The Evolution of Hastily Formed Networks for Disaster Response

Technologies, Case Studies, and Future Trends

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Abstract*— Providing communications during disaster relief continues to be a significant challenge. Difficulties associated with communications between responders, disparate agencies and the outside world continue to plague disaster response efforts. Modern disaster response often requires the transmission of various information including text, voice, video and other types of data. One way of providing communications during disaster response is through the use of Hastily Formed Networks. Hastily Formed Networks are rapidly deployable ad hoc networks which can be generated using a variety of different technologies including 802.11 WiFi, 802.16 WiMAX, and VSAT. Early implementations of these ad hoc disaster networks were slow, primitive and unreliable. In the past, equipment needed to implement Hastily Formed Networks was expensive, cumbersome and in many cases only available to the military or large corporations. Today, many of these technologies are increasingly available and have matured to provide robust rapidly deployable networks. In many cases these networks can provide interoperability between disparate agencies, provide crucial operational information and support real-time situational awareness. This paper reviews recent advances in technologies associated with providing communications in extreme environments and summarizes practical requirements for implementing Hastily Formed Networks in disaster response environments. We also present a model applicable to communications in disaster response scenarios. Case studies from events such as Hurricane Katrina, the Haitian Earthquake and major exercises including Strong Angel and Urban Shield illustrate the evolution of these network technologies, inform lessons, and indicate directions for the future of emergency communications.

Keywords-disruption tolerant networks; hastily formed networks; information and communication technologies; humanitarian assistance; disaster response; disaster communications.

I. Introduction

Hastily Formed Networks (HFN) are portable IP-based networks which are deployed in the immediate aftermath of a disaster when normal communications infrastructure has been degraded or destroyed. Since HFNs create new communications infrastructure they can be very valuable in providing basic communications (voice/video/data) until pre-disaster infrastructure can be restored. HFNs are a particularly effective implementation of Information and Communication Technology (ICT) enabling the crisis communications necessary for a rapid, efficient, humanitarian response.

The high frequency of major global disasters in the past decade [1] have created a growing focus on the international response community's severe challenges associated with effectively communicating, coordinating and interoperating in a multi-national/multi-agency disaster relief operation. Communications have been identified as a key piece in coordinating the diverse organizations (military, government, NGO, industry, academic, volunteer, etc.) involved in humanitarian assistance and disaster relief (HA/DR) [2].

With no communications, on scene responders and remote support agencies have no ability to share situational awareness, manage resource requests, coordinate personnel, or establish unified command and control. HFNs that enable communications infrastructure are therefore essential for a rapid and effective HA/DR response.

There is extensive research on networks in extreme environments. These studies address disruption tolerant networks in extreme environments [3][4], public safety communications in harsh propagation areas [5], mobile networks in disasters [6][7], sensor networks in disasters [8], incomplete ad hoc wireless networks [9], mobile nodes in wireless networks [10], and sparse sensor networks [11]. However, despite this research, academia and the early

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response community have little knowledge of the real-world issues and the requirements for effective HFN deployment in disaster response.

To fill this gap, this paper demonstrates the use of HFNs to support HA/DR. In specific we outline the ICT needed in disaster situations and review the recent evolution of HFNs. We present a model to address the new developments in technology, the increased demand for bandwidth, and the growing use of HFNs in large-scale disasters. The experience of two authors and case studies of major disasters and exercises is used to provide insight on relevant criteria for effective deployments.

II. INFORMATION AND COMMUNICATIONS TECHNOLOGY IN DISASTERS

For most types of disasters, at least for the first several days after the event, the communications infrastructure is often dramatically degraded. Typically we find:

- Minimal or no power
- Degraded or overwhelmed telephony services
- Degraded Push-To-Talk (PTT) radio communications
- Minimal or no radio interoperability
- Overwhelmed Satellite Phone (SatPhone) services
- Not enough satellite equipment and/or oversubscribed services
- Limited Internet access
- Few information technology resources available

The extent of communications degradation can be extensive. The affected area can be extremely large, spanning multiple nations (for example the 2004 Southeast Asian tsunami). The loss of communications can also be inconsistent. For example, during the 2010 Haitian Earthquake response, there were daily periodic blackouts of cellular communications. In the aftermath of the 2011 Japan earthquake, some volunteers had working Internet connections but no cellular phones while others had working cellular phones but no Internet.

To address this unpredictable communications landscape, early responders must bring in their own ICT capabilities. For rapid deployment in the immediate aftermath of a disaster, we find ICT should conform to the following constraints:

- *Small and lightweight.* Disaster responders must often physically carry equipment into hard-to-access areas, requiring equipment to be portable.
- *Commercially available, non-military grade*. Many responders are budget-constrained, making it is critical that communications equipment be easily obtained off-the-shelf instead of military equipment that can be expensive and hard to obtain outside of government channels.
- *Energy independent.* Power infrastructure may be significantly degraded, requiring early responders to supply their own power. Since generator fuel can be difficult to obtain in disaster zones, non-fossil fuel power generation can also be an important consideration.
- *Flexible.* Disaster zone environments can change rapidly, and responders may need to adjust the capabilities to match the current needs. For example, systems that use 3G/4G cellular service and traditional Internet Service Providers will have greater flexibility.

ICT capabilities must allow responders to communicate within the disaster zone, reach back to supporting organizations outside of the affected region, and interoperate with other responding agencies. To operate most effectively and take advantage of the globally available resources requires phones, radios, Short Message Service (SMS), email, data sharing, access to incident management tools, Geographic Information System (GIS) information, social media and many other tools and applications. Many of these capabilities rely heavily on Internet access requiring responder agencies to supply their own Internet connectivity until pre-existing infrastructure is restored. This may require the following ICT:

- Satellite connection to the Internet
- Meshed Wireless Fidelity (WiFi) for wireless Internet coverage
- Worldwide Interoperability for Microwave Access (WiMAX) to tie WiFi mesh networks together, connect to nearest surviving infrastructure, and share limited satellite services
- Voice over IP (VoIP) technologies
- Push-To-Talk radio equipment Ultra high Frequency/ Very High Frequency/High Frequency (UHF/VHF/HF)
- Radio over IP (RoIP) equipment that facilitates radio interoperability
- Standard Internet tools such as email, web access, and video to provide situational awareness and collaboration

Additionally, there is a need for an ICT model to deploy an effective, stable, sustainable, portable, IP-based communications infrastructure. In the following sections, we discuss an updated model of the Hastily Formed Network (HFN) to meet these needs.

III. EVOLUTION OF HFNS: THE CHANGING FACE OF DISASTER RESPONSE

While the basic concepts of HFNs have remained relatively constant over the last ten years, the capabilities of the components have significantly improved. Deployments in exercises such as Urban Shield and Strong Angel III [12] and disasters such as Hurricane Katrina [13] and the 2010 Haitian Earthquake, have shown the effectiveness of HFNs in disaster response communications.

The capacity of HFNs are greater, the components are smaller, more resilient, and affordable for more organizations.

Much of this equipment can now be purchased off-the-shelf by the average consumer allowing for more of it to be deployed. Improvements have been made in the effective deployment of high data high speed HFNs. Endpoint devices that connect to the HFN such as smart phones and tablet computers are increasingly available and used by responders [13].

The growing use of HFNs has caused an increase in the development of data intensive applications driving the need for greater bandwidth as well as faster, more resilient systems. This trend continued in the wake of the 2010 Haitian Earthquake where open source disaster applications were written and deployed to responders in the first days of the response (for example Tradui [14]).

With the advent of smartphones, laptops, tablet computing and cellular infrastructure, data-intensive technologies in disaster response are becoming more prevalent. The average person has rapid access to information and becomes a source of information as well as a consumer. Crowdsourced data is now becoming a major source of information sharing for first responders. For example, in the 2010 Haitian Earthquake response, VoIP, video and applications like Skype, Ushahidi, Sahana, OpenStreetMaps, Facebook, Twitter, Google Maps, and many other social media and crowdsourced applications provided some of the communication and situational awareness for disaster responders [15].

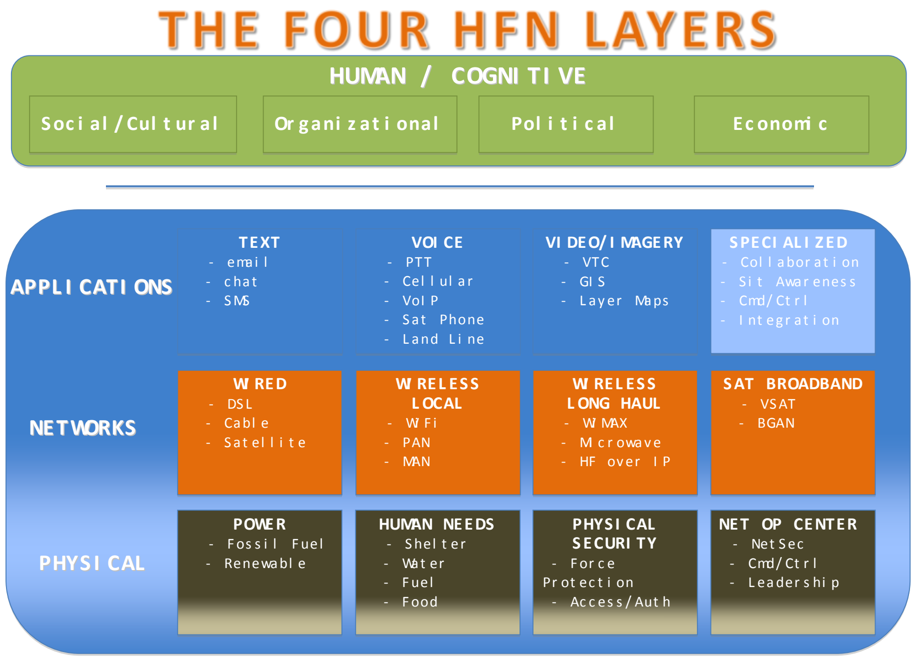

Figure 1. The HFN Architecture Model

IV. A LAYERED HASTILY FORMED NETWORK (HFN) MODEL: PHYSICAL/NETWORK/APPLICATIONS AND HUMAN/SOCIAL

The term “Hastily Formed Network” was coined at the U.S. Naval Postgraduate School after Hurricane Katrina to describe impromptu networks that provide crisis communications [16]. Here we present a model of components and guidance for effective HFNs addressing the evolution of technologies, data-intensive applications and social issues of disaster response, expanding on guidance provided by Denning [16]. The HFN Model “Fig. 1” consists of three main components Physical, Network, and Applications, with an overarching layer that takes into account the Human/Social aspects of disaster response. The model was originally articulated by Alderson and Steckler [17] derived from Steckler [13] [18] and describes the components of an HFN. The actual deployment and configurations can be highly varied and dependent on the circumstances.

A. *Physical Layer: Power, Human Support Needs, Physical Security and Network Operations Center*

The Physical layer deals with the base level of what is required to build an HFN. Without these considerations, the layers above will not function.

1) Power Sources

HFN technology deployments require power. After a disaster, in many cases power normal power infrastructure has been degraded or destroyed requiring in responders to supply their own. One common power source is the generator. However, given the size and weight of these systems and the dependence on a reliable supply fossil fuel they can sometimes be a problem. Also airline regulations prohibit shipping of used generators due to explosion hazard. There are other power sources that do not require fossil fuel such as alternators, solar, wind, hand cranks or fuel cells, but they have their own set of requirements and limitations. A modified automobile alternator can be used, but these also require fossil fuel and availability of vehicles. Solar panels require sunlight and are not practical for heavy regular power demands. Portable micro-wind turbines require winds of about 25 knots or higher to function. Bicycle or hand cranking systems can provide a small amount power, however they require a human to crank them and are very inefficient power generation devices. Hydrogen fuel cells are still in progress in terms of cost, reliability and effectiveness and often require special fuel bottles. Solar, wind, cranks and fuel cells are often better used to charge batteries or to augment fossil fuel solutions, given the unreliable nature of wind, sunlight, fuel for fuel cells, and physical labor. Overall, it is advisable to have integrated multiple power options available.

2) Human Support Needs

It is essential to consider how the early responders will get food, water, shelter, fuel, hygiene, and medical care. Basic logistics can be some of the most challenging problems facing responders. Most responders deploy with at least some of these supplies but will need to procure more after their supplies run out. This can be difficult as local resources are often already at a premium. Frequently supplies must be shipped in from the outside, requiring transportation logistics, customs approval, compliance with local government regulations, and a number of other problems that can delay their arrival. Medical resources are often limited and at a high demand especially if the disaster has caused significant casualties, hazardous materials contamination, disease outbreaks such as cholera, or other problems such as the release of radiation in the 2011 Japan earthquake.

3) Physical Security

One of the most important aspects to consider is physical security. This includes security of the personnel, equipment, and the facilities. For example in Haiti, some medical teams were forced to leave the area due to security concerns [19] and many food distributors were concerned with riots [20].

4) Network Operation Center

The network operations center (NOC) is a central part of any HFN, whether it is in a local building, mobile command unit, or tent. Since providing a communications network is the primary mission of an HFN it is critical to protect it as much as possible. There are several considerations that must be addressed including managing the limited and expensive bandwidth, securing the network, and wireless or other radio frequency (RF) interference problems. Managing the RF spectrum in a disaster can be challenging especially if the local government is not sophisticated enough to manage the RF environment. Sometimes, ad hoc agreements emerge between the various early responders or a combination of the UN Emergency Telecommunications Cluster (ETC), the international military's Joint or Combined Task Force, and the International Telecommunications Union (ITU) work together to manage the RF spectrum.

B. Network Layer: Wired, wireless local network, wireless long haul network and satellite broadband connection to the Internet

The network layer provides the backbone of the communications system. There are a number of technologies that can be used to create the network and the best choice depends on the requirements of the situation. There are three main technologies used to create the network: WiMAX, Meshed WiFi, and Satellite. Below are the basic descriptions of each type of technology.

1) WiMAX

WiMAX also known as IEEE 802.16 is a terrestrial broadband point-to-point or point-to-multipoint wireless bridge technology. A key distinction is that it is a bridging technology. WiMAX works well because it is inexpensive, easy to deploy, reliable, has a range up to 50 miles, high throughput 54 megabits (Mbps) per second, and is readily available. The most common frequencies are non-licensed 5.8 and 2.4 gigahertz (GHz), though some new products are emerging in the licensed 3.5 to 5.0 GHz range. WiMAX antennas should be as high as possible as WiMAX is a "line of sight" technology. WiMAX is typically deployed side-by-side with satellite communications and Meshed WiFi is most useful in a hub/spoke configuration. It is often used to provide connection from disaster zone to the nearest surviving telecommunications infrastructure.

2) Satellite-based Internet access

Satellite communications (SATCOM) provides the ability to connect to the Internet when the normal terrestrial infrastructure is degraded or destroyed. SATCOM can be rapidly deployed in under an hour. While satellite service is costly compared to other typical methods of Internet access, in a disaster environment the use of satellites may be the only available option.

The most common types of portable satellite are VSATs (Very Small Aperture Terminal) which range from 1-3 meter terminals and BGANs (Broadband Global Area Network) which are the size of a laptop. Newer systems are packaged in one or two transit cases each weighing less than 100 pounds. For example the GATR system is inflatable giving it a very small and light form factor. Satellite terminals can be deployed anywhere they have a clear line of site to the service provider's satellites.

Satellite communications provide Internet access speeds ranging from 128 kilobits per second (kbps) to 30 Mbps and the typical frequencies are X, C, Ku, Ka and L bands.

Some issues with satellites include "rain fade", where satellite service can be temporarily degraded by a significant storm either over the end-user ground terminal or over the provider's earth station. Also the use of too many terminals in one area can often saturate the existing service capacity causing service degradation.

Because of the long distance round-trips involved in geosynchronous satellite communications, latency and jitter can affect the network performance for certain timing-sensitive applications such as voice and video. Modern Quality-of-Service (QoS) algorithms are able to mostly compensate for these issues, enabling VoIP and videoconferencing applications to be used effectively by end-users.

3) Wireless Local Area Network (WLAN)/Meshed WiFi

WiFi (also known as IEEE 802.11) access points can be deployed to create a WLAN that provides Internet access for mobile devices like laptops, wireless phones, or remote sensors. They typically provide speeds of 10-100 Mbps.

This WLAN can be extended by strategically positioning multiple wireless access points (WAPs) into a unified network that can increase the footprint of the wireless network up to several square miles.

Once a meshed WiFi WLAN is established it provides a seamless hand off from WAP to WAP allowing clients to move transparently within the mesh while maintaining connectivity.

C. Application Layer: Information Dissemination, Integration, Collaboration

Once established, the HFN becomes the backbone for various critical applications. In the early days of HFNs, these applications were mostly text based like email, basic web access, file transfer, and chat programs. As these technologies matured, VoIP has become increasingly important since it can operate across the HFN and not rely on pre-existing infrastructure.

Traditional Push-to-talk (PTT) radio systems such as UHF, VHF and HF have always been and still are a critical part of HA/DR. However one of the biggest challenges is that each response agency may bring in their own radio systems that may not be interoperable with other agencies radio systems. With the advent of IP, radio technology has adapted to leverage the Internet with Radio over IP (RoIP). Systems such as Cisco IPICS, Twisted Pair WAVE or SyTech RIOS, are used to integrate different radio systems with each other as well as cellular, satellite phones, or VoIP systems. This allows collaboration between local communications systems and to outside systems via the Internet.

With the recent explosion of smartphones, tablets and small cameras, as well as the need for greater situational awareness, demand for video, GIS, collaboration and Incident Management portals tools is increasing. Video streaming and video teleconferencing is enhancing traditional radio and phone communications. Supporting these new demands can create challenges for HFNs. The bandwidth required for voice and video is much greater than text-based systems and it must be stable and continuously available.

The demand for GIS tools has also increased. The greater the understanding of the local terrain and the hazards created by a disaster, the more effective responders can be. However, GIS data can also strain an HFN, requiring the transfer of extremely large amounts of mapping data. GIS and layered mapping tools such as Google Earth Pro, GeoFusion, OpenStreetMap, and ArcGIS, are becoming more popular and by partnering with social network applications they can be populated with real-time crowdsourced information; this was valuable to responders, especially in the 2010 Haitian Earthquake response [21].

Internet access has increased due to the use of desktop and collaboration tools such as Cisco WebEx, or Microsoft SharePoint. Internet access has also increased the use of web portals and incident management tools specializing in complex disaster management such as resource tracking, missing persons, shelters and volunteer management. Some of these include the United Nations ReliefWeb and Virtual On-Site Operations Center (VOSOCC), Sahana, the U.S. military's All Partners Access Network (APAN) or various commercial applications.

D. Human Cognitive Layer: Social/Cultural, Organizational, Political, Economic

As HFNs matured, it became clear that in addition to all of the physical network infrastructure there was a need for a separate layer in the "soft science" human/cognitive realm. The effectiveness of an HFN depends on human components [14]. Some believe this human element is the more challenging part of HFN deployment.

The Human Cognitive layer consists of four key components; organizational, economic, political and social/cultural which are discussed below. Issues in these areas can limit the effectiveness of an ICT deployment. In many cases there are currently no easy solutions or international standards to address these challenges. We see this area as a key focus for future work in the HA/DR community.

1) Organizational

- Unity of effort but no unity of command can often cause agencies to interfere with each other and with normal government/business operations. There are no clear standards as to who should be "in charge" for reconstituting the overall communication infrastructure.
- Lack of interoperability between PTT radio systems causes confusion and wasted resources when disparate agencies cannot coordinate their response. This directly affects a key element of any successful disaster response which is information sharing.
- Transitioning from emergency ICT to recovery ICT requires a process for migrating from temporary ICT to a phase that rebuilds the permanent ICT infrastructure.

2) Economic

- The cost and availability of ICT infrastructure, in particular satellite service, can be too expensive for some organizations.
- ICT equipment brought in by early responders can be viewed as competition by local service providers. This can often interfere with the ability to help support a disaster effectively.
- Many communities and early response organizations have not pre-established contracts to obtain equipment, technical personnel and services in the event of a disaster. This can cause critical services and equipment to be unavailable when they are most needed.

3) Political

- Government rules and regulations around ICT can be challenging. This can include RF licensing issues as well as discouraging use of VoIP because it is perceived as a threat to established telephone carriers. For example, during the 2011 Japan Earthquake response, the government limited the use of C and Ku band satellites, forcing responders to use the slow and oversubscribed L band BGANs. This in turn minimized the support responders were able to provide to the affected communities.
- Customs can delay equipment and supplies so long that by the time it clears, the acute phase of the emergency for which it was needed is over.
- Use of telecommunication equipment by humanitarian organizations is often impeded by regulatory barriers that make it difficult to use without prior consent of

the local authorities. The Tampere Convention [22] is an example of nation states working together to improve communications related HA/DR issues.

- The ability to deploy HA/DR technologies in conflict or wartime environments can be extremely challenging and dangerous reducing the amount of support responders are able to provide.

4) Social/Cultural

The immediate aftermath of a disaster typically brings numerous international responder agencies. Often these early responders have difficulty working with others, due to biases, differences in culture, language, or sponsors.

- Some organizations are reluctant to work with other organizations because of a perceived conflict of interest that may affect their status as neutral parties, or they may fear ramifications involving the comfort level of donors to contribute.
- Organizations with different operating structures such as a very rigid top down command structure can have friction with organizations that have a more consensus driven operating model.
- Existing humanitarian organizations that may have been operating in the region before a disaster can perceive the arrival of disaster responders as disrupting the status quo.
- Technologists often do not understand first responder processes and procedures. In the United States, these issues are addressed through the National Incident Management System (NIMS) [23] and Incident Command System (ICS), but analogous systems often do not exist in international emergency responses.
- New technologies can require a learning curve. Many early responders are uncomfortable using an unfamiliar system.

V. Hastily Formed Networks In Action

The HFN model above describes critical components of HFNs needed in modern disaster response. Below we describe two specific deployments of HFNs that enabled high performance communication in a major disaster (the 2010 Haitian Earthquake) and a major exercise (Urban Shield).

A. Haiti Case Study: HFN Enabled Social Networking Applications Transform Disaster Response

On Tuesday January 2010 at 21:53 UTC, a catastrophic 7.0 magnitude earthquake hit Haiti. The earthquake caused major damage in Port-au-Prince, Jacmel and other settlements in the region. An estimated three million people were affected by the quake [24]. The Haitian government reported that an estimated 316,000 people had died, 300,000 had been injured and 1,000,000 made homeless [25][26].

Infrastructure for communications, transport facilities and power were severely damaged by the earthquake. The public telephone system was not available and all of Haiti's cellular phone providers were affected. Fiber optic and microwave connectivity to the outside world was disrupted. These degraded communications severely hampered early relief efforts throughout Haiti.

Standard HFN technologies were deployed by several disaster response agencies all over of Port-au-Prince and the surrounding areas to provide communications. Cisco Tactical Operations (TacOps) spent three months in Haiti supporting twenty-five agencies including urban-search-and-rescue (USAR), government, NGO and military organizations. TacOps deployed much needed networking equipment including routers, switches, hundreds of IP phones, VSAT, BGANs, and portable network kits with voice, data and wireless capabilities. The team worked with local service providers to rebuild damaged infrastructure including setting up WiMAX links to provide temporary connectivity until the fiber connections could be repaired. The team also provided HFNs with VoIP for the U.S. military and provided wireless bridging between buildings for NGOs [27]. They also installed a video conferencing system for the Haitian Government.

The Naval Postgraduate School (NPS) also spent three months in Haiti deploying HFNs for the U.S. military. The team first deployed to the USNS COMFORT hospital ship, then started deploying HFNs via helicopter from the USNS COMFORT to the U.S. Embassy, the Port-au-Prince port facility, several boat/helicopter landing zones, and out to the NGO community. They were able to help hospitals communicate with the USNS COMFORT and the U.S. Embassy for medical evacuations. The NPS team conducted ICT assessments for the Joint Task Force Haiti Communications Manager ("J6"), helped the Haitian Government with frequency assignments, documented how the NGO community was providing health care and studied how the various militaries, the United Nations and NGOs operating in Haiti were interacting and sharing information.

The HFNs deployed in Haiti were distinct from prior disaster deployments because of the high volume and type of data carried over the communication networks. Haiti was the first all-encompassing test of a predominantly data driven response, due to the fact that much of the usual terrestrial telecommunications infrastructure did not exist and responders had no other option than to use IP-based communications as the core of the response. Most previous disasters were driven more by legacy communications such as telephones and radios.

In Haiti, as far as disaster response and the use of new or existing technologies there was a previously unmatched use of the Internet and social networking applications to provide rescues, coordination on the ground [28], situational awareness, GIS information, crowdsourced information and more. Twitter and Facebook were overloaded with messages asking for help [29]. The American Red Cross set a record for mobile donations, raising U.S. $7 million in 24 hours by enabling the general public to send $10 donations by text messages [30]. OpenStreetMap greatly improved the level of mapping available using post-earthquake satellite photography from GeoEye [31], as well as partnering with Walking Papers to scan in hand drawn local information about the disaster [32]. Google Earth updated its maps to show "clickable" layers of real-time disaster information on top of the GIS imagery and many more. One of the more notable uses of social media in Haiti was using SMS messages to help locate and/or rescue victims. A collaborative effort including Ushahidi, InSTEDD, DigiCel, Crowdflower, Samasource and a host of others produced a system where Haitians could use the SMS short code 4636 to send messages about injuries, about people trapped under rubble or reports of missing people[15][33]. Their messages were automatically uploaded to a database where volunteers around the world translated, geolocated and categorized the messages via online crowdsourcing platforms which sorted the information by need and priority, and distributed it to various emergency responders and aid organizations [33][34].

These examples have shown the growth and benefit of social networking and other data-driven applications in assisting the 2010 Haitian Earthquake response.

B. *Urban Shield Case Study: HFN Enables Video Conferencing to Improve Exercise Communications*

Urban Shield is one of the United States' largest multi-national, multi-jurisdictional full-scale disaster response exercises. On October 15-18 2010, 3000+ responders participated simultaneously in 40+ exercises over a geographic area of 700 square miles, nine counties [35], simulating the response to a major disaster in the San Francisco Bay area. To facilitate coordination and communication among a large number of agencies and to create a testing environment for new technologies, one of the authors (C. Nelson) designed, built, deployed and maintained an HFN which provided a private secure network for communication among a Primary Command and Control site, six Area Commands and 26 Site commands [37]. The network enabled video conferencing, video surveillance, voice communications and wireless internet connectivity around each site, as well as established a test-bed for disaster applications. This system was deployed alongside the traditional public safety radio systems in order to enhance communications via voice, video and data.

The HFN "Fig 2" was created by deploying six Emergency Communications Kits (ECKs), using Internet Protocol Security (IPSEC) Virtual Private Network (VPN) to communicate back to the main hub at the Primary Command and Control Center. ECKs are a portable self-contained IP-based communications unit in a ruggedized shock-mounted rack case [37]. They contain a Cisco Integrated Services Router (ISR) series router, Power-over-Ethernet (PoE) 3500 series PoE switch, wired 7900 series phones, wireless 7900 series IP phones, 802.11 wireless 1200 series access points, and an uninterruptable power supply (UPS). ECKs can use many types of transport to connect to the network including terrestrial Internet, BGAN/ VSAT and cellular data. Video conferencing systems of differing capabilities were connected to the network ranging from high-end high-definition video systems to low-end laptop cameras, allowing site commanders to either make point-to-point calls, or point-to-multipoint calls, creating an exercise wide conference call. The video system was smart enough to allow each video stream to be "tuned" to take advantage of the available bandwidth enabling the high latency and low bandwidth situations usually found in disaster response networks to be mitigated with minimal effects to the video conference quality.

Lessons learned from previous HFN deployments such as Strong Angel III and Hurricane Katrina demonstrated that it is critical for maintaining functionality to protect limited network bandwidth and monitor the overall health of the network. A combination of firewall rules, Quality of Service (QoS), Simple Network Management Protocol (SNMP) based Network Management System (NMS), Cisco NetFlow, and other device monitoring technologies were set in place to monitor network traffic and alert Information Technology (IT) staff when any anomalies occurred.

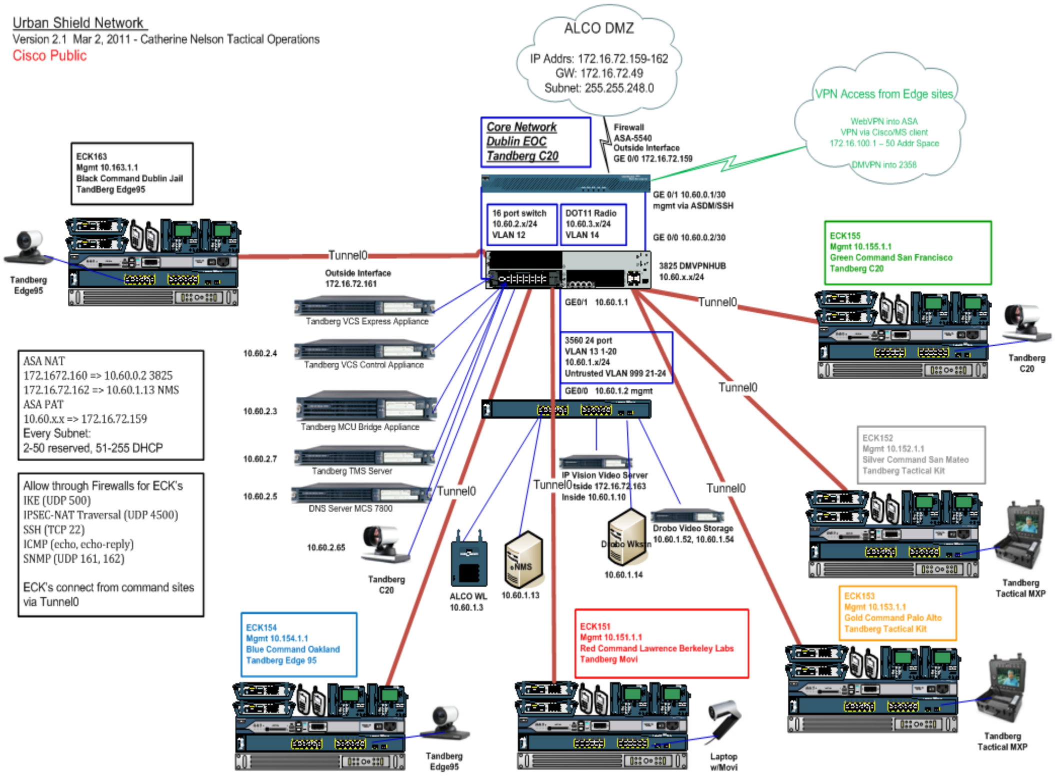

Figure 2. Urban Shield hub and spoke network map

1) *Results of Urban Shield HFN*

This was the first time video conferencing had been used in an Urban Shield exercise. It enhanced situational awareness and operational efficiency by allowing several hundred people to be joined into a single video call within a matter of minutes.

In prior years, it took over 30 minutes to coordinate all sites together on the same phone call. The new technology required some adjustment as first responders did have to be educated on video conference etiquette. These issues were minor and users rapidly adjusted to the new system. The speed of information dissemination provided by video conferencing over HFN was a dramatic improvement for many responders. Remarks such as "Command staff here definitely feels that briefings over video are more effective than the conference calls last year", validated the usefulness of the HFN supporting a large multi-site exercise. The HFN architecture and components performed well [38]. The video units allowed for tuning of devices on a lower bandwidth to get the best experience without impacting the quality of devices connecting over higher bandwidth. The usefulness of the ECKs at different bandwidths including satellite-based networks with high latency and low bandwidth was confirmed. The ease of set up and tear down of the network points was validated. At one point a site needed to relocate, and the non-technical staff was able to disconnect the system, move it and reconnect with no problems. IPSEC Virtual Private Network (VPN) technology created secure tunnels that protected sensitive information. And, the network management tools demonstrated their importance by protecting the network when test software began flooding the network with TCP SYN (synchronize/start) packets. The anomaly was detected by the NMS software and rate-limiting was put in place to protect the core network. Overall the system operated effectively, provided enhanced communications, was secure and well accepted by the first responders.

VI. Conclusion

Hastily Formed Networks provide great benefit to HA/DR response by tying together critical ICT components to provide the breadth of communications needed in complex emergencies. In light of the evolving requirements of end-users for greater access to data, we have presented a descriptive HFN model that has demonstrated tremendous benefit for HA/DR responders in multiple real-world deployments. Key challenges remain in the Human/Social domain, and should be a focus area for future work by the HA/DR community.

We believe that response agencies should consider ICT as a primary service in HA/DR as essential as food, water, shelter and medical care. Therefore agencies must plan for future investment in ICT. Governments, NGOs and other humanitarian agencies should continue work to establish international standards around complex, multi-agency disaster operations to enable a more cohesive response. Agencies also need to test and train with technology regularly to ensure personnel are practiced and able to use it effectively.

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