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Research Article

High Altitude Platforms for Disaster Recovery: Capabilities, Strategies, and Techniques for Emergency Telecommunications

Juan D. Deaton

Homeland Security Directorate, Idaho National Laboratory, Idaho Falls, ID 83415, USA

Correspondence should be addressed to Juan D. Deaton, juan.deaton@inl.gov

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Natural disasters and terrorist acts have significant potential to disrupt emergency communication systems. These emergency communication networks include first-responder, cellular, landline, and emergency answering services such as 911, 112, or 999. Without these essential emergency communications capabilities, search, rescue, and recovery operations during a catastrophic event will be severely debilitated. High altitude platforms could be fitted with telecommunications equipment and used to support these critical communications missions once the catastrophic event occurs. With the ability to be continuously on station, HAPs provide excellent options for providing emergency coverage over high-risk areas before catastrophic incidents occur. HAPs could also provide enhanced 911 capabilities using either GPS or reference stations. This paper proposes potential emergency communications architecture and presents a method for estimating emergency communications systems traffic patterns for a catastrophic event.

1. INTRODUCTION

After Hurricane Katrina Figure 1, all forms of terrestrial communication networks were severely debilitated. Damage to first-responder networks caused multiple problems in command, control, and rescue operations. Two million landline telephones were out of service at the peak of the crisis and New Orleans sustained a 70% cellular base station outage. Two major carriers lost complete coverage for weeks. Nine hundred and eleven (United States equivalent of 112) emergency call systems became completely incapacitated [1]. This unprecedented damage to telecommunications networks has rejuvenated an interest in emergency telecommunication systems.

Due to their survivability, coverage, and capability of being continuously on station, HAPs offer an excellent alternative for providing emergency telecommunications after a catastrophic incident. HAPs are an ideal option for providing emergency coverage over high-risk areas before catastrophic incidents occur [2]. This unique capability provides significant advantages over terrestrial-based deployable systems and even other airborne systems. HAPs could be outfitted to provide needed critical communications for search and rescue, command and control, and critical infrastructure repair. This unique service population and scenario of use require a new mindset for understanding emergency network requirements and traffic loading. Traffic loading has implications to the amount of required equipment and subsequent impacts to the payload of an HAP.

Evolving cellular technologies and first-responder communication systems each have their separate technology nuances, economic models, and interoperability issues. Emergency systems for cellular networks should provide private access to key personnel as well as emergency call capabilities to the general populace. This has implications for special network congestion control, special location determining capabilities, and access management methods and policies. By examining the specific disaster events, it is possible to begin to extrapolate necessary data for consideration of an emergency communications network.

Alternatively, terrestrial assets should not be ignored when considering communications reconstitution. Deployable cellular systems called Cell on Wheels (COWs) or Cell on Light Truck (COLT) can be deployed by carriers or government support agencies in the event of a disaster. Unfortunately, these systems take time to be transported to the disaster scene and may not have access into disaster areas. Although, COWs and COLTs can provide capacity and coverage similar to a quotidian cellular system, both HAPs and deployable terrestrial systems have timeframes or windows around the disaster incident in which they are each most effective.

2. NEEDED CRITICAL COMMUNICATIONS

According to the Bipartisan Committee Investigation of Response to Hurricane Katrina, critical communications needed during Hurricane Katrina could be grouped into these three categories [1].

(1) First-responder communications

Enhanced 911, Emergency Responders, Army, National Guard, and Coast Guard.

(2) Command and control

Situational awareness, supply delivery, coordination of rescue and security forces, and transportation of evacuees.

(3) Critical infrastructure restoration

Clearing debris and restoring power and communication networks.

Interoperable communication between first responders is important. However, without knowledge of citizens in distress, it makes their function problematic. This is why one paramount element in first-responder communications in the United States is Enhanced 911 (E911). E911 provides location information of an emergency call to first responders. Without connecting the first responders, dispatch functions and the citizens, a surfeit of manpower, can be wasted with inefficient searches. Additionally, the many eyes and ears of the local citizens can greatly enhance the situational awareness of the on-scene commander.

Commanders and state officers also need accurate situational awareness during a catastrophic event to make effective decisions. During Hurricane Katrina, reports from the media were used to determine situational awareness. These reports were grossly exaggerated and unreliable, as was evidenced from reports made about the Superdome [1]. E911 call location data points along with Public Safety Answer Points (PSAP) voice streams used in an Emergency Operations Center (EOC) could also be invaluable to commands to determine where to focus rescue efforts, deploy security forces, and manage evacuees.

In addition to search, rescue, and relief efforts, critical infrastructure must be restored so that water, roads, and communications can be made available. Personnel executing this mission also require communications after a catastrophic event.

3. EMERGENCY HAP ARCHITECTURE AND CAPABILITIES

For an emergency HAP platform to be the most effective, it is paramount that its capabilities are integrated into complete emergency communications architecture. The cellular communications available must be representative of the existing wireless ecosystems so that existing devices can communicate with the platform. All communications capabilities on the HAP should be interoperable using gateways and an IP core to allow communications between all networks.

This would require IP gateways that could manage interoperable traffic between systems. Additionally, a Voice over IP (VoIP) server would be required as part of the server to enable these communications. Most likely, this would be based on Session Initiation Protocol (SIP) signaling. Real-time Transfer Protocol (RTP) streams would be created between communicating points over the IP core. Currently, this technique is being widely used by public safety and military to create interoperable networks [4, 5].

Additionally, E911 capabilities should be leveraged to assist in disaster relief efforts. Backhaul is also required either to terrestrial receiving stations or through satellite, to transmit voice and data information into and out of the HAP. Integration with PSAP systems and the Emergency Operations Center (EOC) is important for maximum benefits. Figure 2 shows an example diagram of this architecture.

3.1. Cellular technologies on HAPs

Cellular systems form the basis for E911 functionality as well as an additional communications capability for first responders. Because in the United States, Global System for Mobile (GSM) and Code Division Multiple Access (CDMA, to include IS-95 and 1X) cellular technologies make up almost equal market share and it is likely that these technologies will be used for the next 5–10 years, both systems should be used for emergency calls [6, 7]. In contrast, 82% of the rest of the world rely primarily on GSM and HAPs in almost any other part of the world could rely on a GSM cellular system only [8].

There are limitations with using cellular technologies at high altitudes. Due to channelization via time slots, GSM time guard bands limit link length to 35 km limiting possible coverage areas. The link length could be increased by increasing the time guard bands, but this would come at a cost of capacity to the system [9]. Additionally, interference onto functioning commercial systems is problematic with GSM due to the deployment of Absolute Radio Frequency Channel Numbers throughout the network. CDMA and Universal Mobile Telecommunications systems have fewer issues with interference due to their use of spread spectrum techniques and channelization via orthogonal codes. Regardless of the cellular system, special network configurations are needed to insure that time out scenarios do not occur due to long link lengths and that spectrum licensing is always an issue unless the license owner is deploying the HAP [10].

In terms of proven HAP cellular experiments, CDMA 1x and UMTS cellular communications have been demonstrated at altitudes of 20 km [10, 11]. These experiments

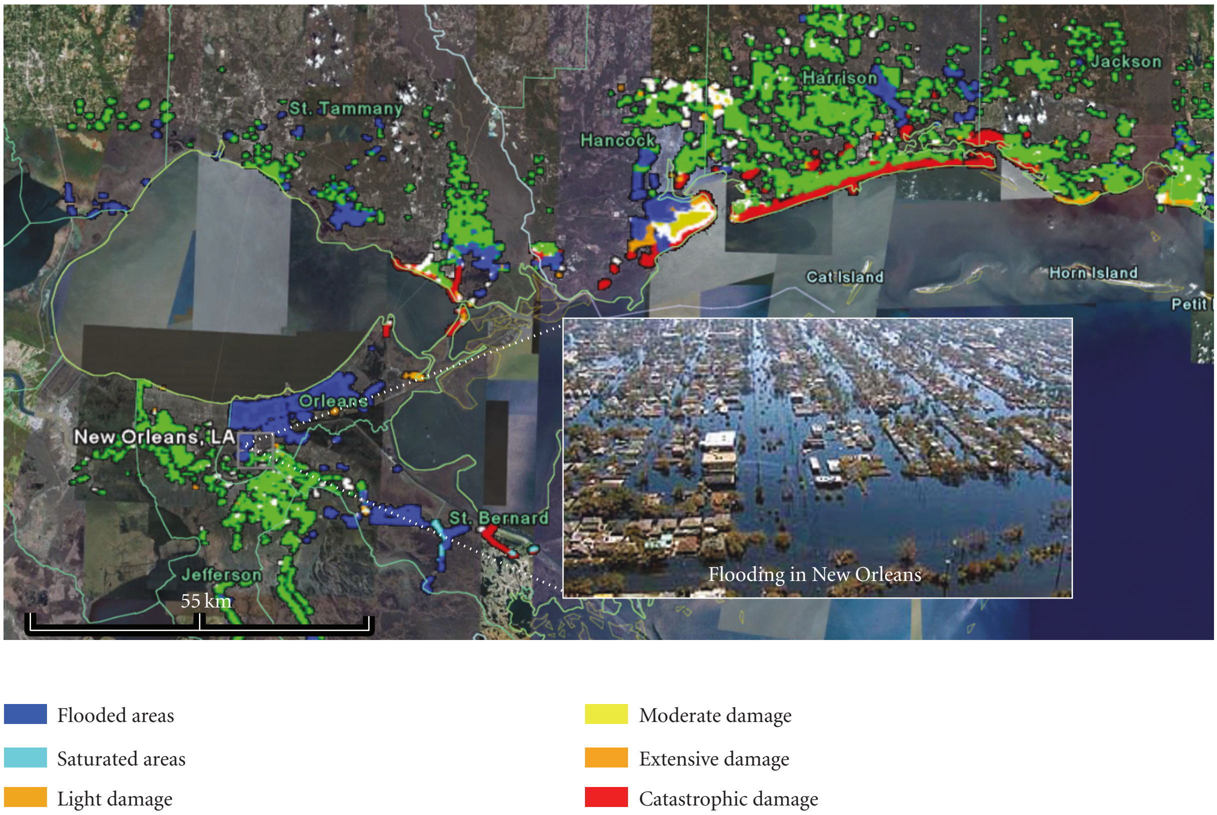

FIGURE 1: Hurricane Katrina damage area [3].

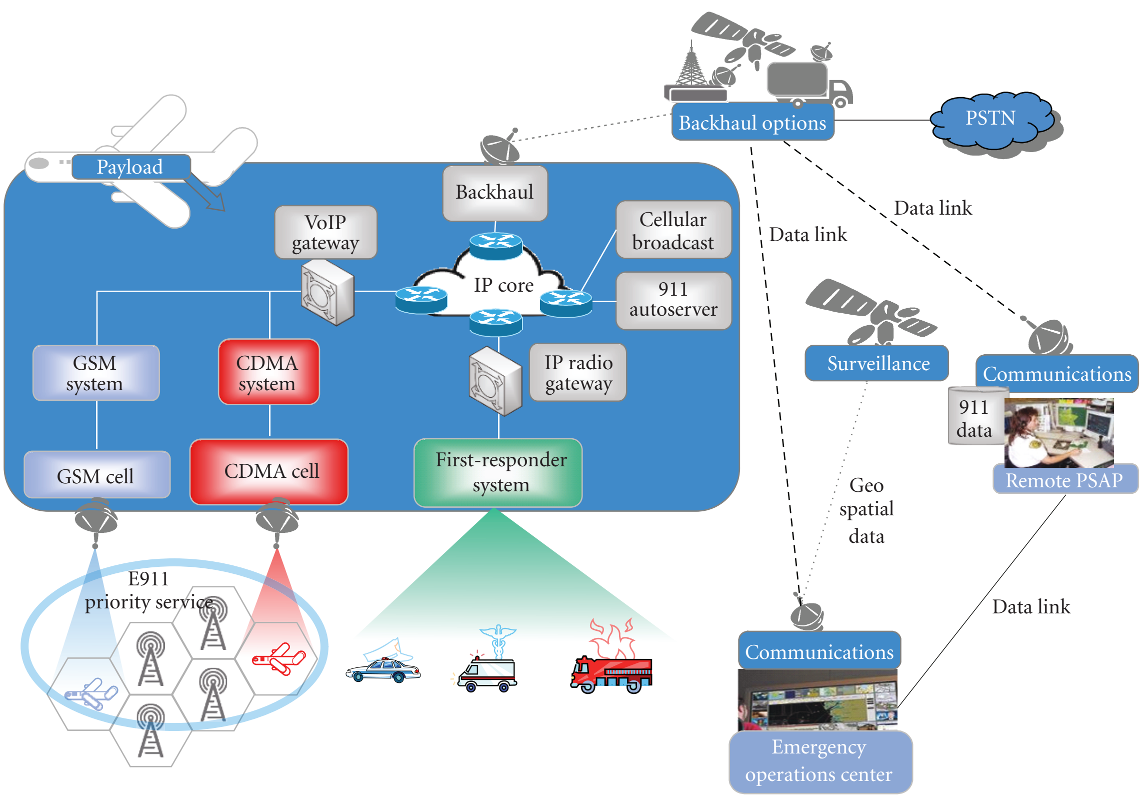

FIGURE 2: Potential emergency HAP architecture.

show that the promise of HAP-based cellular communications is a real possibility for spread spectrum technologies. It also highlights opportunities for experimentation using GSM systems on HAP platforms. Especially since, most of the world relies on GSM technology.

3.1.1. Priority and emergency calls

Regardless of the technology, cellular systems deployed on an HAP should be configured for special access profiles. These profiles should allow for two specific groups: private network access and emergency calls.

Private access to the cellular network could be given to those who require critical communications by creating a special home location register (HLR). This HLR could exist on the HAP. However, it could also reside in a terrestrial location and be connected to the public switched telephone network (PSTN). If standalone cellular systems were deployed on the HAP, messaging to authorize users from the centralized HLR would be done via the satellite link to the PSTN. The authorized mobiles will detect the carrier cellular and be able to roam onto the network.

With regards to emergency calls, most mobile devices will go into an SOS mode once they enter a cellular network that they are unauthorized to use. This means that the mobile is only allowed to make emergency calls. If an emergency cellular network is deployed, mobile devices should automatically enter into the SOS mode and therefore only be able to make emergency calls. Although this is a desired behavior, it does have a disadvantage. Mobiles would not be able to send and receive SMS messages. However, mobiles could receive cell broadcast messages for warnings, evacuation routes, and so forth, if widespread messages needed to be distributed.

3.2. Options for first-responder systems

Due to the disparity between first-responders radio systems, a replacement communications system that utilizes existing first-responder devices is very problematic. Any solution to this problem has drawbacks in critical deployment time, capacity, and network cost. The following are options for a responder system replacement after a catastrophic event.

3.2.1. Radio handout

If an HAP was used to respond to a catastrophic incident with first-responder communications, radios could be handed out to those who needed interoperable communications. This would require a cache of radios with a generic preconfiguration to be available and handed out to first responders upon the event of the incident. Using a P25 or TETRA complaint system would seem to be the least common denominator in a variety of independent first-responder communication systems. If first responders do not already have compatible radios, it is possible that critical time could be lost due to the logistics of the phone handout.

3.2.2. Audio gateway

Audio gateways provide an option for establishing connections between disparate communications by allowing devices of separate system and frequency types to communicate together. This technology is often used for emergency communications to enable interoperable communications between agencies. Figure 2 shows an example of a gateway that allows for three different communications networks to communicate with each other [12]. Audio gateways provide the most flexible option for first-responder communications. Gateways enable dynamic creation of talk groups between different systems and can be used as configurable repeaters when deployed. These systems however do come at a price of time to configure the system and reduced capacity.

3.2.3. SDR systems

Software-defined radio (SDR) provides a theoretical solution to interoperability by dynamically controlling operating frequency and radio link protocols through software. Using an SDR platform on board, the HAP could enable the first-responder radio system to be dynamically recreated on the HAP. Ideally, this system would listen to transmitting frequencies and tune antennas to the appropriate frequencies, then enable recoding of existing air interface protocols such that the devices could communicate again. Utilizing existing devices with SDR could be the fastest option for interoperable communication using an airborne platform. However, the major drawback of this system is cost.

4. METHODS TO MANAGE EMERGENCY CALL TRAFFIC AND UTILIZE EMERGENCY CALL DATA

In order to quantify potential Erlang load on an emergency response HAP, data was combined from various sources in order to estimate emergency call volumes and traffic patterns. Emergency calls were estimated to be 30 seconds long and emergency call trends were estimated by using information from emergency call patterns from the 2006 Israeli-Hezbollah conflict [13]. These trends were normalized and then applied to a worst-case emergency scenario, an improvised nuclear device [14]. The improvised nuclear device scenario estimated the population of evacuated and displaced persons who would require an emergency call. Using the population estimate from the improvised nuclear device scenario and emergency call patterns, Figure 4 was derived. In this estimate, each user was assumed to make only one emergency call.

Although the call volume for emergency calls is very high, the Erlang contributions from the emergency calls are very low. This is because each call was assumed to be 30 seconds long and measured over a 24-hour time period. On day one, 80 000 calls were made, each was 30 seconds long, contributing to a total of 2 400 000 call seconds. When measured over a 24-hour time period, this is 28 Erlang. Given these high call volumes and Erlang load, the requirements for cellular equipment are not as limiting as the need for an automated answering service or more emergency operators.

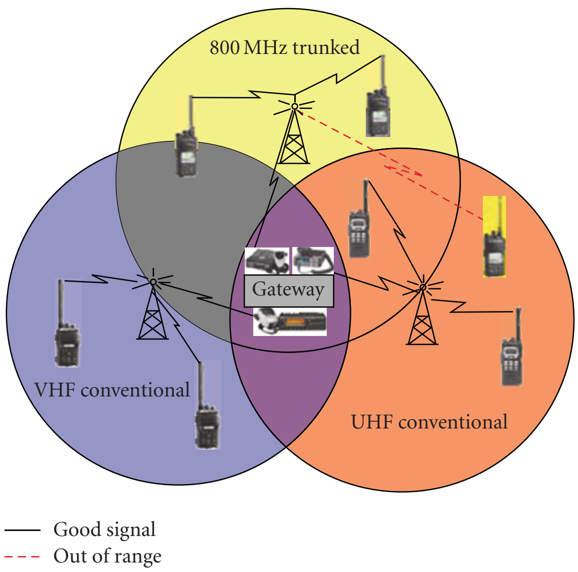

Figure 3: Audio gateway example.

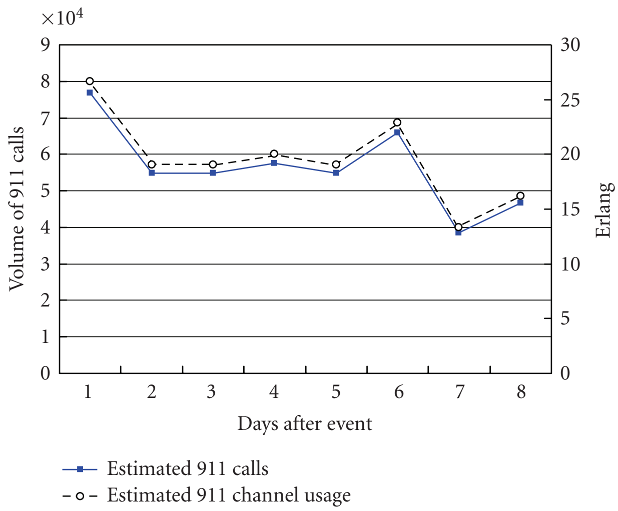

Figure 4: Estimated worst-case emergency call volumes.

This is due to the fact that the number of calls is so very high and Erlang contributions are very small.

To handle the high call volume, an emergency autoserver would be required to provide an automatic emergency answering capability. Once the mobile device detects the HAP cellular network and the user dials the emergency number, the mobile device could then enter an interrogation mode to determine the location, type of incident, and severity. When the phone has its interrogation, it could send an SMS to the emergency autoserver. This server could also use this information to properly direct first responders to the incident, to triage the calls, and to report the high severity calls to the PSAP operators for call back.

This method could significantly reduce air interface resources for determining incidents and locations of emergency calls, but more importantly, reduce the need for emergency operators. However, it would also require phones to have a new application and unique network configuration to perform this function. The users should only be allowed to send an SMS to a specific device and be able to receive calls if required. Current SOS modes on mobile devices do not support these functions.

Using E911 location data and real-time voice feed from emergency callers could also provide accurate situational awareness at the EOC. This information would be used to assist commanders and civil officers who need to have situational awareness for coordination of security and rescue forces. Additionally, this information would be especially useful if overlaid on real-time geospatial imagery. Using this technique, emergency calls could be tracked on a map allowing commanders to "zoom in" to see the disaster, and then dispatch forces appropriately. With PSAP data fed into the EOC, commands would be able to make better decisions based on discrete data points and legitimate situational awareness.

5. E911 TECHNIQUES USING AN HAP

For emergency calls, the HAP should provide E911 location capabilities to facilitate search and rescue operations. Mobile location methods are different for CDMA and GSM systems. 3GPP Release 99 standards support assisted GPS for UMTS, in the United States CDMA operators also use A-GPS technologies, while GSM operators use a triangulation technique to locate the mobile [13]. Unfortunately, GSM techniques require two- or three-cell sites to accurately locate a mobile. Using HAPs to locate mobile devices does present different scenarios since HAPs could be moving.

One potential method is combing the onboard navigation with position determining equipment (PDE) which can calculate the angle of arrival (AOA) and the time delay of arrival (TDOA). This allows the HAP to determine the location of the mobile device with respect to the HAP. Good station keeping would make HAPs an ideal platform to perform this operation. Basic diagram of this technique is shown in Figure 5.

Another option for locating mobiles was tested by Japan's National Institute of Information and Communications Technology (NiCT), the objective of the test was to use reference stations, which locations are known, to calibrate the AOA sensors on the aircraft. An example of this technique is shown in Figure 6. These sensors then took AOA measurements from the target station that was used to calculate its location relative to the reference stations. Using this technique, the NiCT was able to accurately calculate the location of target stations within 5 m [15]. This technique could use operational cellular cell sites or deployable reference stations for reference AOAs. Due to their altitude, HAPs could receive signals from reference stations very far way, out of the disaster area. As an example, a separate NiCT experiment using an HAP at 20 km could receive signals from another transmitting station 200 km away [10].

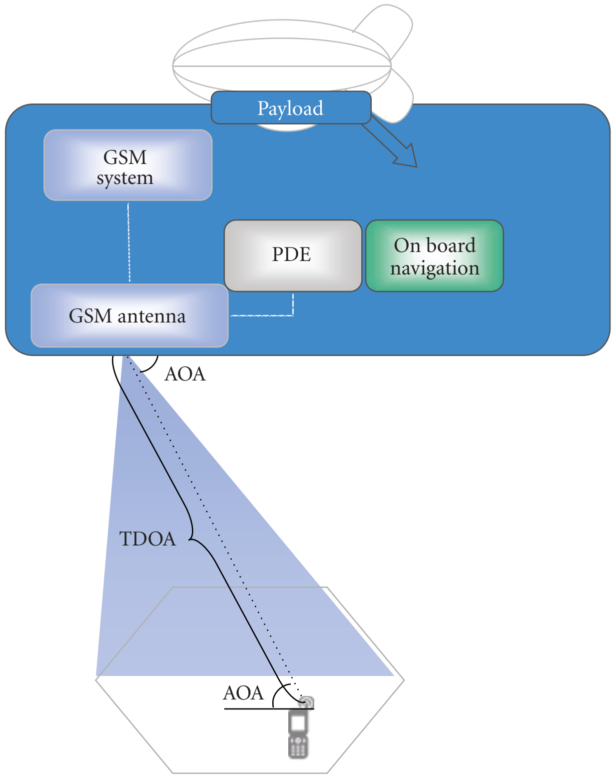

FIGURE 5: A-GPS using HAP.

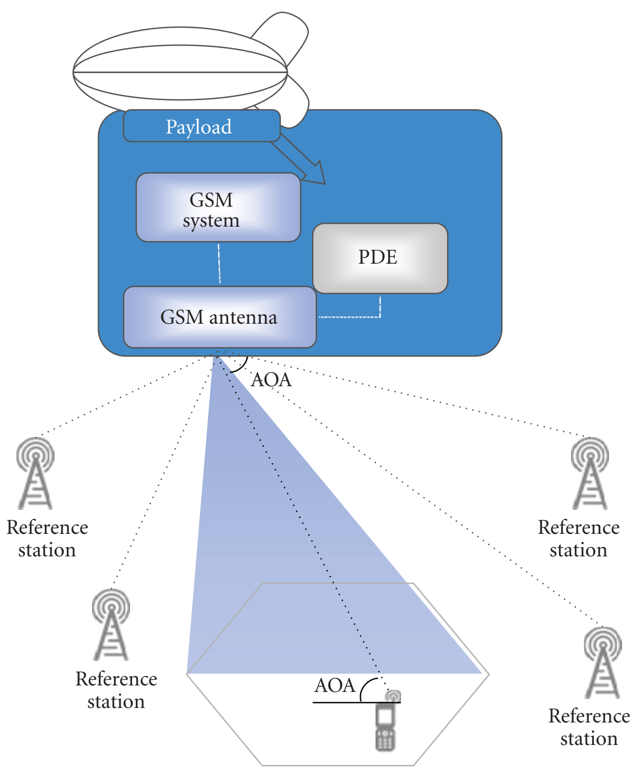

FIGURE 6: Using reference stations.

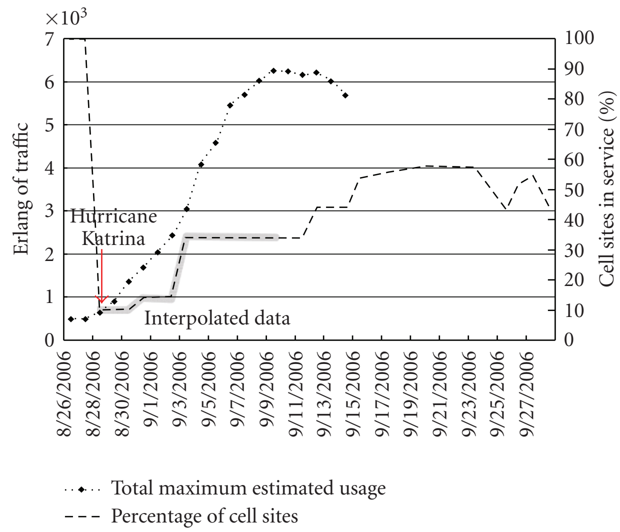

FIGURE 7: Estimated system load and BTS.

6. MAXIMUM CALL LOADING ESTIMATES FOR EMERGENCY TELECOMMUNICATIONS SYSTEM

In order to quantify the communications needed to support a disaster scenario, an understanding of the population size and traffic patterns are necessary. Figure 7 shows a maximum estimated traffic pattern based on user population data and outage periods during Hurricane Katrina [1, 16]. These estimations are a best effort in beginning to understanding the nuances of catastrophic disaster emergency scenario. Figure 7, left Y-axis, represents Erlangs. The total maximum estimated usage line is the summation of priority user traffic and emergency calls.

Priority user traffic was estimated from total populations of military, first responders, and public utility which served during Hurricane Katrina [1, 17]. Out of the daily military population, the number of commanding officers was estimated and each was assumed to need a mobile device. Since daily populations of first responders and public utility workers were unavailable, a total population estimate of 15 000 was used and 50% were estimated to need a mobile device. All users were given a conservative 0.2 Erlang. Then total Erlang usage was then calculated.

Figure 7, right Y-axis, represents the percentile of cell sites in service. The solid line shows the actual and estimated amount of cell sites in service after Hurricane Katrina. Cell site outage data is not available for the two-week period immediately following the Hurricane. As a result, a worst-case scenario was assumed and the data was interpolated. Regardless, it is evident from the first given data point (two weeks after the Hurricane) that the cell outage of ~70% is extremely severe. Following the initial data point for another two weeks, the networks continuously suffered high outages.

Figure 7 reveals important information with regard to large-scale disasters. First and most obvious is the need for emergency communications immediately after the disaster and an ideal placement for a continuously on station HAP. Second, catastrophic events will have persistency on

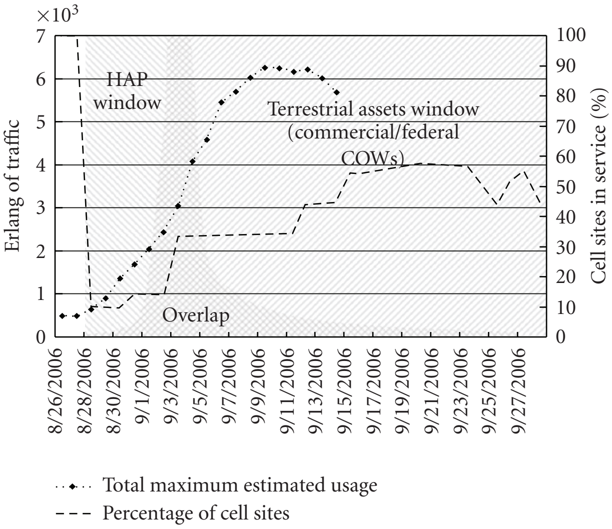

Figure 8: Effective disaster response windows.

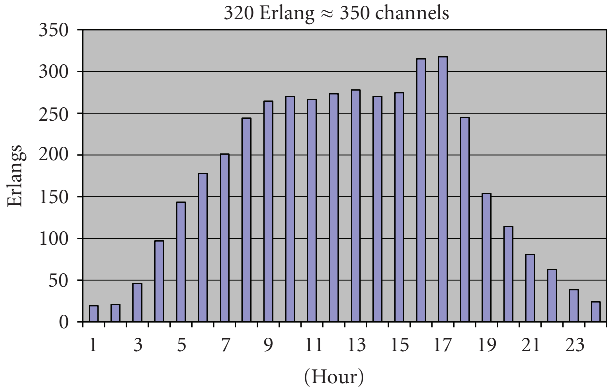

Figure 9: Daylight rescue.

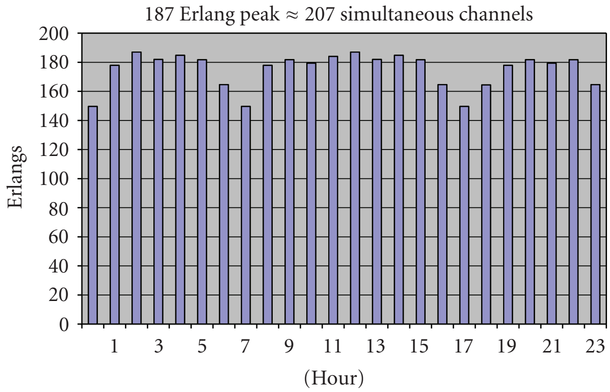

Figure 10: Continuous rescue.

telecommunications networks. Large-scale network outages could be expected to last weeks or even months. Third, traffic estimations show an immediate need for emergency calling capabilities and a capability to support a significant amount of users on a private network.

7. EFFECTIVE TIME FRAMES FOR HAP EMERGENCY SYSTEM AND TERRESTRIAL ASSETS

A complete coverage strategy between deployable terrestrial assets and the HAP is important since use of HAP will be most effective up to two weeks after the disaster occurs. This is due to the following reasons. First, emergencies after disasters require immediate attention in order to minimize loss of life. Second, the average maximum standby battery life of a mobile device will last ~300 hours [18, 19]. Third, it is highly unlikely that terrestrial assets will be unable to access areas due to the hazards caused by the catastrophic event. Inaccessible areas could result from natural hazards, debris, or security issues.

Following this initial HAP window, there will be a period where both the terrestrial assets and the HAP could be simultaneously deployed in time. Also at this time, evacuees will be moved into recovery areas where terrestrial assets can be deployed. However, the HAP capability could still be used in areas where search efforts and infrastructure restoration efforts are occurring. This overall process would require coordination between various different government and commercial agencies to insure that coverage areas are provided equitably and without redundancy. Figure 8 shows the HAP and terrestrial effectiveness windows pictorially.

7.1. *Traffic sizing*

Within the HAP effectiveness window (see Figure 8), a daily maximum traffic peak is estimated at ~4200 Erlang. Using the daily maximum traffic and estimated the hourly call trends, it is possible to determine the number of needed simultaneous channels needed for the emergency response system. There are two assumptions that can be used for daily traffic patterns. The first assumes that daylight search and rescue efforts. The second assumes a continuous rescue effort. In the daylight rescue case, call traffic patterns will likely be very similar to normal patterns but shifted in time. Using 4200 daily Erlangs load and applying a normalized high traffic day with hourly trend shifted in time, Figure 9 can be derived. From this estimate, the standard Erlang B table can then be used to calculate the number of simultaneous channels needed to support the hourly peak with grade of service of 1%. This yields ≈ 350 simultaneous channels. In the continuous rescue case, 8-hour rescue shifts were assumed and a normalized traffic curve was estimated. Using this estimate and amount of total daily traffic, this yields Figure 10 [20]. Based on this call load model, the estimated Erlang peak was 187 Erlang which yields 207 simultaneous channels needed from the Erlang B table. In discussions with integrators of the deployable cellular systems used by federal agencies, a payload of ≈ 500 kg could support 300 simultaneous CDMA 1x cellular channels using commercial off-the-shelf equipment [21].

8. CONCLUSIONS

HAPs provide an excellent option for emergency communications. Their survivability during a disaster and ability to be continuously on-station offer an ideal solution for an emergency communications capability. However, the nature of providing emergency communications still provides unique challenges. CDMA-based cellular communications have fewer difficulties deployed than TDMA-based systems, and recovering first-responder systems is problematic at best. Additionally, GSM E911 capabilities are also more difficult to implement on an HAP. Due to the high volume of emergency calls, an automated scheme is required to answer and manage the calls. This will require more experimentation and development. Understanding the traffic patterns of an emergency communications system is difficult due to the availability of data and requires many estimates. Estimates given here were worst-case scenarios; however, more research is required with more detailed data and/or simulations to understand more about the behavior of emergency traffic patterns. These traffic patterns have a direct impact on equipment needed and payload of the emergency communications platform. Despite these difficulties, the events of Hurricane Katrina have made us more aware of the requirements for providing emergency communications where HAPs provide an excellent platform alternative for emergency communications and assist in saving lives.

REFERENCES

[1] T. Davis, *A Failure of Initiative: Final Report of the Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina*, U.S. House of Representatives, Washington, DC, USA, 2006.

[2] G. M. Djuknic, J. Freidenfelds, and Y. Okunev, "Establishing wireless communications services via high-altitude aeronautical platforms: a concept whose time has come?" *IEEE Communications Magazine*, vol. 35, no. 9, pp. 128–135, 1997.

[3] U.S. Federal Emergency Management Agency and National Geospatial-Intelligence Agency, "Katrina Damage Assessment," Google Earth KMZ file, September 2005, http://bbs.keyhole.com/ubb/showthreaded.php/Cat/0/Number/99819/page/0.

[4] M. Lawlor, "Internet protocol network protects troop convoys," *SIGNAL*, November 2006.

[5] T. Schofield, "Dallas Launches City-Wide Interoperability Network," CoCo Communications Press Release, November 2006.

[6] CDMA Development Group, 3Q 2006 Subscribers Statistics, June 2006, http://www.cdg.org/worldwide/cdma_world_subscriber.asp.

[7] Yankee Group, "New opportunities for vendors as global carrier capex accelerates," *Cellular-News*, November 2006.

[8] GSM World, GSM Facts and Figures, June 2006, http://www.gsmworld.com/news/statistics/index.shtml.

[9] K. Akalestos, D. Grace, and T. Tozer, "Emergency communications from high altitude platforms," in *Proceedings of the 1st International Workshop on High Altitude Platforms Systems (WHAPS '05)*, Athens, Greece, September 2005.

[10] M. Oodo, H. Tsuji, R. Miura, et al., "Experiments on IMT-2000 using unmanned solar powered aircraft at an altitude of 20 km," *IEEE Transactions on Vehicular Technology*, vol. 54, no. 4, pp. 1278–1294, 2005.

[11] Northrop-Grumman, "BACN CDMA Subsystem Test Results," June 2006.

[12] Interoperable Communications Technical Assistance Program, "Audio Gateway Handbook," March 2006, http://www.npstc.org/documents/Audio%20Gateway%20Handbook_320_Final.pdf.

[13] D. Howe, "PLANNING SCENARIOS, Executive Summaries," The Homeland Security Council, July 2004.

[14] MTC Group, "Mobility: A Nation Under Siege," June 2007, http://www.mtctelecom.com/.

[15] H. Tsuji, "Japan, recent developments for HAPS applications in Japan," in *Proceedings of the WHALES Conference*, Palmdale, Calif, USA, March 2007.

[16] K. Martin, "Written Statement of Kevin J. Martin Chairman Federal Communications Commission Hearing On Public Safety Communications From 9/11," U.S. Senate Committee On Energy and Commerce, September 2005.

[17] D. Gilbert, Executive Director (Interim) Orleans Parish Communication District, Interview, October 2007.

[18] Krusell, "The Best Selling Mobile Devices In 2006," January 2007.

[19] Standby Power Specifications for Various Mobile Device Types, October 2007, http://www.gsmarena.com/.

[20] R. F. Duncan, Rear Admiral, U.S. Coast Guard, Interview, November 2007.

[21] J. Tackett, VP Homeland Security Rivada Networks, Interview, August 2007.