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Enhanced Remote Sensing of Geo-Space by Cellular Connected Unmanned Aerial Vehicles (UAVs)

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Abstract: Military and civil applications of unmanned aerial vehicles (UAVs) are increasing at rapid pace. These applications range from battlefield surveillance to remote sensing of geospace. To ensure enhanced utilization of UAVs in future, particularly in the field of real time remote sensing, it is important to have reliable and high data rate wireless communication links between UAVs and their ground stations. For achieving this objective, UAVs can be integrated into existing cellular networks as aerial users. One way of enhancing the cellular communication support to UAVs is to use multiple antennas at the ground base stations. In this article, an overview of this promising technology is presented, by initially covering UAV cellular communications along with its potential benefits and challenges. Subsequently, the concept of real time remote sensing of geospace by UAVs is explained along with various techniques used in analysis of remote sensing data.

Keywords: Remotely Piloted Aircraft System (RPAS), Unmanned Aircraft System (UAS), Third Generation Partnership Project (3GPP), 5G Communication, Long Term Evolution (LTE). Remote Sensing (RS)

I. Introduction

An unmanned aircraft, which is piloted by a remote control unit or by an on board computer is called an Unmanned Aerial Vehicle (UAV). The word UAV is most frequently used for unmanned aircraft. However, aviation agencies of many countries often use the term Drone, UAS (Unmanned Aircraft System) or RPAS (Remotely Piloted Aircraft System), where UA or RPA describes an aircraft and UAS or RPAS describes complete operating equipment including an aircraft, control station and wireless data link. UAVs are made of light composite material to reduce their weight and increase their maneuverability in air. They are primarily equipped with aircraft systems, along with sensors, camera and a transceiver with antenna for communication. Traditionally UAVs have been used for military applications of battlefield & airspace surveillance and patrolling. However, lately the civil applications of UAVs are increasing at rapid pace due use of advance control systems and electronic instruments. These applications include search operations during natural disasters, crowd or traffic surveillance, wildlife conservation, goods transportation etc. One of the latest application of UAV is Geospace Exploration. Geospace is defined as the region of outer space near earth. UAVs can operate in geospace only if there communication links with ground stations, have enhanced ranges.

A. Attributes of UAV Communications

Major attributes exhibited by UAV Communications include nature of wireless links, ability of dynamic deployment and establishment of UAV network by substituting UAVs as base stations. As UAVs are flying in sky, they have high probability of connecting with ground base stations & ground users via line of sight (LOS) wireless links. Thus, UAVs can provide long distance reliable transmissions and superior quality of links. UAVs can be deployed dynamically as per requirements, which is not possible with static ground based cellular infrastructure. With the capability to being employed as aerial base station, a network of UAVs in air can be formed by set of UAVs, thus provide omnipresent connectivity to users on ground. Such UAV based swarm networks are highly flexible and expandable in faster timeframes.

B. Paper Contributions and Organization

Real time remote sensing is a game changer in Geospace exploration. Utilization of UAVs for this purpose is gaining popularity. The best way to achieve high data rate real time remote sensing is by utilizing cellular networks of UAV communication. Although many viewpoints of UAV communications have been provided through various existing studies, still there is a need to discuss fundamental characteristics, potentials and challenges in provisioning cellular communication support to UAVs, along with methods of mitigating the inadequacies of existing cellular networks, by utilization of multiple antennas in base stations. In this article, we are aiming to give the reader basic understanding of UAV cellular communications and concept of use of cellular connected UAVs in real time remote sensing for geospace exploration.

II. Review of Cellular Communication Support to UAVs

Wireless connectivity is required by aerial UAVs to support their communication needs. WiFi (Wireless fidelity), ZigBee etc are the existing wireless technologies that are presently used by UAVs to communicate to their respective remote control station situated on ground. Such technologies have few drawbacks such as low mobility, extremely short range and low throughput, which restrict their usage primarily for wireless access for indoor scenarios. However, UAVs need features such as high mobility, long range, low latency and high throughput for their communications, which could only be provided by a fresh advance technology.

A. Communication Requirements of UAVs

UAVs have peculiar communication requirements. For authorization and authentication of UAVs, appropriate communication is needed. For operation of UAVs, Command and control communication is required. To support high data rate video streaming, payload data transmission is needed. To avoid collisions with nearby UAVs, communication with other UAVs is needed. Licensed or unlicensed spectrum may be used for provision of wireless UAV communication. However, unlicensed spectrum is not ideal as it is shared and prone to interferences. Moreover, users do not get exclusive access to specific channels in unlicensed spectrum. Hence, using licensed spectrum of conventional cellular networks is considered most suitable option for UAV communications. Typical requirements of UAV communication are scalability, availability, reliability, low cost, low complexity, suitability for mass market and easy integration.

B. Cellular Communication support to UAVs

Ideal choice to support UAV communication is through presently deployed cellular communication networks. Cellular networks have the resources and potential to fulfill these requirements:

- **Global availability**: Cellular networks established as per standardizations defined by 3rd Generation Partnership Project (3GPP) are globally available. Utilization of existing cellular network infrastructure obviates the requirement of rolling out custom made new communication infrastructure for UAVs. Thus, presently deployed cellular networks provide cost effective solution which can evolve as per UAV communication requirements.
- **Frequency Spectrum**: Utilization of dedicated frequency spectrum in licensed frequency bands helps in provisioning of reliable communications required for mission critical UAV applications, especially in military environment.
- **Superior Efficiency**: Compared to one to one wireless link between UAV & ground station, utilization of cellular communication networks for UAVs, improves the efficiency and performance in terms of throughput, security and reliability.
- **Secure Channels**: Encryption mechanisms used in cellular networks enhances the communication security of channels.
- **SIM (Subscriber Identity Module) and IMEI (International Mobile Equipment Identity) based Identification:** The detection and identification of UAVs can be carried out in the similar manner as it is done for mobile users in cellular networks, by use of SIM and IMEI.
- **Navigational Robustness**: Conventionally UAV navigation is achieved by use of Global Positioning System (GPS) satellites. Such navigation may get disrupted due to blockages caused by obstacles such as high rise buildings, bad weather etc. Utilization of cellular signals as complementary for GPS navigation, provide navigational robustness.

Unlicensed spectrum is usually used for establishing communication link between ground station and UAV. The factors of transmit power and frequency spectrum dictates the usage range between ground station and UAV. If we utilize existing cellular networks, we can achieve enhanced ranges. Now the ranges are not limited by existing unlicensed frequency spectrum. The UAVs will have ranges similar to the coverage of cellular networks, if the cellular network provide data rate as per requirement of UAVs. Figure 1 depictsone to one communication link connectivity of UAV with ground station. Figure 2 depicts communication link of UAV with a cellular network. Communication link with cellular network enables communication of UAV with its handler, communication between UAVs and communication of traffic control and UAVs. Thus, provide communication support for UAV identification, collision avoidance, data transmission, mission operation, command & control etc.

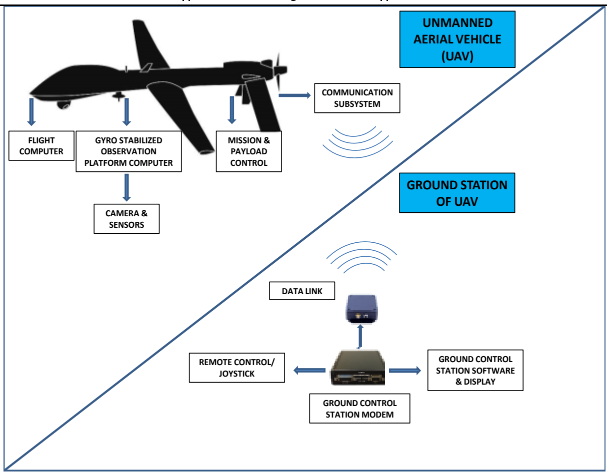

Figure 1 : UAV connectivity with Ground Station using one to one wireless link

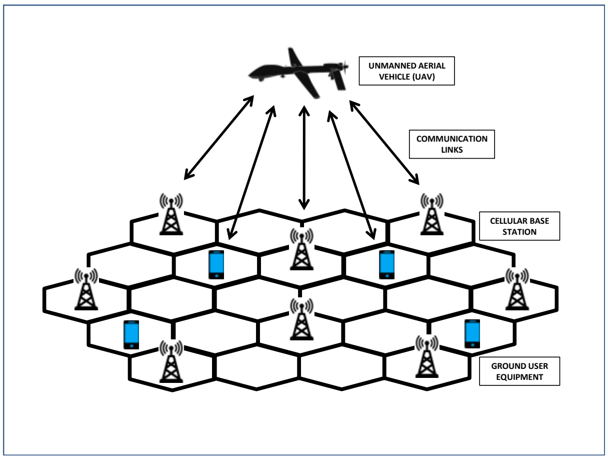

Figure 2 : UAV connectivity with Cellular Network

C. Challenges and Inadequacies in implementation of Cellular Communications for UAVs

Implementation of cellular communication for UAVs has numerous benefits. Apart from regular telemetry information, a cellular connected UAV gets real time air traffic information, emergency incidents information and weather information. Cellular connectivity enables remote operation of all prior flight manual tasks of UAV operator. Cellular technology has been continuously growing to support new user services. Currently deployed, 4G Long Term Evolution (LTE) has wide range of capabilities to support UAV communication. Next generation of cellular technology, 5G has enhanced capabilities to connect more devices at higher data rates. Therefore, 4G/5G cellular communication technologies can be effectively utilized for UAV communications. However, implementing cellular communications for UAV, is a challenge in terms of deployment, channel modeling, network security, energy efficiency etc. The implementation of cellular communication support to UAVs has following challenges:

- **Channel Models**: Being aerial objects UAVs have typical channel characteristics of 3D space and time variations. These characteristics cause increased complexity of air to ground channels as compared to ground to ground channels.
- **Mobility and Deployment**: UAVs are aerial objects having high mobility and specific channel characteristics. To reduce physical collisions and handovers, these aspects are required to be considered for optimal deployment.
- **Trajectory Control**: Each UAV follows a particular trajectory in air based network comprising of set of UAVs. UAVs have to establish simultaneous links with neighboring UAVs as well as ground user. As a result, because of practical constraint, the identification of optimal flying trajectory for UAVs is a complex task.
- **Altitude of Operation**: Because of size, weight and power constraints of UAVs, different variants of UAVs have different altitudes of operation.

- **Management of Interference**: Co-channel interference is experienced between air to ground channels and ground cellular network. Similar interference may also be experienced between different air to air channels.
- **Energy Limitation**: The mission operating time of UAV is limited by power constraints or energy consumption, which is provided by battery of UAV.
- **Backhaul Links**: Large bandwidth wired links are used for backhaul between ground base stations and core networks. High capacity wireless links are used for backhaul between UAV base station and ground base station.

The existing cellular communication networks are found to be non-appropriate for few typical requirements of UAVs communications. Major reason for this is the fact that antennas of ground station are bend or tilted towards ground. This enables them to provide low altitudes and low elevation angles coverage only. Other reasons are distinct mobility patterns of UAVs in air and channel interference because of neighboring cells. If we use multiple antennas at ground base stations, the inadequacies of presently deployed cellular networks can be removed. The use multiple antennas enable utilization of 5G networks for cellular communication. Such integration provides capability to transmit higher data rates suitable for various applications. One such application is remote sensing of geospace. The application of cellular connected UAVs in remote sensing is described in subsequent section.

III. Remote Sensing of Geospace by UAVs

UAVs applications have become an ever-expanding area in remote sensing (RS) in recent years. This is primarily because of inherent advantages of utilization of UAVs for remote sensing. With the use of cellular connected UAVs, the advantages further increase [11]. The advantages are given below:-

- Availability of high data rates for real time streaming of information.
- Capture of ultra-high resolution (UHR) imagery.
- High availability of geometric and spectral data.
- Integrated multi-sensor data fusion.

Due to the low flying altitude, UAVs can easily acquire very detailed information of observed objects with a spatial resolution under one decimeter, which allows for accurate geometrical and semantic analysis for a reasonably broader area than a single site. This analysis can be carried out by two types of applications or techniques namely object detection i.e land cover/image classification and change detection. The quality of RS would depend on the type of sensor used on UAVs.

There exists a wide range of sensor options for UAV applications in RS. Many existing RS instruments for aerial and satellite platforms are now embracing their miniature and low-cost versions for UAV platforms, such as multispectral, hyperspectral, short/mid-wave range cameras e.g., thermal and light-weight LiDAR (light detection and ranging). UAV data should be better processed and analyzed given their resolution advantages for either the traditional or novel RS applications.

A. RGB Cameras

Modern UAV based RS starts with remotely controlled plane models mounting a normal RGB cameras. Basically, a consumer-grade camera mounted on a drone, integrated with/without navigation sensors such as GPS constitutes necessary components of a UAV-surveying system. There exist a wide range of RGB cameras in market, and for different applications, selecting appropriate RGB cameras mounted on a UAV can be a key to success. Common parameters for selecting RGB cameras include camera lens and resolution.

B. Light-Weight Multispectral Cameras

Multispectral cameras are one of the most commonly used sensors in addition to RGB cameras in the UAV sensors family, because of their benefits of obtaining spectral information in the red-edge and near-infrared band for vegetation applications in an extremely high resolution.

C. Light-Weight Hyperspectral Sensors

Hyperspectral cameras in RS are very capable but are comparably less accessible due to their high cost and constraints in sensor compatibility to drones. In order to capture images with hundreds of narrow bands (5–10 nm bandwidth), most of the current light-weight hyperspectral sensors are linear-array cameras. Undoubtedly, the hyperspectral sensors capturing such high volumes of information are extremely useful for many applications.

D. Light-Weight Thermal Infrared Sensors

As one of the mid-infrared-range passive sensors (wavelength between 3 and 35 μm), the thermal infrared sensors are broadly used in various surface temperature and thermal emission measurements. The classical issue on kinetic temperature and emissivity determination through the intensity and its distribution over the wavelength region of UAV-borne sensors can be slightly different from the airborne or space borne thermal sensors. As for UAV-borne sensors, the atmospheric effects are ignorable, lab-level calibration are more accessible and the temperature measurements are theoretically more accurate. However, in consideration of the limited payload, light-weight thermal infrared sensors generally do not come with cooled detectors, thus resulting in lower capture rates, lower spatial resolution and lower sensitivity as a compensation to a reduced signal-to-noise ratio.

E. UAV LiDAR

LiDAR sensors have been known as one of the most accurate ways for geometric data acquisition. The airborne, mobile, and terrestrial LiDAR are widely used in forestry, building information modeling etc. Their advantages over photogrammetry are their high reliability and the ability to penetrate thin forests through multiple returns. However, as a sensor depending strongly on the direct positioning accuracy of the host platform, UAV-borne LiDAR is rather rudimentary as compared to UAV photogrammetry. The GPS sensors in a UAV platform are very often inaccurate with respect to the sensor resolution, and the platform is also more instable when flying. Thus, even with well-calibrated light-weight LiDAR sensors, the obtained point clouds accuracy is comparatively low. Reported highly accurate UAV-borne LiDAR systems are normally those coming with differential GPS stations.

IV. Remote Sensing Data Analysis by UAVs

RS data acquired through UAV platforms with their sensors are intended to be no different from those traditionally used in airborne and spaceborne RS sensors. However, the UAV sensor data would embrace higher likelihood of distinct characteristics of UHR, high availability of geometric and spectral data and integrated sensor data for multi-dimensional data analysis. This lead to completely different application scenarios, data quality, and availability of different dataset that call for more targeted analysis techniques.

A. Object detection or Land-Use/Land-Cover (LULC) Mapping

LULC mapping is usually carried out via a standard approach with various types of satellite images (spectral/spatial resolution). Now, LULC mapping using UAV images is increasing in utility due to high resolution of images. Which in turn provides option of precise object detection through appropriate data processing technique.

B. Change Detection

Change detection is a very important application in RS. With availability of much finer spatial scales there is increase in the scope of change detection applications such as detection of illegal waste dumping, street facility misplacement, crowd anomaly detection etc. The obvious advantages of having higher spatial resolution and availability of geometric information, brings the ability to detect changes of objects in a finer scale with higher accuracy. UAVs flexibility of mounting different sensors as well as the minimal ready-to-fly logistics can facilitate a much higher temporal data acquisition, such as daily, hourly, even real-time monitoring using video streams.

V. UAVS Remote Sensing Applications

UAVs are considered to be most suitable for real time RS applications of earth observation, climate monitoring, aerial photography, mapping, surveying, seismic events, major incident, and pollution monitoring etc. Other specific applications of remote sensing by UAV are:-

- **Precision Agriculture and Vegetation.** Precision agriculture requires mapping the spatial variability of as many variables as can be measured (e.g., crop yields, terrain features/topography, organic matter contents, and moisture levels) as the input of decision support system for farm management. For this reason, RS techniques are widely used in agriculture and agronomy.
- **Urban Environment and Management.** Observed at fine scales, the urban environment is highly dynamic due to the human activities, which produces the desire for various challenging UAVs urban applications including real-time traffic control, management of urban infrastructures, and building observation.

- **Disaster, Hazard, and Rescue.** RS is seen as an important tool for risk assessment and rescue operations. Low-cost UAVs are now indispensable for onsite rapid data collection in aid of disaster management, such as mapping, monitoring, and autonomous deployment of flying robots.

VI. Conclusion

This article has surveyed various aspects of opportunities, challenges and inadequacies in provisioning cellular communication support to UAVs for enhancing the ranges of UAV Communication links for their utility in remote sensing applications. By utilizing multiple antennas at ground base stations, these inadequacies of existing cellular networks can be mitigated. Cellular connected UAVs have tremendous utility for earth observations, climate monitoring, mapping, surveying etc. Provision of high-speed and high-quality remote sensing data by UAVs is comparable to the data provided by the remote sensing satellites. Development of future technologies for communication support to UAVs and future research in remote sensing field would enable much more effective utilization of UAVs for remote sensing of geospace.

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