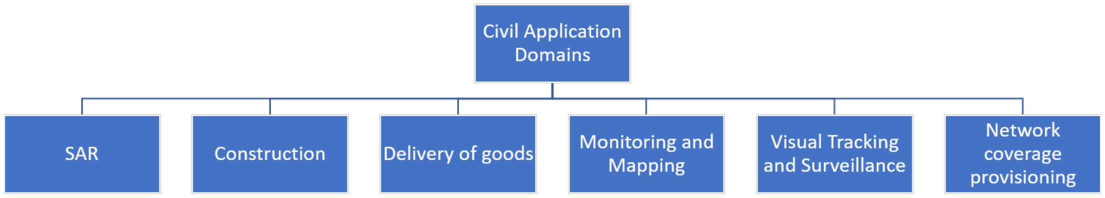

Figure 1: Civil application domains for UAVs.

capability of the UAV to search and find targets (single or multiple), to keep the track of the intended target, and to manage the rescue as soon as possible [29]. Due to the critical requirements of SAR, the time response and reliability are the most significant features. Additionally, demanding equipment are used (cameras, sensors), real time images are exchanged and positioning features care from the UAVs to the ground station [30] are implemented. As for performance it depends on the kind of mission and it varies from 4.8kbps (transmission of images) to 2Mbps (video streaming). SAR' s coverage area, depends on the mission case. ZigBee and MQTT can cover short-area missions with satisfactory data speed rate. MAVlink supports similar data rates with the previous protocols. However, it doesn't contain any authentication mechanism. Open-LTE and LoraWAN apply on long-area missions. LoraWan can't support video streaming, since it performs on slow data rate. Open-LTE is the best option. It overcovers the required maximum data speed transmission. Also, offers high reliability and quick response, supporting mess network topology which usually apply on SAR missions. Open-LTE requires licenses which increases the cost. However, this cost is considered as insignificant due to the importance of the SAR application domain.

- Construction

Construction is one of the most recent application domains for UAVs. It refers to the cooperation of a group of UAVs to accomplish constructions like buildings. More precisely a team of UAVs cooperate to place components to specific places in order to complete the construction. This application domain is based on good synchronization with emphasis on safety and reliability. The construction area range at 10x10 meters. Therefore, short-range, quick-response and real-time protocols can be applied; like ZigBee, MAVlink, and MQTT. Long-range protocols like LoRaWan are low response in order to cover large areas, hence isn't suitable for construction. On the contrary, Open-LTE performs on high data rate transmission with low latency, but it is more expensive than the recommended short-range protocols. MAVlink is a lightweight and quick response protocol, but it doesn't provide any secure mechanism [31]. MQTT and ZigBee are quick response, real time protocols that can apply on construction. But the best option for this case is ZigBee. It consists of a system of nodes, which act as smart objects and carry out different functions, with high reliability and flexibility [32]. ZigBee's mess topology can support a swarm of UAVs whenever is necessary. Moreover, it operates efficiently, overcoming problems caused by interference and position accuracy.

- Delivery of goods

In several places around the world, drones are being used for time-sensitive deliveries, such as medicine, and for deliveries that would be difficult to make using traditional vehicles. Delivery drones have the potential to change last mile delivery economics for smaller and lighter packages by replacing many deliveries currently made by traditional delivery vehicles. A delivery drone is an unmanned aerial vehicle (UAV) used to transport packages, medical supplies, food, or other goods. Delivery drones are typically autonomous, low power and rely on ground control systems both for safe operations and for their commercial operations. For safe operations, the drone operator needs to manage their fleet of aircraft and how they integrate into the broader airspace. For commercial use cases, the ground systems allow for receiving and tracking orders. The parameters for delivery of goods requires long-range and low power telemetry communication, with high security and reliability of UAVs communication with the ground control station [33]. MAVlink, ZigBee and MQTT are short-range protocols, hence they can't apply on this case. LoRaWAN and Open-LTE are suitable for those kinds of applications due to the long-distance coverage. Open-LTE can perform on 100Mbps, because it supports packet-switched traffic and hard QoS. Additional, is a reliable and secure protocol. Open-LTE disadvantage is the increased cost, due to the subscription requirement. Compared to LTE, LoRaWAN supports low power technologies which performs between 0.3 and 50 Kbps, nevertheless delivery of goods doesn't require real time data transfer (< 250Kbps). Additionally, LoRaWAN offers AES security and it can interconnect with more than one drone. LoRaWAN is the best option for delivery of goods domain application.

- Monitoring and Mapping

The usage of UAV's technology on the monitoring and mapping areas (such as forests, agricultural fields, archeological sites), is widely widespread. These applications usually begin data processing after the UAV finishes its mission, hence the process of monitoring and mapping is non demanding on data rate and the data transmission isn't required to be in real time (it supports periodic data traffic). The most significant feature for this application domain is the lightweight and the high reliability [34]. According to [35], the area coverage can be classified in three domains: small, middle and large size areas. For small size areas (e.g., inspection in mining areas), ZigBee, MAVlink, MQTT can support the telemetry requirements. Zigbee's technology of nodes with smart objects increase the reliability of this protocol. MQTT is a high reliability protocol too, thanks to maintaining the stateful session awareness [36]. MAVlink is more suitable in this case because is more lightweight than ZigBee and MQTT, data rate traffic in this case isn't considered as high priority. Additionally, the missions for small sized areas are offering operations in the line of Sight, so the lack of security system doesn't affect the mission's success. The middle and large areas can be handled by the LoRaWAN and Open-LTE technology, because they can cover large areas. Open-LTE has high data speed rate unlike LoRaWAN but the speed of data traffic isn't considered as high priority. LoRaWAN has slow data transmission, but using the minimal possible infrastructure, makes it lightweight and low power system, which is ideal for these kind of area missions.

- Visual Tracking and Surveillance

Over recent years, as result of the rapid development of UAV technologies, visual tracking and surveillance not only can be fully performed, but also continues to evolve rapidly. The most common usable applications considering object detection e.g., person identification and observation of the vehicles during traffic. Visual surveillance is a demanding application. The detection, identification and observation of the target requires high resolution images with large frames, fast response and real time processing. The transmitted data, liking SAR, can vary from 4.8Kbps to 2Mbps (video streaming) [37]. ZigBee, MAVlink, MQTT and Open-LTE are high speed rate protocols and offer real time traffic response. LoRaWAN performs at 50kbps, therefore it isn't suitable in this case. MAVlink lacks in authentication, which makes it less secure. ZigBee and MQTT are very reliable, lightweight protocols with similar performances on data rate, fast response and low cost [38]. Open-LTE supports the highest data rate, 10 -100Mbps with extreme low latency and can apply on demanding implementations, like surveillance with video streaming. Open-LTE requires subscription which increases the actual cost, but it is the best option because it covers all the possible implementations of this application domain.

- Network coverage provisioning

In addition to the above-mentioned applications, UAVs also provide a very promising solution to many problems in the specific field, ranging from ensuring coverage in emergency situations and rural areas to network densification for highly populated areas, offering network coverage, taking into account the challenges faced by communication networks to manage increasing demand and different services. Breakdown of essential communications is one of the most widely shared characteristics of all disasters. Whether partial or complete, the failure of telecommunications infrastructure leads to preventable loss of life and damage to property [39]. Unique features of UAVs pertaining to high mobility in three-dimensional space, autonomous operation, flexible deployment tend to find appealing solutions for aerial network coverage. Main telemetry requirements for aerial network coverage scenario in case of a disaster, is high-speed, real-time video streaming and long-range telemetry communication [40]. MAVlink, ZigBee and MQTT are short-range protocols, thus they can't cover large areas. LoRaWAN and LTE are long-range protocols. LoRaWAN is a lightweight, energy efficient protocol but it can't apply on demanding data rate transmission implementations. Open-LTE can provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments with high-speed transfer rate up to 100 Mbps, with high reliability for data transfer and has a nearly unlimited range of communication that depends on the antenna setup and network configuration. Consequently, Open-LTE is the only choice.

Table 1 summarizes the telemetry requirements that are included in each UAV application domain using the symbol “X”. At the last line, a list of the most suited protocols for each application domain is proposed. The first protocol on the list is the best option.

According to the table 1, the corresponding requirements for SAR are quick response, real time, reliability and authentication. The range depends on the mission and it can be short or long-range. The proposed protocols for SAR are Open-LTE, ZigBee and MQTT. Open-LTE is the best option. Construction domain requires short range and real-time protocols, reliable, authentication and power efficient. ZigBee and MQTT are presented as suitable protocols and ZigBee are the most efficient one. For delivery of goods the requirements are long-range, energy efficiency, which also provides reliability and authentication. In this case LoRaWAN and Open-LTE are proposed. LoRaWAN is the best option. Monitoring and mapping is a domain application that covers small areas or middle and large ones. For small areas short-range protocols are required, while in middle and large areas long-range protocols are required. Therefore, in both cases monitoring and mapping needs lightweight and high reliability protocols. The recommended protocols for small areas are MAVlink, ZigBee and MQTT. The most suitable is MAVlink. In middle and large areas LoRaWAN considered as better option than Open-LTE. For visual tracking and surveillance, the related requirements are short-range real-time, reliability, authentication and lightweight. The suggested protocols are Open-LTE, ZigBee and MQTT. The Open-LTE is the best choice. Lastly, for network coverage provisioning the corresponding requirements are long-range, quick-response, real-time and reliability. Open-LTE is the only option.

4 CONCLUSIONS

In this paper, a survey for UAV open-source telemetry protocols is presented. We compare the most used open-source telemetry protocols for drones, in terms of their key features. The comparison was made based on the most common application domains used by drones. After the analysis performed on the telemetry protocols, it is concluded that for implementation of each application, specific requirements have to be met from the drone telemetry protocol.

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Table 1: Evaluation of Telemetry protocols

	Application Domain					
	Searchand Rescue	Construction	Deliveryof goods	Monitoring and Mapping	Visual Tracking and Surveillance	Network coverage provisioning
Requirements						
Short Range	X	X		X	X	
Long Range	X		X	X		X
Quick-response	X	X			X	X
Real-Time	X	X			X	X
Reliability	X	X	X	X	X	X
Authentication	X	X	X		X	
Lightweight		X		X		
Energy Efficient		X	X			
Applied Protocols	Open-LTE ZigBee MQTT	ZigBee MQTT	LoRaWAN Open-LTE	MAVlink ZigBee, MQTT, LoRaWAN, Open-LTE	Open-LTE ZigBee MQTT	Open-LTE

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