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Use of UAVs for Restoring Communications in Emergency Situations

Abstract

When infrastructure is damaged by a significant disaster event, the restoration of communications is one of the most urgent and important tasks. Unmanned aerial vehicles (UAVs) have started being used for several important roles in the process of restoring communications infrastructure. One role for UAVs is to act as flying cell sites, which can provide mobile cellular coverage as an alternative to ground-based cell towers.

This report introduces some of the ways in which UAVs are being used and explains the technical and logistical considerations. This report may be used by emergency planners and organizations that provide UAV-based communication services during disasters to assist with preparation and execution of disaster recovery.

Foreword

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1. Introduction

If infrastructure is damaged by a significant disaster event, then the restoration of communications is one of the most urgent and important tasks. Communication services are important in order to:

- Coordinate emergency and recovery operations.
- Facilitate the rebuilding of other infrastructure.
- Allow the public to contact emergency and rescue services.
- Provide reassurance to the public by allowing them to contact family and friends.

Recovery of fixed-line communications is a well-established priority. However, now that users have become very oriented towards the use of wireless services, it is also important to consider restoration of cellular and other wireless networks.

Provision of wireless services from various types of Unmanned Aerial Vehicles (UAVs) has played an important role in recovery operations in Puerto Rico and other areas recently hit by natural disasters. Flying cell site technology will continue to feature in future recovery operations. A common message from experts is that effort spent planning and preparing for operations occurring after a disaster improves the speed and quality of recovery efforts.

This report captures the planning and operational aspects to be considered in preparing for the use of UAVs to provide communication services when responding to an emergency. It considers aspects including:

- Roles that UAVs may play in recovering communications services.
- Technical considerations regarding the use of UAVs.
- Logistical and organization aspects.
- Regulatory implications and coordination needed between governmental and non-governmental entities.

This report may be used by emergency planners and organizations that provide UAV-based communication services during disasters to assist with preparation and execution of disaster recovery.

2. Roles of UAVs in Providing Communications Services

Overview

Following a disaster, the ground-based cellular communications infrastructure may be damaged. Depending on the scale of the disaster this damage may range from individual cell sites to wide-spread damage to multiple cell sites and other communications infrastructure.

Recently, it has become possible to carry telecommunications equipment on UAVs. This allows UAVs to act as cell sites for mobile cellular communications networks ("flying cell sites"). UAV-hosted cell sites use antennas attached to the UAV as an alternative to antennas attached to ground-based structures. These cell sites have all the capabilities of a conventional mobile cell, i.e., they add new capacity and are not just relays for available ground-based coverage.

UAV-hosted cell sites can be made ultra-portable which can allow them to be deployed more quickly and conveniently than alternative solutions for temporary coverage. UAV-hosted calls can have a role in the early stages of restoring communications until more permanent solutions are deployed. As the emergency response progresses, the cells hosted on UAVs may be replaced by cells sites mounted on vehicles ("cells on wheels") or by conventional fixed infrastructure.

As well as hosting cell sites, UAVs will have other roles in communication service recovery, such as inspection of infrastructure for damage.

Cellular Coverage from Tethered Low Altitude UAVs

Several network operators have the capability to deploy cell sites using tethered low-altitude UAVs to carry remote radio heads (RRHs) as a payload. The UAV payload consists of radio equipment and external antennas connected to a separate base station via a high-bandwidth link. Compared to the entire base station the RRH is relatively light and can be carried by a UAV. The bulkier base station components are located on the ground. These UAVs operate using a physical tether between the UAV and the ground. The tether carries communications (e.g., fiber or Ethernet) and power between the ground and the UAV. The use of a tether to supply power allows the UAV to stay aloft

continuously for long durations. Testing has shown continuous operation for at least 5 days is possible. An example of such a UAV is shown in Figure 1.

Figure 1: Low-Altitude Flying Cell Site

Operators may have a variety of options for temporary deployment of cell sites including cells mounted on trucks and cells mounted on trailers. If there is no permanent structure available to support the antennas, these ground-based solutions require antennas to be mounted on a temporary tower which must be transported to, and installed, at the cell location. Compared to ground-based options a tethered low-altitude UAV carrying an RRH has the following advantages:

- Ability to position the antennas at higher altitudes, overcoming ground clutter (in the US, up to 400 feet above ground level, or if positioned next to existing structure, the height plus 400 feet).
- Ability to operate from smaller sites as space is not needed for a tower base and guy wires.
- Faster deployment than traditional cells on wheels.

Low-altitude UAVs operate from a physical site at the base of their tether. A number of aspects need to be considered in relation to this site, including:

- An electrical power source is required for the UAV and other equipment. If electricity is not available, power could be provided via a generator (though this will require fuel).

- Connecting the cell to the rest of the network will require fronthaul and backhaul communications as described in Section 3.
- Expert personnel will be required on site to deploy and maintain the cell.
- The UAV and other equipment must be transported to the site, requiring equipment to be suitably packaged for the available transport.
- The site must be physically safe and stable (there might be risks on-site due to existing damaged infrastructure). This may require a survey of the site prior to deciding to use UAV for operations.
- There must be adequate physical security at the site to protect against theft or tampering with equipment.

Cellular Coverage from Free-flying Medium and High-Altitude UAVs

Several companies have solutions providing cell coverage from free-flying UAVs operating at medium and high altitudes. These UAVs could be balloons or fixed-wing drones. In contrast to low-altitude UAVs, these normally operate without any physical tether to the ground and rely on power sources carried on the UAV (e.g., solar cells and batteries). Examples of such free-flying UAVs are shown in Figure 2.

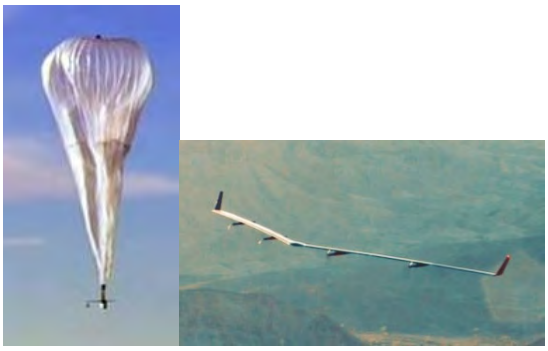

Figure 2: High-Altitude UAVs Carrying Cell Site Capabilities

Free flying UAVs can often be launched outside the disaster area and flown to the deployment site. The possible distance between the UAV launch site and the UAV deployment position will vary greatly depending on the range of the UAV. In order to deploy this type of UAV, a suitable launch site with support facilities and personnel must be found within range of the deployment area. Once launched these UAVs may be operated remotely, but a suitably equipped and staffed operations center must be available. Compared to tethered UAVs the use of free-flying UAVs has the advantage of

allowing more of the operations to be conducted from outside the immediate disaster area.

UAVs operating without a tether need wireless solutions to carry fronthaul and backhaul traffic. Often this involves peer-to-peer routing of traffic between UAVs before handing the traffic over to a suitable ground-station. It is necessary to have a suitable ground station to connect free flying UAVs to the rest of the network.

Their altitude gives these UAVs a large field-of-view (FOV) of the ground. This can be an advantage in terms of their ability to cover area but limits the traffic density that can be supported. Therefore, they are more suited to areas of low population density or where conditions prevent the use of other solutions.

Traffic that is routed via high-altitude UAVs will experience high traffic latency due to the time taken for the speed of light to cover the distance between the ground and the UAV. The maximum acceptable latency for conversational voice services is often taken as 200ms. If the traffic latency exceeds this figure, then services provided by UAVs will be unsuitable for conversational voice. Due to this limitation, high-altitude UAVs may be more suitable for message and delay-tolerant data services.

UAVs for Inspection of Infrastructure

Following a disaster, it is necessary to establish the condition and safety of infrastructure in order to decide what is safe to use and how repairs should be prioritized. Infrastructure to be inspected includes buildings, communications infrastructure, and linear infrastructure such as roads and power transmission lines. Free-flying low-altitude UAVs can have an important role in performing these inspections. Using UAVs can speed up inspections and reduce the need to transport personnel from site-to-site. This is particularly true if technology is used that can automate parts of the inspection process.

In addition to surveys for accelerated restoration, UAVs can be used to determine safe ingress and egress of sites, checking for dangers such as exposed power lines and wildlife. Further, the reconnaissance can determine flooding and receding water forecasts.

If the UAV is operating within line of sight of a pilot, then local point-to-point communications are normally used between the UAV and the pilot, so there is no dependency on any external communications infrastructure. In some circumstances, the

UAV pilot can be elevated with a bucket truck or manlift to see the UAV for extended distances and ensure regulatory compliance.

However, in order to quickly survey wide areas without having to physically transport pilots to each survey location it is advantageous to have UAVs that can operate beyond the pilot's line of sight. In that case, a communications system is required that can connect the pilot to the UAV. The cellular network is a candidate to provide this connectivity, but if the cellular network is unavailable an alternative solution would be needed.

3. Spectrum and Other Technical Considerations

Wireless Services to User Devices

If a UAV is used to host a cell site providing wireless services to end users, then suitable electromagnetic spectrum will need to be allocated for these services. Typically, the wireless services from the UAV will be mobile cellular services and thus operate in licensed spectrum bands.

For cellular services, the licenses to the necessary frequencies are typically owned by mobile network operators. In the case where the UAV-hosted cell site is being managed by a mobile operator, then they would normally use spectrum within their existing licenses. If the UAV is substituting for a single conventional cell, then the frequencies allocated to that cell may be directly transferred to the UAV. If there is more general disruption to the fixed cellular infrastructure, then special planning may be needed to allocate suitable frequencies to the UAV-hosted cell site. In most spectrum bands, licensing terms would permit use of the spectrum for UAV-hosted cells. But in some specific cases (e.g., 850MHz in the US) there may be restrictions on the maximum altitude of cell site antennas.

Where the UAV is being managed by a third-party who does not have a suitable spectrum license, then special arrangements for access to spectrum must be made. These may include:

- Bilateral agreements between the party managing the UAV and the network operator holding the spectrum license.

- Temporary permission from spectrum regulators to the party managing the UAV to use spectrum not normally allocated for cellular communication services in that location.

Any wireless services provided from UAVs must operate in spectrum bands that are accessible to the available user equipment. If the goal of deployment is to provide mobile cellular coverage to the general public then the spectrum used should align to the bands supported by the mobile phones that have been sold in that region.

When antennas are mounted on UAVs then the size and weight of the antennas, which depend on the frequency band in use, become a consideration. Bands such as 1800MHz, 1900MHz and 2500MHz are suitable. Lower frequencies (e.g., 900Mhz) or very high frequencies (e.g., 6GHz bands) may require larger antennas.

In some situations, it is possible that UAVs may be used to host services such as Wi-Fi that operate in unlicensed spectrum. This avoids the need to obtain a license, but services in unlicensed spectrum are unpredictable in terms of capacity and level of interference.

In summary, it is recommended that the following factors are considered when planning the spectrum to be used:

- Service technology to be used (e.g., LTE) and the bands where this technology is supported.
- Determination of frequencies supported by the target user equipment.
- Access to a suitable spectrum license and any relevant licensing terms for the frequencies to be used.
- Suitability of the spectrum for UAV-based operation considering factors such as antenna size.
- Interaction with other services operating in the same frequency bands.

Backhaul and Fronthaul

Cell sites require communication to the mobile core network in order to provide connectivity between users and to Internet services. This communication takes place over the *backhaul* between the cell site and the mobile core network. Some mobile cellular standards, such as LTE, also require direct communication between adjacent cells in order to manage mobility. This communication path is sometimes called the *fronthaul*.

Depending on the type of UAV service, different methods of providing backhaul and fronthaul connections are possible. The option chosen will depend on factors including the type of UAV and the location of a suitable point of presence to interface backhaul and fronthaul traffic to the fixed infrastructure. Options for this connection can include:

- Use of a physical tether to the UAV to carry backhaul and fronthaul traffic to the ground.
- Licensed point-to-point or non-line of sight (NLOS) microwave links.
- *In-band* or *self-backhaul* using the same communications technology and frequencies as the mobile cellular service.
- Bespoke solutions using such as backhaul via dynamically constructed peer-to-peer networks of high-altitude UAVs.

These options may also be used in combination (e.g., a physical tether to carry traffic to the ground followed by a microwave connection to a suitable point of presence).

In all cases the capacity of the backhaul and fronthaul must be planned with sufficient capacity to support the amount of traffic that will be delivered to the UAV-hosted cell.

4. Organizational Aspects

Decision Making

The decision to use UAVs as part of communications recovery should be made by the mobile network operator. The decision-making process should include consultation with other relevant agencies, for example, in relation to the availability of transport in to the recovery area. The decision on whether to use UAVs should consider the technical requirements of the recovery operation, as well as the logistical considerations discussed in this report.

Lifecycle of UAV Operations

The goal of a communications recovery operation is to provide temporary solutions for communications services while normal permanent infrastructure is repaired or rebuilt. As discussed in Section 2, the use of UAVs may be particularly relevant during the early phases of a recovery operation. In later phases, UAVs may be replaced by conventional

fixed infrastructure. The decision-making process should include considerations of the overall roadmap for the recovery operation.

Access to Airspace

UAVs require access to suitable airspace to operate. Airspace can be a very overloaded resource during disaster recovery operations. For example, use of low altitude UAVs to provide communications services may interfere with manned helicopter or fixed-wind operations in the same area. The use of UAVs for communications recovery must be coordinated with airspace managers and other airspace users. During disaster recovery special arrangements for managing the use of airspace may be applied including the establishment of local operation/control functions and modification to normal FAA rules.

Logistics

Logistics for equipment and personnel to install and operate UAVs should be planned to allow rapid deployment with minimal impact on constrained resources in the disaster area. Factors to be considered include:

- How to structure operations so that only essential equipment and personnel are transported to the disaster area.
- Packaging equipment to be transported for minimal weight and size.
- Planning of transport modes to be used for equipment and personnel. This may include a need to package and qualify equipment for transport on military aircraft or ships.
- Pre-staging of equipment and personnel in safe locations from which they can be rapidly deployed. Assignment of any credentials required to personnel for UAV support as first responders.

5. Conclusions

Mobile cellular operators have actively supported the development of flying cell site solutions and tested their use for a variety of purposes, including disaster recovery applications. The technology is now proven and its capabilities and operational needs are well understood. Flying cell sites have been used to provide cellular coverage as part of disaster recovery operations such as those in Puerto Rico following Hurricane Maria in 2017.

Experience has shown that effort applied to advanced planning can significantly improve the speed and quality of disaster recovery operations. This report provides a high-level view of some of the aspects that should be considered in the planning phase. Flying cell site operators and emergency managers may use the information in this report as input to their planning processes.

UAVs have now demonstrated their value as part of disaster recovery operations in a variety of roles. By acting as flying cell sites, UAVs can help provide mobile cellular coverage after permanent infrastructure is damaged. Flying cell sites can offer important advantages over other temporary solutions (e.g., cells on wheels) including faster deployment from smaller sites and the ability to operate above ground clutter.

6. Abbreviations

FAA Federal Aviation Authority

FOV Field of View

NLOS Non-Line of Sight

RRH Remote Radio Head

UAV Unmanned Aerial Vehicle