Structures and Deployments of a Flying Network Using Tethered Multicopters for Emergencies

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Abstract. In recent years, the interest of tethered UAVs high-altitude platforms has been widely constantly increasing in many fields. The long-time operating possibility is one of the main advantages of tethered unmanned high-altitude platforms compared to autonomous UAVs. In the paper, a flying network for emergencies using tethered multicopters is proposed. The combination of tethered unmanned high-altitude platforms and groups of UAVs in flying network for emergencies is expected to enhance the effectiveness of search and rescue operation in the wilderness as well as after natural disasters.

Keywords: UAV · Flying network · Tethered multicopters · Search and rescue

1 Introduction

Over the past decade, the emergence of new technologies as well as the development of science and technology has greatly assisted search and rescue operation in emergencies. The dissemination of UAVs for civilian purposes has turned them into a useful search and rescue (SAR) tool in different situations, such as for emergency prevention, monitoring emergencies, searching for missing people after natural disasters, or urgently delivering the necessary cargo to places where it is needed in an emergency. In addition, UAVs are used for environmental purposes, such as to protect beaches, study the melting of polar ice, monitor forests, monitor the coast and water areas, determine the effects of various pollutants, etc. [1,2].

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Multifunctional complexes with UAVs in control and communication systems are utilized for relaying signals or in studies of the pattern of radio signals transmission, and for inspection of cell towers [8]. In some cases, UAVs can work as "network nodes" to connect the network to the Internet (Internet of Drones - IoD) [9]. Moreover, in order to expand the working area, cellular networks can also be employed as an additional communication channel to UAVs, along with conventional P2P (point to point) networks, for example, in automated air traffic control systems. In many scientific articles [3–7], using groups of UAVs had been proven to be much more effective than using only one UAV. However, the main disadvantage of UAVs is a limited time of operation due to the small battery resource of UAVs equipped with electric motors or the fuel reserve for internal combustion engines. In order to solve this problem, tethered UAVs high-altitude platforms are consider. They can support long-term operation with power supply of engines and payload equipment is provided from the ground-based energy sources.

Due to above-mentioned features of UAV groups, in this study, the paper provides a Wi-Fi network based on groups of UAVs and tethered UAVs high-altitude platforms, called flying network for emergencies using tethered multicopters, that can help rescuers to communicate with victims or find their locations using Wi-Fi signals generated from their phone. In addition, the deployment of rescue operations in difficult or dangerous areas for rescuers is also addressed with the help of flying network.

2 Tethered UAVs High-Altitude Platform

At present, research centers in leading countries of the world are carrying out intensive scientific work on the design and implementation of tethered UAVs high-altitude platforms [10–17], given the wide spread of their practical application. The long-time operating possibility is one of the major advantages of tethered unmanned high-altitude platforms compared to autonomous UAVs. UAVs can be presented by two types: multicopter type and fixed wing type. Fixed wing type UAV has a high flight duration, maximum flight altitude, high speed, and high payload. On the other hand, multicopter type has the ability to stay stable in the air, as well as high maneuverability [21]. With these advantages, multicopter type is more suitable for tethered UAVs system due to its structural characteristics and missions (Fig. 1).

Tethered UAVs high-altitude platform consists of terrestrial and flying modules. The terrestrial module contains a ground control station for a high-altitude platform (TCS), a ground voltage converter, a winch of a tethered cable of a high-altitude platform and a mooring device (Fig. 2).

A tethered UAVs system consists of a multicopter, cable and flight platform. A new energy transfer technology will provide the multicopter with the ability of lifting to a height 300 m and with a payload of up to 50 kg, and a long working time (up to 24 h) which is limited only by the reliability characteristics of the multicopter. The cable, of either copper wires or optical fiber, ensures the transfer

Fig. 1. Tethered UAV high-altitude platform application example

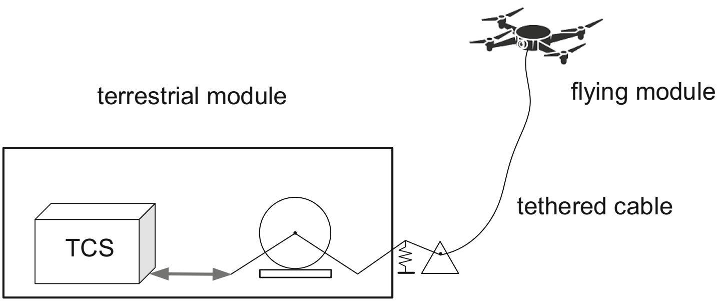

Fig. 2. Tethered UAV high-altitude platform components

of large amounts of information from board to ground and vice versa. Local navigation systems equipped in high-altitude platforms, provide high positioning accuracy and increase noise immunity compared to satellite navigation systems.

The architecture of the tethered high-altitude unmanned platform includes the following main components:

1. An unmanned multi-rotor aerial vehicle of large carrying capacity and a long operating time, designed to lift up to 300 m. and hold the telecommunications payload, video surveillance equipment, etc.
2. A high-power ground-to-board energy transmission system that provides power energy to the propulsion systems of the unmanned multi-rotor flight module and the payload equipment.
3. Control and stabilization system of the high-altitude platform, including a local navigation subsystem with ground-based radio beacons, providing increased positioning accuracy and noise immunity in the absence of signals from satellite navigation systems.
4. On-board payload equipment, including base station of the cellular network of the fourth generation (LTE); radar and radio relay equipment; equipment for video surveillance and environmental monitoring, etc.
5. Cable-rope on Kevlar base, including copper wires of small cross-section ($0.5\,\text{mm}^2$) for transmission of high-voltage (up to 2000 V), high-frequency (up to 200 kHz) signals and optical fiber for digital information transmission with a speed of up to 10 Gbit/s.
6. Ground control complex, which includes an AC voltage converter 380/2000 V, a system for diagnostics of the parameters of the high-altitude platform and an intelligent wrench with a microprocessor unit to control the cable-rope tension during lifting, descending and wind loads. In mobile configuration, the ground control center is located on a mobile platform with an electric generator installed on it, the output power of which is not less than 20 kW.

3 Flying Network for Emergency Using Tethered Multicopters

One of the important applications of UAVs in communication systems is the UAVs network or FANET (Flying Ad-Hoc Network). Nowadays, FANET is widely used in various fields: military, commercial, agricultural, etc. In particular, an application of FANET in the search and rescue operations was developed, named Flying network for emergencies (Fig. 3) [18].

Flying network for emergencies consists of two segments: a flying segment and a terrestrial segment. In the flying segment, UAVs are divided into groups, which are able to simultaneously communicate with each other and to the emergency services, victims or sensor nodes in the terrestrial segment without having any predefined and fixed infrastructure. In order to solve critical issues in FANET, such as communications and networking of the multiple UAVs, the modified of protocol IEEE 802.11p, called CMMpP, was presented in [19]. CMMpP - a

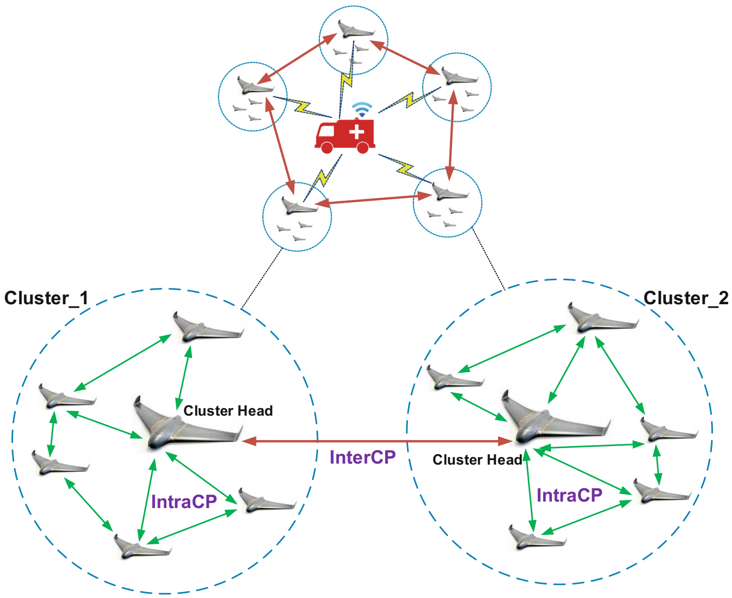

Fig. 3. An architecture of flying network for emergencies

new MAC protocol based on IEEE 802.11p and IEEE 1609.4 protocols to perform communications between UAVs as well as between groups of UAVs, which consists of cluster management protocol (CMP), intra-cluster communication protocol (IntraCP) and inter-cluster communication protocol (InterCP) (Fig. 4).

IEEE 802.11p was originally developed for VANET - Vehicular ad hoc networks [20]. It was adopted as the Medium Access Control (MAC) and Physical Layer (PHY) specifications for the lower-layer Dedicated Short-Range Communication standard (DSRC), which has advantageous characteristics, such as being able to operate in the frequency range of 5.9 GHz (less disturbed by other devices), wide coverage (up to 1000 m), fast transmission rate (up to 27 Mbps), self-organization and fast convergence.

Nevertheless, one of the weaknesses of UAVs in flying network for emergencies is the short working time. For multicopter type, the flight time is about 30–60 min, and for fixed wing type, it can reach 1–2 h. However, this is a relatively short time in the search and rescue missions, which often leads to inefficient operations or the need to replace UAVs many times. To increase the effectiveness of search and rescue operations, using tethered UAVs in flying network for emergencies is proposed, because of the following advantages:

- The effectiveness of the tethered UAVs system in various civilian areas, their mobility, compactness and cost-effectiveness compared to very expensive satellite systems;
- Super long working time, UAVs can operate up to 24 h powered by ground;

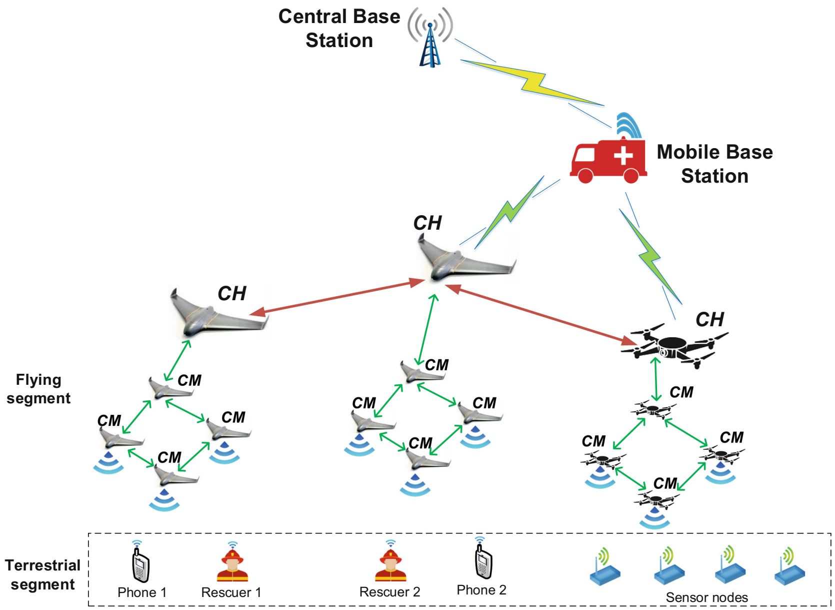

Fig. 4. Interaction of UAV groups

- Possibility of lifting the platform to a height of up 500 m with a payload of up to 50 kg;
- Ultra-wide bandwidth for data transmission through optical fiber inside the cable;
- The ability to shoot high-definition video and images acquired by the camera mounted on the UAV and then they are sent back to the ground through an optical fiber inside the cable;
- The system either can be freestanding or mounted on the rear of the vehicle. It is suitable for various industrial applications, such as television broadcasting, alarm relays, video surveillance, etc. When the system is installed on a car, the attached UAVs themselves can follow the car within a speed 25 km per hour;
- Local navigation system based on tethered UAVs system provides high positioning accuracy and increased noise immunity compared to satellite navigation systems;
- A relatively short time of deployment of tethered UAVs system, approximately no more than 10 min;
- Tethered UAVs system provides the possibility of its operation at temperatures from −50 to +50 degrees Celsius, and the UAV itself can perform a flight with wind up to 15 meters per second;
- The ability to expand the operating range of the tethered UAVs system by using a chain of UAVs tethered one to the other. The first UAV in the chain is tethered to a ground station, while the last one serves as end effector.

Architectures of flying network for emergencies using tethered multicopters are considered in following scenarios:

- Collecting data from sensor fields in flying network for emergencies using tethered multicopters;
- Interactions within Flying Network for Emergencies using tethered multicopters;
- Multimedia transfers over the flying network for emergencies using tethered multicopters.

3.1 Collect Data from Sensor Filed in Flying Network for Emergencies Using Tethered Multicopters

After a natural disaster, it is impossible for most telecommunication infrastructures to avoid from being destroyed, so the consequences and scale of the destruction must be assessed first. To do this, it is necessary to read data from sensory nodes, located in the destruction zone. Since sensor nodes can communicate with UAVs using various technologies, it is advisable to use a heterogeneous gateway for data collection. Such a gateway, mounted on a UAV, will allow collecting data from sensor nodes and delivering them to a public communication network [23,24].

In a SAR operation, mobile base stations will deploy groups of UAVs, including tethered UAVs, to areas around MBS to gather information. All UAVs are equipped with a heterogeneous gateway, which is a network device or a relay system designed to ensure the interaction of two information networks that have different characteristics, using different sets of protocols and supporting different transmission technologies [22]. The gateway can support technologies, such as ZigBee, 6LoWPAN, LoRa, Bluetooth, NB-IoT, and act as a connecting link between sensor nodes and mobile base station. With tethered UAVs, more data can be collected and the coverage is also extended. An architecture of collecting data from sensor fields in flying network for emergencies using tethered multicopters is shown in Fig. 5.

3.2 Interaction of Flying Network for Emergencies Using Tethered Multicopters

In the flying network for emergencies, communication among UAVs in a group and among groups of UAVs is of paramount importance. Technology IEEE 802.11p with the modified protocol CMMpp in [19] was developed to solve this issue. Moreover, tethered UAVs can be used in this network, which is presented in Fig. 6. Tethered UAVs become super cluster nodes, which can receive information from cluster nodes of the groups or can replace cluster nodes when all of UAVs in the group can not be the cluster head. With the advantage of having a very long flight time, tethered UAVs will keep the network stable and reliable during the mission.

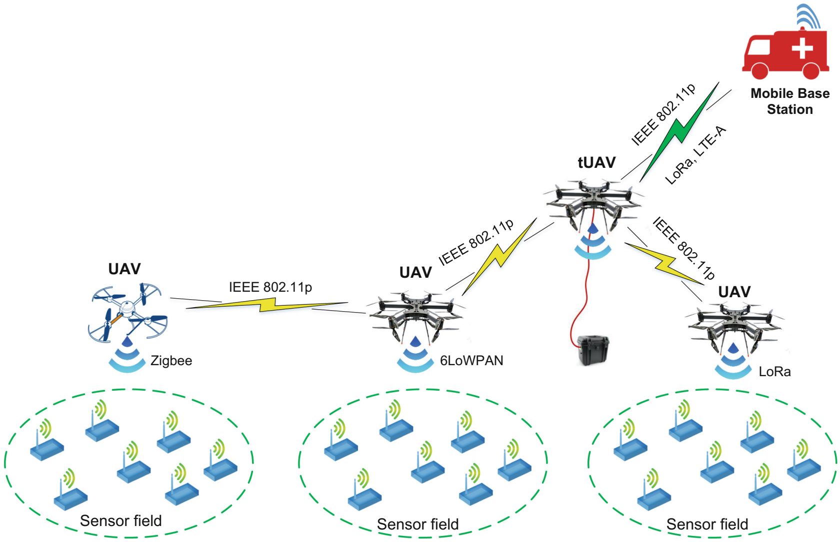

Fig. 5. Collect data from sensor filed in flying network for emergencies using tethered multicopters

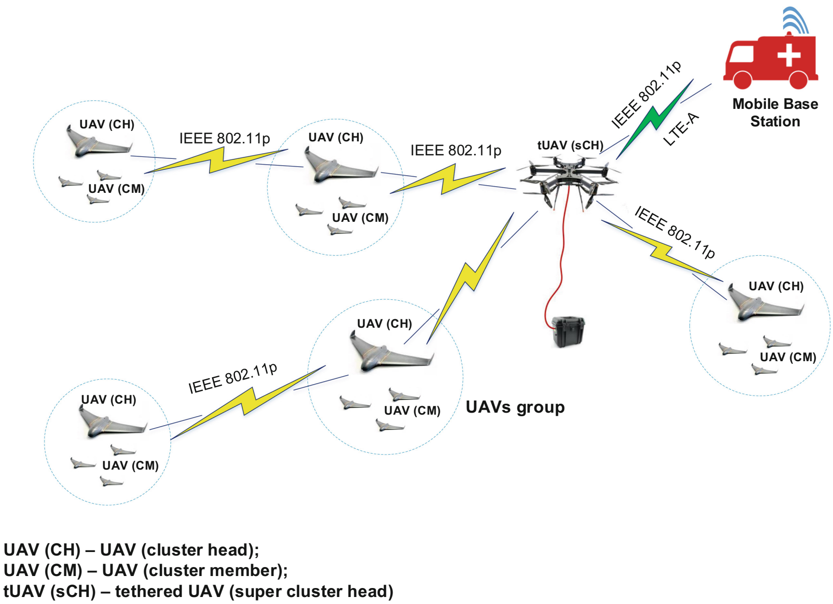

Fig. 6. Interaction of Flying Network for Emergencies using tethered multicopters

3.3 Multimedia Transfers over the Flying Network for Emergencies Using Tethered Multicopters

Being equipped like any other UAVs, tethered UAVs can be joint in the multimedia transfers over flying network for emergencies. Assuming that there are subscribers wanting to call each other or rescuers trying to connect to missing people via VoWi-Fi using UAV groups in a destroyed area. According to functioning algorithms of mobile phones, in the absence of communication with the base station, the phones switch to scanning mode of available Wi-Fi networks. After a natural disaster occurred, scanning in the area will help discover subscribers who might be injured or buried under the rubble, waiting for help. A call between two subscribers will be performed through a chain of UAVs interacting with each other. UAVs can receive voice traffic by IEEE 802.11n or IEEE 802.11ac from subscribers, transmit it through a chain of UAVs to the mobile base station, and connect to mobile operator to set up the call (Fig. 7).

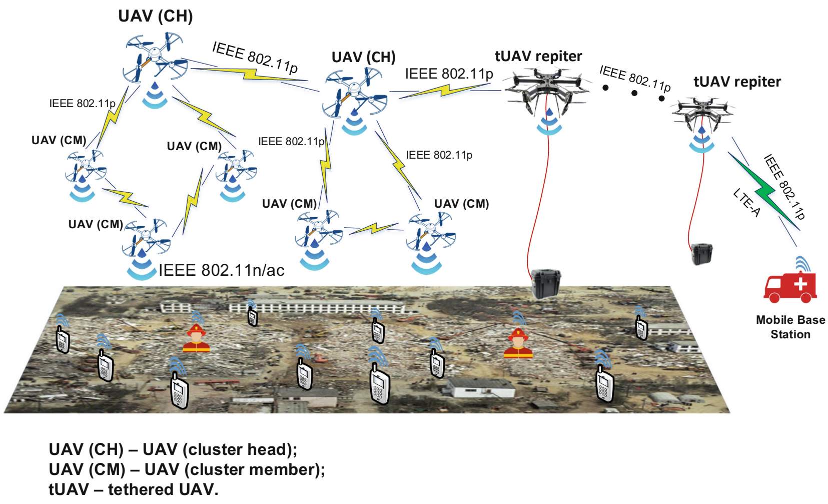

Fig. 7. Multimedia transfers over the flying network for emergencies using tethered multicopters

4 Conclusion

The paper provides a brief overview of tethered UAVs high-altitude platforms analyzing their advantages and disadvantages. With the benefits of the tethered UAVs high-altitude platform, flying network using tethered multicopters was proposed for emergency situations. Different architectures of this network were presented in order to enhance the effectiveness of search and rescue operations. In the future work, the research will prioritize in conducting a series of experiments and simulations to evaluate the performance of the proposed architectures.

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