Recovering Communications After Large Disasters

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ABSTRACT

Present ad-hoc approaches to communications recovery after large incidents need to be improved and systematized. This paper views disaster recovery as a layered process to provide an orderly restoration of communications after large incidents and identifies some of the missing pieces needed to make this happen. Current solutions and future advanced techniques using software defined radios are presented.

1. INTRODUCTION

Public safety has made great strides in achieving interoperability since the events of 9/11. The focus on interoperability also highlighted the need to maintain operability during large incidents such as earthquakes and storms like Katrina. The traditional approach has been to build stronger infrastructure and backups to ride out the incident. However, it is also clear that the awesome power of nature cannot be completely overcome. The best efforts of humans could still fail in a major event. No tower is completely impervious to storm winds, and sometimes debris flies into generator cooling radiators and shuts down a system (Katrina). A widespread event such as the earthquake and tsunami in Japan or even a more contained event such as the quake in Haiti can wreak havoc and leave the populace stranded without administration to provide immediate help.

When communications infrastructure is unavailable or disrupted in a large area, first responders often turn to satellite communications (satcom). The satcom element will be referred to as the **Space Layer (SL)** in this paper. Some responders are well versed in the use of satcom. Firefighters fighting wild land fires, for example, may use satcom terminals for data, situational awareness and incident management. However, when a major disaster such as Katrina, which spanned several states, strikes, the disruption in its path is not easily repaired. Moreover, those affected may not be conversant with the use of satcom technology if it is not in regular use or exercised regularly. The communications needs of both emergency personnel and the general populace could be great while a few satcom terminals flown in are only able to provide localized communications. The yeoman services provided by satcom with voice and data were critical to the early stages of recovery from the Indian Ocean Tsunami of 2004 in some parts of the world and Hurricane Katrina in the US. Still, their limited capacity to handle heavy traffic over large areas (spatial capacity) results in critical needs not being met. Even commercial terrestrial services which survive may not be designed to operate over extended periods of time after power failure.

To avoid breaking out unfamiliar equipment in a time of crisis, satcom needs to become an integral part of every Emergency Operations Center (EOC) and Emergency Management Agency (EMA) location. Satcom could provide alternate live paths for command communications with state, local and central administrative centers. First responders on the field need to make satcom part of any exercises. This is the only way to keep this equipment working and ensure that first responders are trained to use them in an emergency.

Most importantly, the inability of first responders to use their regular land mobile radio (LMR) handsets and mobiles means that law and order, as well as all forms of disaster response and rescue, are compromised. The citizenry is left to survive on its own. When command, control, and communications (C3) are disrupted, the resulting loss of situational awareness may sometimes result in inadequate response from central or state government and possibly overly optimistic statements from state and national leadership!

2. ARCHITECTURE

The normal terrestrial communications we are all familiar with will be referred to as the **Terrestrial Layer (TL)** in this paper. The satcom element is called the **Space Layer (SL)**, as indicated earlier. The approach suggested in this paper is to also formalize the use of an **Airborne Layer (AL)** in the emergency communications mix and propose an integrated strategy, while also looking at powering needs. The overall approach is shown in Figure 1.

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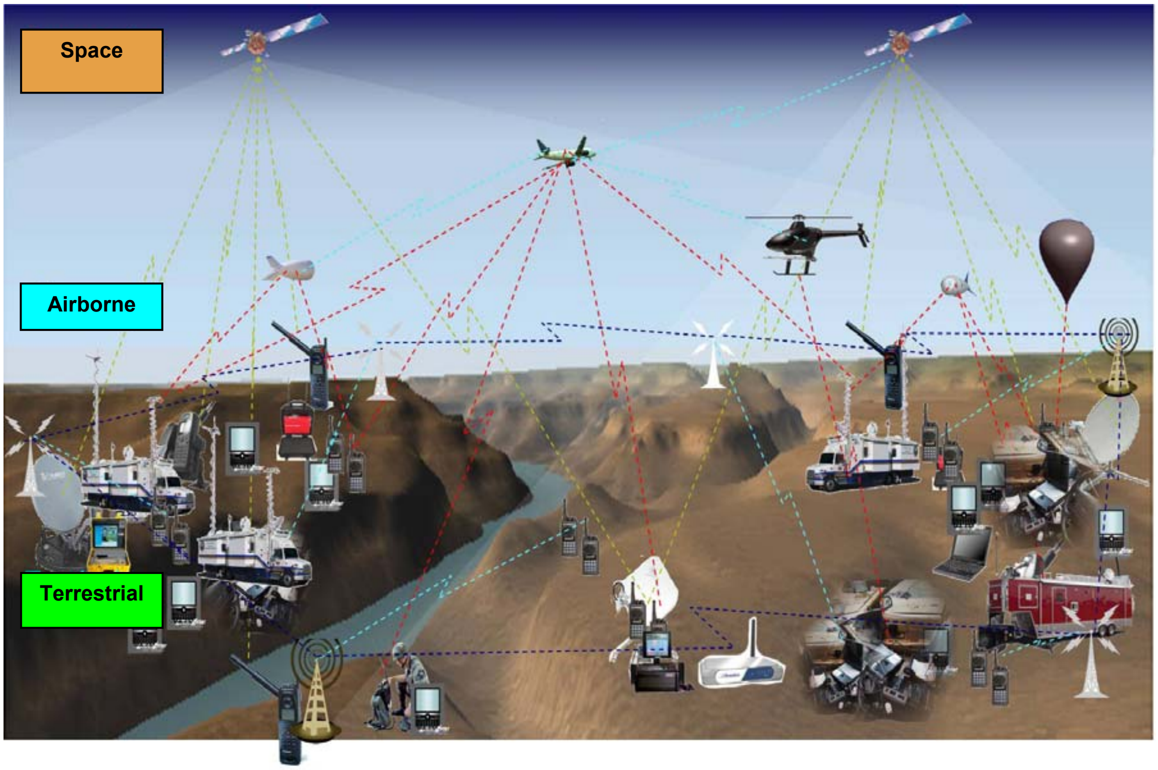

Figure 1: The Three Layers of Recovery Communications

2.1. The Space Layer

This is often the first phase of the recovery (Figure 2), as discussed previously. However, it usually requires specialized Terrestrial Layer terminals. The regular terminals most used by first responders are rendered inoperable due to infrastructure damage. Hybrid terminals which incorporate satcom into terrestrial systems' terminals may also be available for use on the ground. In the second phase, the SL will work with the AL to relay higher capacity communications.

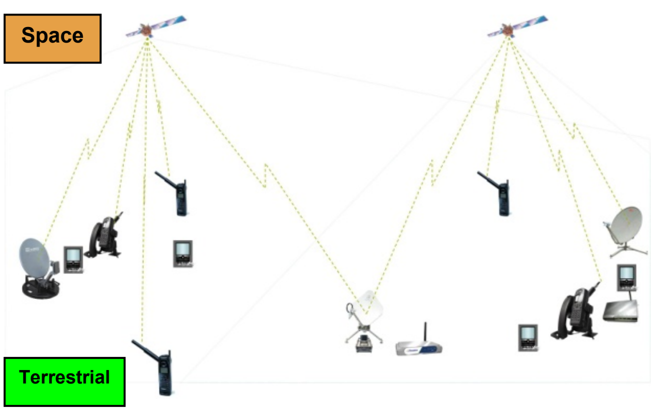

Figure 2: The Space Layer in the First Phase of the Recovery

2.2. The Airborne Layer

The AL functions as a temporary replacement for the destroyed infrastructure and also enhances the capacity of the SL. It can be considered in three stages.

The first AL stage consists of fixed-wing aircraft which, at 6,000 to 15,000 meters, can initially fly above the storm and its aftermath in a station-keeping pattern. They can carry equipment that communicates both with satellites and with ground satcom terminals which are either in place or brought in by aid agencies. This allows them to aggregate the traffic and relay it with high bandwidth connections to the satellites, thus increasing spatial capacity. They are not power-limited. These are sometimes called "surrogate satellites."

Depending on the LMR technology, these craft may also be able to carry LMR base stations. Despite their high speed, attendant Doppler effects are usually not a problem if the aircraft is overhead. They may even be able to perform airborne command post functions, much like U.S. military Airborne Warning and Control System (AWACS) aircraft. However, these are specialized aircraft and will probably need to be federal (and perhaps state) assets. They are manned and will require refueling and frequent crew change and replacement.

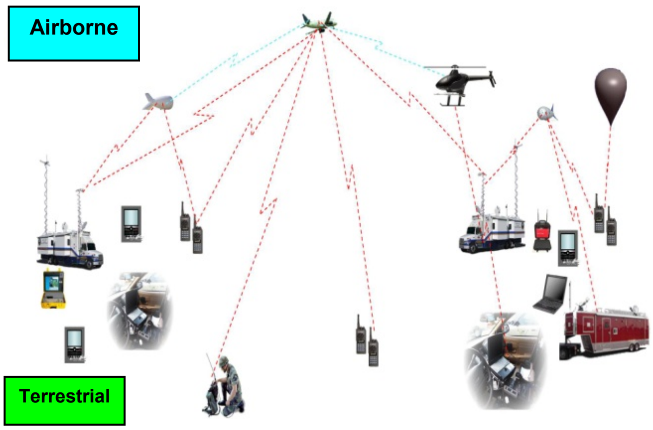

Figure 3: The Airborne Layer is used with Existing Terrestrial Terminals and the Space Layer

The second AL stage could consist of stationary, lower flying, rotating-wing craft (helicopters) flying from 1,500 to 6,000 m. These can be regular craft that can be quickly outfitted with LMR base stations since there is no concern about piercing a pressure hull. The direct line-of-sight communications to these high platforms means their base stations can be low-powered. They will allow the first responders on the ground to immediately use their traditional mobiles and handhelds. The stage two platforms could also carry mobile satellite equipment to relay the communications out via the SL to distant EMAs. Since they fly lower, their coverage is less and hence they will use more craft to cover a large area, thereby increasing spatial capacity. Finally, they could be outfitted with mesh networking equipment to connect with other craft so that an extended network can be formed to support ground LMR communications. The initial stages of ground communications recovery will be underway.

In the third AL stage, as the weather calms further or when there is time to bring in new assets, other craft such as unmanned heliostats and slow-flying, solar/ fuel-cell powered airplanes that can operate for weeks at a time can take over, further increasing capacity. Even free-flying, low-cost balloons with repeaters, which can be replaced with others as they drift out of range, have been proposed. Finally, these can be supplemented or replaced by tethered balloons, carrying lightweight base stations flying at 150 m or less and powered through the tether. We now have an operational LMR system. Most important, first responders are able to use their regular mobiles and handsets which they use day-to-day (though perhaps in conventional, analog mode). They can be dispatched from active fixed or mobile dispatch centers.

2.3. The Terrestrial Layer

The TL may initially need to use specialized terminals to work with the SL, though hybrid terminals may also be available. These should have been incorporated into more regular use during normal operations. However, once replacement infrastructure is provided by the AL, perhaps working together with the SL, emergency workers can use their regular terminals/ Land Mobile Radios to resume communications, command and control.

3. BROADBAND AND CIVILIAN COMMUNICATIONS

Although the above discussion has focused on communications for first responders, lightweight broadband/ cellular-communications equipment could also be flown in suitable AL platforms. These would be modeled after the "Cells-on-Wheels" infrastructure commonly brought in to restore commercial service. Designed for airborne use, these could be deployed for both emergency workers and the general populace. Initial use of these broadband services could be limited to text and email messages. Voice communications and low-bit-rate video could be added as capacity increases and connectivity is established with the rest of the world.

Commercial service providers would pay for the cost of deploying their cell sites on the AL platforms, since these would enable them to restore some communications to their paying customers. This also helps defray the cost of deploying the AL platforms for first responders.

4. POWER FOR THE RECOVERY

A less glamorous aspect of this strategy is the need to keep first responders' terminals powered and operating. The restoration of the infrastructure outlined above is useless if the users' terminals are dead and there is no ground power to recharge them. One option is to look for decentralized powering solutions such as solar panels and propane fuel cells in addition to any available generator power, though the latter may be needed to run the base stations. For example, it is estimated that a 1.2square-meter solar panel can provide about 180 watts to power several handset chargers. This should be enough to serve a small first responder post. Smaller, portable units could be placed in first responders' homes, particularly if there is time to pre-plan, so that personnel are available for duty even if their work location has been damaged or destroyed.

This approach buys time until the regular communications and power infrastructure is repaired. C3 is restored quickly in an orderly fashion. Situational awareness is maintained. Necessary aid can begin flowing in as roads are repaired. Law and order and rescue units are able to function.

In the earthquake and tsunami in Japan, and even in a relatively well-contained disaster area such as Haiti after the earthquake, the above approaches could have provided several benefits. Satcom and airborne assets could have relayed communications to the surrounding cities which suffered minimal damage.

5. ACTION PLAN

What is needed to implement this approach? The AL needs airborne assets with satellite relay and mesh networking capability that can work with multiple satellite types and ground terminals. These need to be stationed around the country for quick deployment by a national agency such as the Federal Emergency Management Agency (FEMA) in the United States. Next, lightweight, portable equipment that can be quickly installed and taken up with helicopters are needed, both for satcom and LMR. These may be kept in regional centers from which helicopters can be dispatched.

Low-cost, lighter-than-air craft can also be placed in regional locations to facilitate rapid deployment in sufficient numbers. Finally, local agencies may keep balloons, which could be quickly inflated and tethered, as emergency backups for towers. However, since transportation infrastructure may be sufficiently restored by the time these are deployed, they may be trucked in. They could also be brought into the area in advance of a major storm. Additionally, some federal agencies, such as U.S. Defense Department installations and the U.S. National Guard, may already have such equipment, which could be used to relay civilian communications in an emergency with appropriate portable base stations, provided the necessary Standard Operating Procedures (SOPs) and Memoranda of Understanding (MOUs) are executed.

The Space Layer could also use a small number of specialized Emergency Communications Satellites (ECS) as national assets. These are justifiable in the same manner as Global Positioning System (GPS) or weather satellites are national resources and could cost much less. They could be made available for use without charge by the central government. Another approach is to leverage commercial satellites that are redirected to support emergency use in a public-private partnership. The satcom industry could work with first responders to minimize tariffs while ensuring that they have a steady stream of revenue supporting normal traffic: for example, between EOCs and the state and, where suitable, as alternatives to microwave relays. This is particularly important since operational funding to pay for satcom as part of day-to-day activities is perceived as being difficult to obtain under current funding mechanisms.

6. CHALLENGES

While many of the pieces of this approach may be already present, there are some technical and operational challenges as well. These include:

- Possible effects of surrogate satellites deployed for the emergency on existing ground terminals that are connected via the space layer.
- Possible effects of the rapid motion of the first stage high speed airborne relays on links that normally work with geosynchronous satellites or terrestrial networks, especially if the aircraft is significantly downrange. One workaround might be to provide slow, high-flying solar or fuel-cell powered airplanes, airships and other High Altitude Long Endurance (HALE) Unmanned Aerial Vehicles (UAV) as communications platforms as soon as possible. Some of these may even be able to fly above the weather.
- Delays introduced by these alternate space and airborne relays on inter-system links, which would normally be implemented on low-delay terrestrial infrastructure such as fiber and microwave.
- Possible interference with surviving infrastructure, or infrastructure beyond the disaster area, that is operating normally.
- Various communications links, such as the self-organizing mesh networks proposed above to link the various platforms, may need to be optimized or standardized and built into lightweight, compact, hardware packages.
- Software and middleware needed to connect dissimilar systems together in the SL, AL, and some of the TL.

Operational challenges include a desire expressed by some first responders that the emergency equipment should simple to operate and automatically select the most appropriate space or airborne infrastructure without user intervention, leaving them free to concentrate on their primary emergency response tasks. This could require:

- Multi-band, multi-protocol, multi-waveform, multi-network capability radios that would intelligently configure themselves to the available space, airborne and terrestrial resources. This is clearly the domain of software-defined and cognitive radios.
- Electronically steerable and tracking antennas in various bands

- Cognitive aspects of the above task, to select the most appropriate resource, band, frequency, and protocols to serve the communications needs. They may also need to automatically switch to different resources as the recovery progresses.
- Low-cost recovery communications terminals which may be integrated with existing terrestrial terminals. Some of these have already been demonstrated. It should be noted, however, that the aim is to minimize the use of specialized terminals in the hands of the first responders.

Another important area to consider is to designate frequencies which could be used in airborne LMR nodes in disasters in the various bands, and also the licensing of airborne satcom relays. These could be used if there is a declaration of disaster and the infrastructure is down. Regulatory mechanisms for using existing ground frequencies with damaged infrastructure and mutual aid channels in low-power airborne nodes may also need to be explored. Clearly, there would be no time for specific regulatory relief applications and studies!

The Software Defined Radio Forum's satcom and public safety special interest groups (Satcom SIG, Public Safety SIG) are jointly studying some of the hardware, software and operational aspects involved in building such hybrid architectures. Professional bodies such as the Association of Public-Safety Communications Officials - International (APCO), national/ federal/ state governments, the European Union, and industry need to provide leadership.

Finally, these approaches may not be very useful if first responders are not trained to work with the multiple recovery layers before ground infrastructure is restored. SOPs and MOUs are critical. The concepts of operation (CONOPS) need to be developed and all parties need to know the playbook so that relief is provided quickly.

7. SUMMARY

Present ad-hoc approaches to communications recovery after large incidents need to be improved and systematized. This paper views disaster recovery as a layered process to provide an orderly restoration of communications after large incidents and identifies some of the missing pieces needed to make this happen. Current solutions and possible future advanced techniques using software defined radios are presented.

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