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DRONESCAPE:Distributed Rapid On-site NEtwork Self-deploying Cellular Advanced Phone Environment

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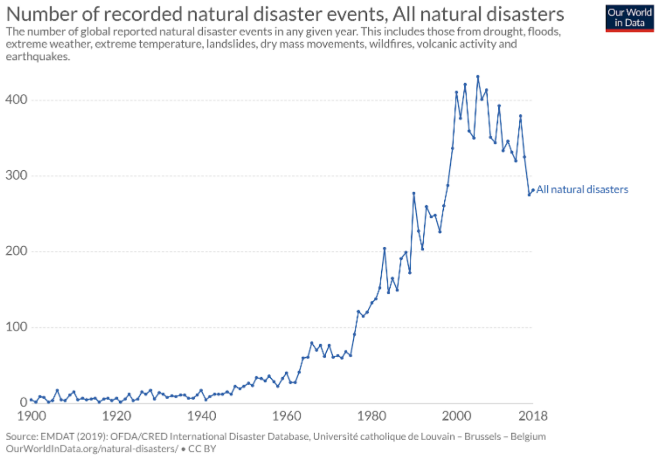
***Abstract*— When disasters happen, the speed with which first responders and emergency personnel can contact and be contacted by the people affected by the disaster during the first minutes or hours is critical. Early communications can make the difference between life and death. During a disaster communications infrastructure of the affected area is likely to be compromised. This project proposes an inexpensive, rapidly deployable cloud of autonomous drones, each coupled with a micro-cellular base station that deploys from a transportable deployment module. The goal is to temporarily restore communications for both first responders to communicate amongst themselves as well as for the rest of the impacted population.**

Keywords—disaster, drone, cellular, security, crisis management, emergency services

I. INTRODUCTION

Disasters are on the rise worldwide as illustrated by Figure 1. Providing emergency medical and life saving relief to survivors during the first minutes or hours of an emergency is critical to minimizing or limiting the long term negative effects of a disaster. The ability of survivors to communicate with rescue personnel and emergency services to alert them to their needs and location are paramount to positively affecting the outcome of rescue operations. During a disaster or crisis, the ability to communicate effectively is often lost. Natural disasters such as hurricanes, tornadoes, and tsunamis may destroy or disable physical communication infrastructures. Telephone poles are easily damaged, disrupting landline telephone communication and power distribution. Damage is likely to include cellular voice & data as well as other emergency communication infrastructures by taking out towers, power, or upstream cellular links. This leaves survivors with no means to let rescuers know where they are, that they need help, or what kinds of help they need. Such an event was noted in the NYTimes article of 29-October-2019 “California blackouts hit cellphone service, fraying a lifeline” [1] Disasters can also come from other sources (such as transportation accidents, chemical or nuclear power plant failures, or terrorism). In each of these scenarios, the communication infrastructure may be disrupted impeding the effort of relief works to get the help needed to the survivors.

Communication is necessary during the hours and minutes immediately following an event. Immediate, effective communication can be the difference between destruction and protection of critical infrastructure, as well as life and death for victims. Emergency personnel, such as fire, medical, & law enforcement benefit greatly from an in-place communications infrastructure. A rapid response to restoring communications after an interruption can prevent a small event from escalating into a larger one.



Source: EMDAT (2019): OFDA/CRED International Disaster Database, Université catholique de Louvain – Brussels – Belgium
OurWorldInData.org/natural-disasters/ • CC BY

Figure 1- Number of recorded natural disaster world wide[2]

Physical destruction or impairment of roads, communication infrastructures and power distribution facilities can hamper or delay rapid resumption of communications. Obtaining access to a communications facility without road infrastructure may be impossible in the near term.

II. CURRENT SITUATION

Some current solutions solve the problem of emergency communication through the distribution and use of handheld devices by emergency personnel. These devices may use UHF, VHF, Satellite, or other licensed bands not typically available to the general public or the potential victim. Responding agencies may also utilize incompatible communication equipment making inter-agency coordination difficult or impossible. For example, during the September 11, 2001 attack in New York City, the incompatible radio systems employed by the various agencies that responded prevented their sharing of critical information by first responders [3]. This failure jeopardized both the emergency personnel and the victims. Cell phones are standardized and do not suffer from this incompatibility. Cell

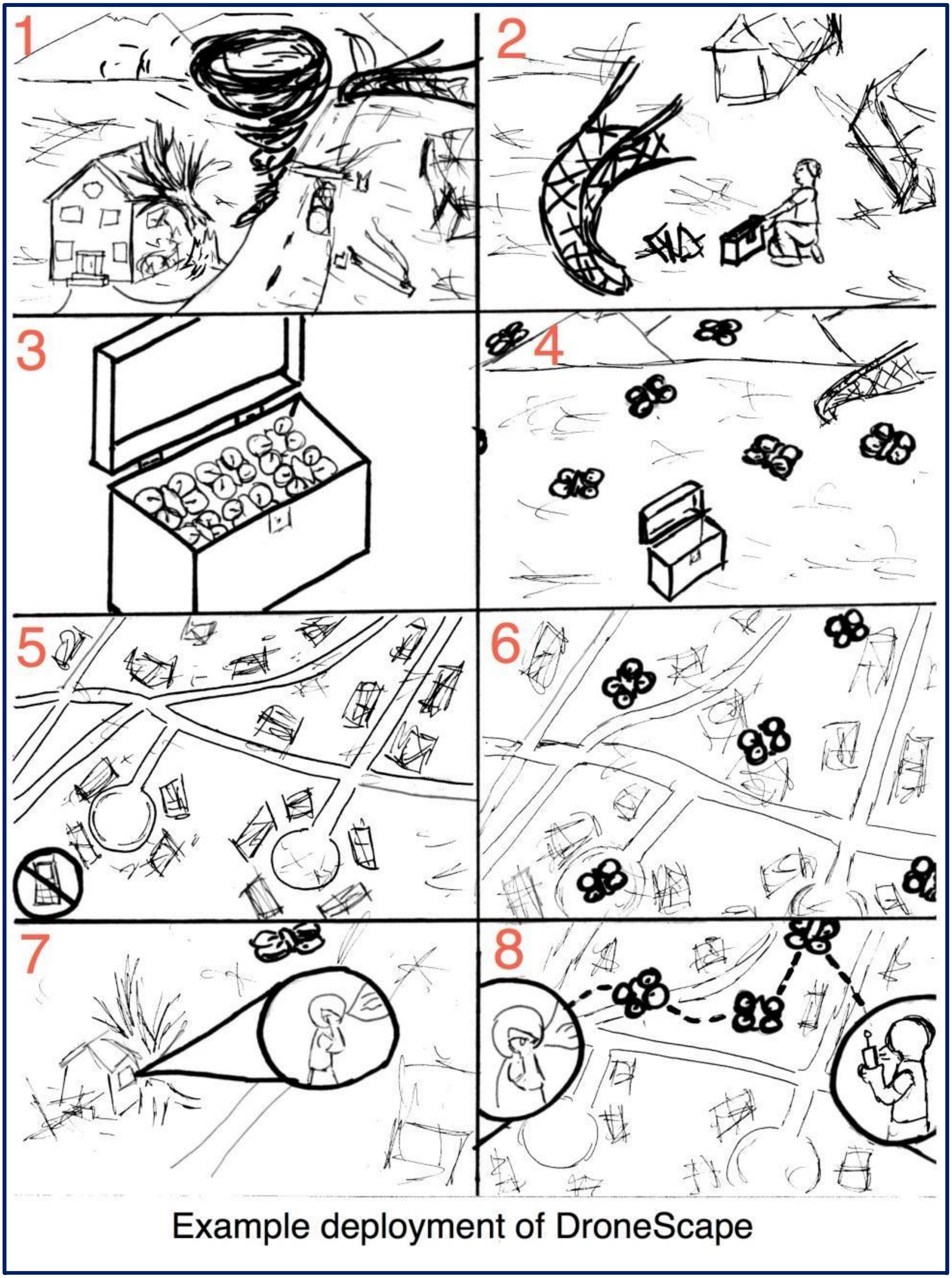


Figure 2- Illustration of DRONESCAPE deployment scenario

phones on the other hand are ubiquitous; there are more mobile devices worldwide than there are people (see figure 3)[4]. Most victims already have one (or more than one) cell phone available to them during an emergency. If the disaster also takes down the cell towers and interrupts service, mobile phones are no longer useful. The DRONESCAPE proposal is to provide cellular infrastructure in a temporary, rapidly deployable form to support existing end nodes (cell phones) that are already in the hands of the victims and emergency responders at the time of the disaster.

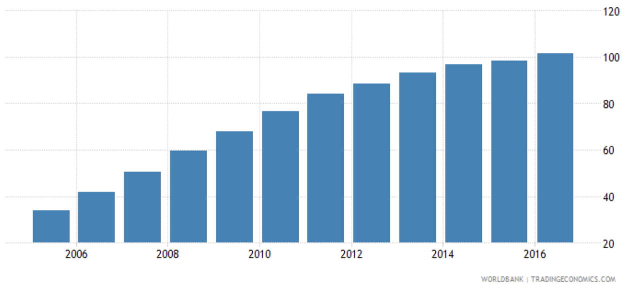


Figure 3- World - Mobile cellular subscriptions (per 100 people)

Other solutions include the LOON project [5] from Google. We intend to consider ideas advanced by LOON (such as solar panels to increase the lifetime of the devices [6]). Since DRONESCAPE will deploy into a known fixed grid, the issue of transmitter movement experienced by LOON would not have an impact on network availability with DRONESCAPE.

III. PROPOSED SOLUTION

DRONESCAPE proposes a mobile, distributed cellular communications infrastructure intended to be rapidly deployed in a temporary fashion. (Note this proposal does not address RF band licensing issues - this would be for adopters or emergency management personnel to address with the FCC or other responsible licensing organizations. The proposal is intended to research the feasibility and design of a proof of concept to validate that such a system is deployable.) It is anticipated the FEMA Wireless Emergency Alert (FWEA) would interoperate with this system. The FWEA broadcasts could be relayed through DroneScape to all cellphones within the affected area. This system is intended to be deployable within minutes or a few hours of an event. It is expected to provide cell service for a short period of time, 1-2 days, while the existing cellular infrastructure is repaired and made available. DRONESCAPE is intended to be inexpensive enough to have multiple systems prepared, pre-positioned strategically within a locality, and ready to deploy immediately. The cellular area to be covered can be adjusted by the size, and number of drones assigned to a deployment system, and precise GPS positioning. The drones are outfitted with a micro cellular base station and battery. Figure 2 illustrates a typical scenario deploying DRONESCAPE into a disaster affected area. Frames 1 & 2 illustrate the devastation caused by a disaster damaging cellular equipment. Frame 3 displays the Deployment Module (DM) with the enclosed, charged and ready to deploy drones while frame 4 shows the drones having left the deployment module and on route to their target positions.

The concept revolves around three technologies: micro cellular base stations, semi-autonomous aerial delivery, and the Delivery Module. Frame 5 shows a neighborhood without cell phone service. Frame 6 shows an example deployment arrangement in the neighborhood. Frame 7 shows cell phone service restored and frame 8 shows the public contacting emergency service for aid.

There are five major components to DRONESCAPE:

A. *Deployment Module (DM)*

The Deployment Module (DM) can be constructed as either a box that could fit into the bed of a standard pickup truck or a trailer that could be towed by any vehicle with a trailer hitch. Essentially, the DM is a large box with the drones nested on top of each other in stacks in the box. The drone stations in the DM will be kept at full charge by pass-thru power connectors from the DM. Those pass-thru connections will also provide data communication capability from the Drone Management Station (see Figure 4) allowing for system management of the drones, configuration and status communication, and designation of the specific target location for each individual drone. The proposed connectors in the DM and on the drones, shown in Figure 4, allow the drones to self-deploy on command once configured, the DM box is opened, and the drone directly above it has deployed. No manual assistance is necessary for the drones to “fly out of the box”.

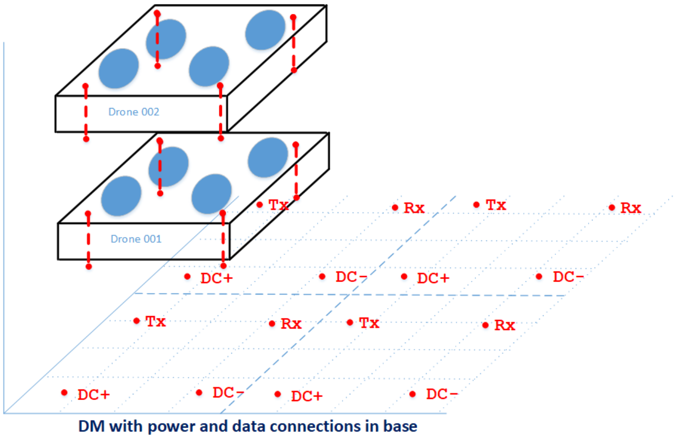


Figure 4- Deployment Module power and data bus structure to every drone

The chest would be composed of some number of modules to include: power, uplink, drone communications, drone monitoring, and inventory. The DM will be able to plug into multiple electrical sources: vehicles, portable generator, 110v and 220v stationary power, as well as solar and wind. The DM will manage utilizing some or all of these sources to acquire sufficient power. The DM will have the capacity to discover and utilize multiple uplink possibilities for tying into outside communication facilities such as: still functioning wired telephone, cellular, and cable infrastructure, satellite phone, and microwave and RF wireless signaling. DM to drone communication can be supported by cellular data once established or RF. While in the chest, the DM will monitor the drones for battery charge readiness and provide power to keep them at full charge, perform periodic self-tests for each drone to update the DM's inventory of drone capacity and capability. The DM with this information can influence the distribution of drone during deployment knowing the number of available drones in the chest. The DM will also keep track of information about the drones deployed such as power utilization and battery level, precise location, cellular signal strength, associate cellular clients and specifics, communication traffic and demands, and the ability to issue recovery calls. The DM could also hold several drones in reserve to deploy to locations where a drone died or did not reach its intended target.

Each drone will carry an identical RF "Micro-Cellular Base Station". From delivery on site to drone deployment should take place quickly (minutes to an hour at most). At time of deployment, the carrier "releases" the drones. The drones will disperse themselves over some pre-defined geographic area as directed by the Drone Management Station. The goal is to provide overlapping, low power, cell-based coverage to that area. Since the DM ensures a full charge on all drones, the only lag time would be the time to get the DM from storage to the disaster area. The final cost of the DM and drones will determine the density of DM staging and thus the maximum time to delivery on site. While one large drone might work, the division of the work to multiple drones allows for the network of micro-cellular base stations to adapt and function with the loss of one or more of the drones or a malfunctioning battery. This army of drones provides redundancy in an unfriendly environment such as is likely to be encountered in a disaster area.

B. Drones

As with any electrically-powered Unmanned Aerial Vehicle (UAV) there are a number of engineering and design decisions that will need to be made. Battery life, for example, can be impacted by many factors and is critically important. The weight of each resource accumulates into the overall project. The number of motors on the drone (typically 3 to 6 in consumer UAVs) impacts weight. Rotor pitch also impacts power consumption. Tests might reveal that 6 rotors are necessary for stability and performance during storm conditions. Since DroneScape will be deployed in likely inhospitable weather conditions, additional rotors may be necessary and must be considered. The type and size of battery will affect weight but also impact cost. The lightest and most efficient batteries cost significantly more. The additional overhead of a separate battery for drone operation and cell service support will be considered. This could make power for recovery more likely. Separate batteries might ensure recovery methods but a joint battery could provide more power for longer cell service or further conveyance.

Alternate supplementary power sources will be explored to compliment battery power. Solar is possible but during a storm cloud cover might make solar ineffective. Wind is a more likely power source during a storm. As an incremental power add, it might be possible to, upon landing the drone, to position it such that the fans are facing into the wind and utilize them as wind generators (see Figure 5). It is understood that this could be intermittent or sporadic. This might provide power support for a longer duration deployment. Methods to power down or utilize low power modes and suspension of unnecessary components will need to be considered to extend available power sources.

Precise location data of the drones, such as GNSS RTK, will be necessary to deploy the drones to a specific target location and recover them after they are no longer needed. More importantly, accurate positioning data will aid in detecting if a drone and it cellular radio have been moved during the disaster. That could happen either because of wind, or erosion, or in the event that a drone is picked up or stolen. When the drone detects any movement it can issue an alert. The alert can be used to either track the stolen drone, attempt repositioning of the drone to affect coverage, or to requisition the deployment of a replacement drone.

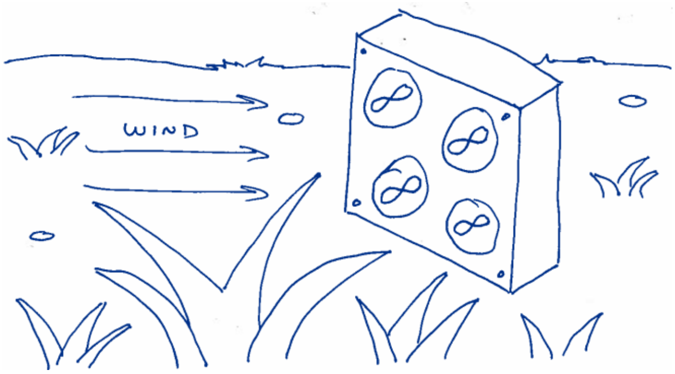


Figure 5 Wind as a potential power source

C. Micro-Cellular Base Station (MCBS)

Deployed with each drone, this unit would provide a cell base station, using software such as OpenBTS [7] and OSMOCOM [8], for connection from any cell phones within reach, and would relay either to the Communications Relay Center (CRC) directly if close enough, or to another MCBS for relaying to the CRC (a la ad-hoc networking). Power management and support of appropriate voice or data technologies are to be managed by the MCBS. The MCBS will have: limited battery life, smaller coverage radius than a typical cell tower, and only BASIC cellular functionality (likely no billing, limited authentication, and only support for carrier standards - GSM for AT&T and T-Mobile, CDMA for Verizon, etc.). Cellular data will be supported at possibly reduced speeds to ensure the maximum number of cellular clients can get shared access.

Even though many features or chargeable services might be disabled or not billed, security will still be a concern. Authentication in one form or another will be necessary to prevent abuse and fraud. During an emergency is when we are most at risk of loss by thieves and looters. With DroneScape, we must protect the communication resources from abuses such as non-emergency consumption of telecommunication and internet services. The communication infrastructure created by DroneScape is limited and while we believe it will be sufficient to support emergency needs during the first hours or days of a disaster it may not support non-emergency uses such as gaming, movies, or large downloads.

D. *Drone Management Station (DMS)*

The drone management station will typically be part of the DM or nearby and tethered to it. The drone management station controls the selection of the geographic area to be covered and options for the deployment. Coordination of the drones is key to maximal coverage of the area targeted [9][10]. It then relays deployment instructions to each of the drones in storage in the DM and triggers their release. This station also monitors and controls the operation of the drone swarm during and after deployment. The DMS will compute specific location destinations for each drone before deployment, upload instructions to the drones in the DM, and can adjust deployment locations accounting for drone failures to ensure optimal coverage of the affected area. The DMS also maintains information on all drone actual landing locations and constantly updated information on the drones status and cellular health.

As the drones will be deployed on the ground or on top of surface structures, the geography of the target area will need to be taken into account in the dispersion algorithm placing drones around the area. For example, a drone deployed on top of a building could cover a larger area than one deployed on a flat wooded area. Deployment on a small hill might benefit from 2 or 3 drones positioned on the sides of the hill. In addition to the geography, the dispersion algorithm could also take structures into account. This will also require advanced topographic and structural knowledge for potential deployment locations. The possibility of landing drones in tall trees should be explored as well (see Figure 6). The height might add to the cellular coverage at the expense of recovery and potential damage to the drone and equipment.

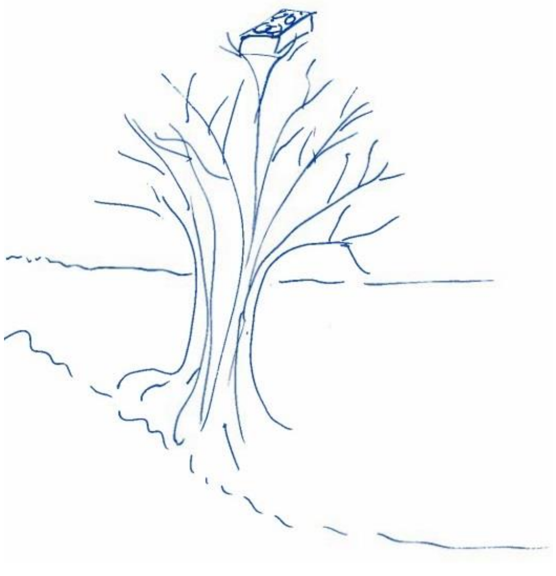


Figure 6 - Tree placement of cellular radio

E. *Communications Relay Center (CRC)*

The Deployment Module incorporates a smart head node. This node provides the ability to connect to a variety of available communications facilities if any are available and seeks a successful connection to off-site communications resources when available. If none are functional or available, the CRC can have satellite uplink service to provide connectivity to locations outside the affected area. If no uplink can be established, all cell phones within the DroneScape umbrella of coverage can still communicate with one another. The goal is to relay traffic from the drone swarm to the outside world and vice versa. This might include DSL, POTS, Satellite, LAN, existing deployable emergency network solutions, or any other available technologies to which the CRC is capable of connecting and over which communications traffic can be relayed.

As battery life will likely be a major limitation, the intent is for a short term solution to fill the immediate need during the first minutes and hours of the disaster event. This provides first responders and the public with the necessary communications needed during that critical first few hours of a disaster or emergency. During this window, a long term solution can be brought to bear to fully restore communication; service can be cut over to the long term solution when it becomes available. In this context, short term might mean hours or days. If longer term solutions are needed, deployment of another round of drones would be possible. Light weight solar panels could also be deployed on each drone to extend the battery life if that is feasible. It would be part of the planning process to have nearby DMs brought into the area in case they need to be utilized to extend the short term solution until a longer term solution can be implemented.

Once the emergency is resolved the issue of the recovery of the drones can be addressed. If the cost of the drones is low enough, recovery of the drone may not a concern. The drones could be tagged with a “return to Emergency Relief Agency for a reward” label. The drones could be designed with an easily locatable trait such as glow in the dark, flashing light, etc. Lastly the drones could be ordered to fly to a pick up location if sufficient drone battery still exists. The utilization of GPS-RTK to give precise, 1-2 cm resolution, location information of the drones actual parking location would be shared to the DMS at the time of deployment[11]. This information would allow for a straight forward “truck roll” to that location and manual pick up of the drones if all else fails.

IV. RESEARCH QUESTIONS

Areas of research to be conducted:

- *drone deployment solutions* to determine the best selection based on characteristics of flight control, weight carrying capacity, and battery life.
- *power and longevity* requirements and solutions. What solutions exist to provide extended power resources such as recharging or increase battery life?
- *radio solutions* - including software defined radio - that can provide the best ability to provide necessary cell phone tower functionality. For example, the ability to dynamically control features - even to power them down in order to conserve battery life - will be considered.
- *antenna deployment solutions* such as released whip, balloon deploys, power raising, and others for best selection and alternative environments.

- design of a *mating collar* between the micro-cell tower device and the drone with the idea that it be flexible enough to be compatible between several drone and radio solutions.
- assess the value to emergency personnel to know the *number and general location of persons* in the affected area. Cellphones will automatically make contact with the micro-cellular bases once deployed even if a victim is unconscious or unable to make a call. This information can be collected from the micro-cellular base stations and shared with responders and planners.

V. EXPECTED RESULTS AND IMPACT

All of the sub-components making up this project exist right now. The challenge is to bring them together, providing the glue to make them interoperate, control drone guidance, manage engineering questions, and co-ordinate with other communication services necessary to achieve the desired results.

The primary goal of the project will be the research and design of a solution to each of the elements outlined above. The successful deployment of a drone-carried payload to support a mobile emergency cellular network would be the first step, followed by field testing of the system during a simulated emergency, disaster, or hazardous situation.

VI. ACKNOWLEDGEMENTS

We wish to thank Megan Fritts for taking our concept and turning it into an easy to follow story board of the DroneScape proposal. It was most helpful addition to our paper.

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