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**THESIS**

**INTEGRATION OF VIRTUAL MACHINE TECHNOLOGIES  
INTO HASTILY FORMED NETWORKS IN SUPPORT OF  
HUMANITARIAN RELIEF AND DISASTER RECOVERY  
MISSIONS**

by

Albert Barreto III

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Thesis Advisor:

Dan Boger

Second Reader:

Glenn Cook

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INTEGRATION OF VIRTUAL MACHINE TECHNOLOGIES INTO HASTILY  
FORMED NETWORKS IN SUPPORT OF HUMANITARIAN RELIEF AND  
DISASTER RECOVERY MISSIONS

Albert Barreto III  
Lecturer of Information Sciences  
M.S., University of Phoenix, 1999

Submitted in partial fulfillment of the  
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NAVAL POSTGRADUATE SCHOOL  
December 2011

Author: Albert Barreto III

Approved by: Dr. Dan Boger  
Thesis Advisor

Glenn R Cook  
Second Reader

Dr. Dan Boger  
Chair, Department of Information Sciences

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## **ABSTRACT**

The exploration of the applicability of virtualization technologies, particularly the Virtual Desktop Infrastructure (VDI) as developed by VMware incorporated, and virtualized applications in support of humanitarian relief and disaster recovery efforts will be the focus of this research. The current Hastily Formed Network (HFN) (Denning, 2006), as developed at the Naval Postgraduate School (NPS) and deployed by NPS faculty and students to recent disaster areas in New Orleans, Louisiana, and Haiti has provided ad hoc networking for disaster relief workers, local emergency responders, and civilians. Capabilities provided have included radio communications, access to the Internet, and Internet Protocol (IP) telephones to name a few. However, no provision has been incorporated into the HFN system, which provides for access to applications and data which may be of a mission critical nature. The ability to have a portable Emergency Operations Center (EOC) with virtual desktops, applications, and data, supported by the communications and power infrastructure deployed and described as a HFN should add significant capabilities to the original HFN design and value for the users of the system as they attempt to return to normal day to day operations.

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## LIST OF ACRONYMS AND ABBREVIATIONS

3G	Third Generation
4G	Fourth Generation
AAR	After Action Report
AD	Active Directory
AMD	Advanced Micro Devices
ANSI	American National Standards Institute
ARP	Address Resolution Protocol
ATA	Air Transport Association
BGAN	Broadband Global Area Network
CA	Civil Affairs
C2	Command and Control
C3	Command, Control, and Communications
CHSC	California Homeland Security Consortium
COP	Common Operating Picture
CPU	Central Processing Unit
DISE	Distributed Information Systems Experimentation
DHS	Department of Homeland Security
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name Services
DRS	Distributed Resource Sharing
EIA	Electronic Industries Alliance
EOC	Emergency Operations Center
ESX	Enterprise Server Virtualization
ESXi	Enterprise Server Virtualization without Console
FLAK	Fly Away Kit
FEMA	Federal Emergency Management Agency
GB	Gigabyte

HA	High Availability
HA/DR	Humanitarian Assistance/Disaster Recovery
HFN	Hastily Formed Network
IEEE	Institute for Electrical and Electronic Engineers
IETA	Internet Engineering Task Force
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
JRV	Joint Reconfigurable Vehicle
LAN	Local Area Network
LOS	Line of Sight
LTE	Long Term Evolution
MB	Megabyte
MOP	Measure of Performance
MOE	Measure of Effectiveness
NBNS	NetBIOS Name Service
NEMA	National Electrical Manufacturers Association
NIC	Network Interface Card
NIMS	National Incident Response System
NGO	Non-government Organization
NLOS	Non Line of Sight
NYT	Not Yet Tested
OFDM	Orthogonal Frequency Division Multiplexing
OS	Operating System
OSI	Open System Interconnection
PMP	Point to Multipoint
PoE	Power over Ethernet
PoP3	Post Office Protocol 3
PPP	Point to Point
R&D	Research and Development



RF	Radio Frequency
RPM	Revolutions Per Minute
RU	Rack Unit
SAS	Serial Attached SCSI
SATA	Serial ATA
SIM	Subscriber Identity Module
SMTP	Simple Mail Transfer Protocol
SOS	System of Systems
SQL	Structured Query Language
SSD	Solid State Drive
SSID	Service Set Identifier
TAC	Technology Assistance Center
TB	Terabyte
TCP/IP	Transmission Control Protocol/Internet Protocol
TIA	Telecommunications Industry Association
UDP	User Datagram Protocol
VDI	Virtual Desktop Infrastructure
VM	Virtual Machine
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
Wi-MAX	Worldwide Interoperability for Microwave Access

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## EXECUTIVE SUMMARY

The Hastily Formed Network (HFN) system has been developed at and deployed from the Naval Postgraduate School (NPS) for several years, and has included students and faculty from several departments as well as many industry experts. The first deployment in support of a humanitarian assistance/disaster relief (HA/DR) effort which coincided with the hire at NPS of this researcher was to New Orleans, Louisiana to assist in HA/DR efforts after Hurricane Katrina devastated much of that city and the surrounding communities. At roughly the same time, efforts were begun at NPS by LCDR Stan Bush, a Lecturer in the Information Sciences department, to virtualize much of the Graduate School of Operational and Information Sciences classroom support technologies, particularly application servers used to support classes. Although this researcher has not participated in a humanitarian relief effort, he has continued the efforts begun by LCDR Stan Bush, to include the evolution of the virtualization effort, not only virtualized servers, but the design, deployment, and support of a complete virtual desktop infrastructure (VDI) solution, which includes virtual desktops, thin and zero client technologies which support several NPS graduate courses each quarter.

The motivation for this thesis has been two-fold: First, by continuing to monitor on-going relief efforts, continued evolution of the HFN model, and virtualization technology, particularly in the VDI area, this researcher began to see that a gap existed in the HFN model, and that

advances in virtualization technologies could enable adoption of a virtualized Emergency Operations Center (EOC) to bridge that gap. Second, as new communications protocols have been created and standardized, and thin and zero client technologies have evolved, technological limitations which have kept a virtualized EOC out of the HFN model have been at least partially eliminated. The research outcome of this thesis will include the integration of a VDI solution into the existing HFN model as developed at NPS and deployed at Katrina and most recently to Haiti where it was used after the earth quake in 2010. The expectation is that having a mobile and easily transportable EOC in a box for use in a humanitarian relief effort will enhance and improve the efforts of emergency responders in situations where much, if not all, of the power and communications infrastructure has been destroyed. The integration of a three-tiered solution of power, communications, and computer systems into a single system of systems (SOS) creates a true mobile EOC in a box.

A set of re-usable measures of performance and measures of effectiveness (MOP and MOE) and evaluation procedures will be applied to this research. A deployed system must be able to survive in austere environments, and provide reliable services with the resources at hand. It is important that the EOC in a box be able to survive and thrive with the deployed power and communications equipment. System component size, weight, and power consumption have all been evaluated to determine applicability of each component.

Currently, virtualization of hardware, software, and even applications is being evaluated and implemented across several DoD and DHS specific systems and all branches of the military. At some levels, the investigation into feasibility and cost/benefit analysis is already being done while at others the technology is just being explored, and information gathered here, and testing and measuring techniques established here will be useful when evaluating future system design.

The funding source, which allowed for the purchase of the software and hardware used in this research, was made possible by a Department of Homeland Security (DHS) research grant administered by the California Homeland Security Consortium (CHSC) at NPS. The Independently Powered, Command, Control, and Communications (IPC3) project is developing the power, communications and EOC system of systems which this thesis is derived from, and is developing the EOC in a box as one part of the deliverables.

The EOC in a box, along with the power and communications developed in the IPC3 project, is a leave behind system, which will be transferred to the members of the CHSC, and will be a longterm proof-of-concept deployed solution which will act as an exemplar system for others to evaluate or model their solutions from. The system will also be available to other members of the CHSC for various uses in the event of real disaster situations should one occur anywhere in Monterey County.

This thesis will contribute to the body of knowledge on hastily formed networks, virtual networks, virtual desktop infrastructure deployments, and alternative power sources and provide a reference framework for those seeking to apply these technologies to other problem domains.

## ACKNOWLEDGMENTS

This list must start with God, for without Him, none of us would be here, and be given the opportunities and the choices we have to fail or to succeed; I have chosen to succeed, and believe I have chosen wisely.

Next, I must thank my family. Without their support for these past too many years, this thesis, and my graduation, would not have been possible. So, to my wonderful wife, Jane, and exceptional children, Katherine, Cameron, and Margaret, I thank you for your support, understanding, and patience while your father completed his degree journey. Please don't wait too long to start yours.

In addition to my immediate family, I need to thank my in-laws, friends, and co-workers who helped me through the process. They, like my wife and children, have understood the efforts involved and pressure of pursuing this degree while working at the Naval Postgraduate School at the same time.

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And, of course, no degree journey would be complete without trying to pursue hobbies and outside interests while trying to study, enjoy my family, and stay reasonably sane. So again, to all of you, thank you for your support, love, and understanding. I promise I won't do it again.

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## I. INTRODUCTION

### A. HASTILY FORMED NETWORKS AND VIRTUALIZATION

Hastily formed networks (HFN) (Denning, 2006) and virtualization are two models which will be merged to form a system of systems comprised of power, communications and a mobile Emergency Operations Center (EOC). The current HFN as defined by (Denning, 2006) has been deployed by NPS faculty and students to recent disasters. These include: New Orleans, Louisiana, and Haiti and have provided ad hoc networking for disaster relief workers, local emergency responders, and civilians. Technological capabilities provided have included radio communications, access to the Internet, and Internet Protocol (IP) (Postel, 1981) telephones to name a few. However, no provision has been incorporated into the HFN system, which provides for access to applications and data which may be of a mission critical nature other than those accessible via a web browser. The ability to have a portable EOC with virtual desktops (VMware, 2010) , applications, and data, supported by the communications infrastructure deployed and described as a HFN should add significant capabilities to the original HFN architecture and value for the users of the system as they attempt to return to normal operations.

According to (Denning, 2006), An HFN has five elements: it is (1) a network of people established rapidly (2) from different communities, (3) working together in a shared conversation space (4) in which they plan, commit to, and execute actions, to (5) fulfill a large, urgent mission. The *shared conversation space* is what technology

helps to enable in the HFN model, and is the area most benefited by the addition of virtualization technology.

Virtualization is a technique, which allows for the abstraction of multiple computers and applications from a single computer or application. It can be traced to the original IBM System 370 Mainframe, which was introduced in 1970 (Creasy, 2011 "Hardware-assisted virtualization was first introduced on the IBM System/370 in 1972, for use with VM/370, the first virtual machine operating system" (Networks & Servers Blogspot, 2011). In 1977, a move to the client-server model began on the UNIX operating system (O/S) platform. "The first use of the concept of client-server programming, as it is represented in its current form came with the 1977 release of the Unix operating system for the DEC VAX computer, as implemented at the University of California, Berkeley" (Graff, 2009). With the shift from large mainframe computer systems to the desktop computer, virtualization would soon be possible. The release of the IBM 5150 Personal computer in September of 1981, (IBM , 2006) made it possible to create a virtualized environment using a commodity desktop and server computers. These were based around Intel and AMD Central Processing Unit (CPU) architectures.

Companies like Microsoft, Red Hat, Novell, and VMware have evolved the technology and produced modern virtual machine managers known as hypervisors, which have direct access to the CPU rings (Guarte, 2008) as illustrated in Figure 1.

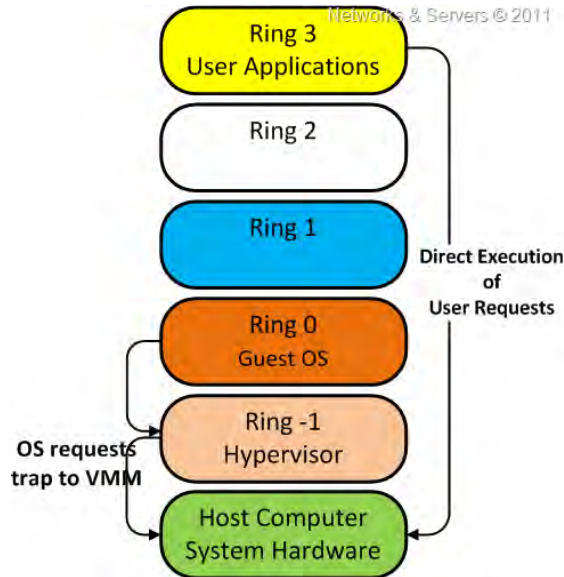


Figure 1. Hardware Rings (From Networks & Servers, 2011)

It is the convergence of the advances in hardware and software technologies, which enables the introduction of virtualization technologies into the HFN architecture in the form of an *EOC in a box* with virtualized servers, desktops, and applications supported by the existing power and communications systems of the current HFN architecture.

## B. RESEARCH QUESTIONS

For successful integration of virtualization technologies into the existing HFN architecture, two capabilities were addressed, power and communications. Sufficient power must be available to power devices, regardless of climate conditions, and sufficient bandwidth

must be available from the satellite communications systems to support the demands of the EOC in a box.

1. How will the existing independent power sources and communications channels of the HFN support the proposed Virtual desktop Infrastructure (VDI) system?
2. What communications and power technologies are required to provide adequate bandwidth, network security, and power, and does the current HFN design provide those?
3. What other communications and power capabilities are available to the HFN team?

#### **C. BENEFITS**

By incorporating the ability to deploy a mobile EOC with the current HFN architecture, participants in a HA/DR mission no longer need rely on a connection to the Internet to access applications and data that might be of a mission critical nature. A mobile EOC with localized applications and databases provide the ability to maintain situational awareness, eliminate or reduce dependency on a satellite link to the Internet for reach-back to wherever those services normally reside. It also improves response time by eliminating latency normally found in satellite communications.

A mobile EOC in a box will support up to 50 concurrent users accessing virtualized desktop computers from a myriad of devices, thus reducing interoperability concerns and allowing the shared conversation space of the HFN to be as

device agnostic as possible and expand across the disparate communities, which in the past have included military, civilian, and multiple Non-Government Organizations (NGOs) from several countries. It also aids in the successful adoption of guidelines defined by the Federal Emergency Management Agency (FEMA) in the Federal Incident Response framework. This framework was updated after careful review of the response to Hurricane Katrina. Most notably: "Many private-sector organizations are responsible for operating and maintaining portions of the Nation's critical infrastructure" and "During an incident, key private-sector partners should be involved in the local crisis decision making process or at least have a direct link to key local emergency managers" (National Response Framework, 2008). The EOC in a box will enable the shared conversation space in the HFN while temporarily replacing critical infrastructure power, communications, and data center capabilities.

#### **D. METHODS**

The methods used for this thesis were to design and construct a VDI solution using hardware and software from the current marketplace, and to develop and apply measures of performance (MOP) and measures of effectiveness (MOE). New technologies that offer solid-state hard drives built into modular VDI devices known as appliances, efficient communications systems with new protocols, higher bandwidth communications systems, and alternative power sources are now available and were evaluated, tested, and adopted. A system was designed, built, and field tested, and MOP and MOE were applied and taken to evaluate the usability of the

system, and applicability of a VDI to the target users. These MOP and MOE include such things as power consumption, bandwidth utilization, and resiliency to high-latency satellite connections, and user acceptance of system response time. Care was taken to design a system that is easily deployable, ruggedized as needed for use in inclement conditions, and be as vendor agnostic as possible to avoid vendor lock in and difficulty in finding replacement parts or acquiring support.

A series of field experiments were performed and coordinated with efforts by other research teams from NPS that replicated real-world scenarios. The experiments included researchers in the form of faculty and students from NPS, as well as the end-user customer for this technology, which is the California Homeland Security Consortium (CHSC) members from throughout the County of Monterey, specifically the Monterey County Offices of Emergency Services.

## **E. THESIS ORGANIZATION**

### **1. Chapter II: Technology Overview**

Chapter II will provide an overview of the architecture of the existing HFN system, and explore the current state of virtualization technologies to include the architecture of virtualized hardware, virtualized software, virtual networking, and the virtual desktop infrastructure. It will also include an overview of end user devices that are used to access the virtual machines, which will be hosted on the EOC in a box.

## **2. Chapter III: System Architecture**

Chapter III will define the system architecture of the two existing components of the current HFN model as well as the new component, the EOC in a box that is being designed for this thesis. It will examine and describe the three systems: power, communications, and EOC in a box, which make up the system of systems that is the result of the research done here. The chapter is organized by Power, Communications, and EOC in a box as each of these systems are dependent upon the others. Components are described in detail and capabilities defined.

## **3. Chapter IV: Research Design and Experiments**

The design, assembly, and testing of the system is detailed in Chapter IV. A series of six field experiments have been designed and executed, which have taken place at various locations. With each experiment, refinements to the system have been made, problems identified and rectified, and a maturation of the system has occurred. Various levels of integration with systems from other members of the CHSC were accomplished, and each experiment is an evolution of the previous with problems identified and remediation applied to the configuration before the next experiment took place.

## **4. Chapter V: Results-Remedies and Conclusions**

The results of the six experiments conducted in Chapter IV are summarized in this chapter, as well as recommendations and areas for future work. Each experiment was an evolution of the previous, and the conclusions show the effects of the iterative process on the final state of

the system, which will be delivered to the CHSC in the spring of 2012. This chapter also outlines future research as not all the components that will be in the delivered system were available for integration and field testing.

This research is on-going and will continue as part of the DHS funded, CHSC project, but extends beyond the time allocated to this thesis. Additionally, the applicability of the system of Systems to other agencies within the First Responder, DoD and other NGO communities needs to be explored. Such applicability would come into play when "The incident may cause significant disruption of the area's critical infrastructure, such as energy, transportation, telecommunications, and public health and medical systems" (National Response Plan Catastrophic Incident Annex, 2011).

Additionally, President George W. Bush created the Directive on Management of Domestic Incidents in which he states "The Federal Government recognizes the roles and responsibilities of State and local authorities in domestic incident management. Initial responsibility for managing domestic incidents generally falls on State and local authorities"(Directive on Management of Domestic Incidents, 2003). This directive clearly shows the need for the local community to rapidly deploy the shared conversation space quickly and efficiently.



## II. TECHNOLOGY OVERVIEW

### A. HASTILY FORMED NETWORKS (HFN)

The definition of a HFN for the purpose of this thesis was created by (Denning, 2006) in a paper to the Association for Computing Machinery.

"An HFN has five elements: it is (1) a network of people established rapidly (2) from different communities, (3) working together in a shared conversation space (4) in which they plan, commit to, and execute actions, to (5) fulfill a large, urgent mission" (Denning, 2006).

Further definition of the *conversation space* illustrates that it has three main components. "The conversation space is (1) a medium of communication among (2) a set of players (3) who have agreed on a set of interaction rules" (Denning, 2006).

Once these capabilities are established and participants of the newly formed conversation space understand the rules, it is critical that members of the newly formed HFN have the skills needed: (Denning, 2006)

An HFN is thus much more than a set of organizations using advanced networking technology. To be effective in action, HFN participants must be skilled at:

- Setting up mobile communication and sensor systems
- Conducting interagency operations, sometimes called "civil-military boundary"
- Collaborating on action plans and coordinating their execution

- Improvising
- Leading a social network, where communication and decision making are decentralized, and there is no hierarchical chain of command or ex officio leader (Denning, 2006)

Most participants do not have a need for these skills in their individual organizations. When they come together, therefore, they find it difficult to accomplish these tasks. When combined with the overwhelming nature of the urgent event, these inherent difficulties can lead to a breakdown in the conversation space. (Denning, 2006)

To ensure an effective HFN, (Denning, 2006) has defined 8 key issues in his paper "Guide to Effective HFNs:

- 1) The quality of the conversation space is critical for success
- 2) The physical communication systems
- 3) The participating organizations are another part of conversation space
- 4) Information glut on the network
- 5) Understand and practice the effective technologies for collaborative networks
- 6) Prepare to overcome the barriers of international collaboration
- 7) Prepare for organizational conditioned tendencies to appear under overwhelming stress
- 8) Train the skill of improvisation

This thesis specifically addresses numbers two, four, and five, respectively.

## **B. GUIDE TO EFFECTIVE HFNS TWO, FOUR, AND FIVE**

(2) The physical communication systems are part of conversation space. Plan and test mobile technologies that can be set up quickly when the regular infrastructure is down. Arrange for security forces to protect the temporary infrastructure. Use and test all communications equipment regularly. Use standard software and protocols—interoperability and simplicity of interconnection will be important. Web services are a good example.

(4) Information glut will be a problem in the network. As communications are initially restored, the victims will overload the severely limited bandwidth as they try to communicate with their families. The responders themselves will overwhelm their colleagues with situational reports and other data. New technologies will be needed to manage information glut and keep the network functioning.

(5) Understand and practice the effective technologies for collaborative networks. These include Web servers to distribute information, wiki and discussion thread software, chat and instant messaging services, virtual markets, and coordination services such as Groove (but Groove is restricted to Windows platforms) (Denning, 2006)

Number two outlines the importance of the communications system and of usability and interoperability. Number four addresses information glut and limited bandwidth. Number five the importance of understanding the technology and tools, and illustrates Groove as an example of a proprietary software package that is restricted to a particular operating system.

The EOC in a box design pays particular attention to these four guidelines as it is designed to be accessed by any device such as a laptop, tablet PC, or even a mobile phone using Microsoft Windows, Apple OS, or Android OS as

their operating system. With limited training, the system can be setup and managed by civilian, DoD or NGO personnel. The software packages and data available on the system will provide the command and control necessary to maintain situational awareness while reducing the dependency on satellite reach-back to the Internet or data residing outside the disaster response area.

### **C. HFN LESSONS LEARNED AT KATRINA**

Using the Katrina after Action Report (AAR) (Steckler, Bradford, & Urrea, 2005) as a reference, issues addressed in (Denning, 2006) guide arose. As the NPS HFN Director, Mr. Steckler has participated in responses to Thailand, Hurricane Katrina, and most recently in Haiti. While leading teams from NPS, he experienced first-hand the difficulties in setting up and operating HFNs in austere environments, and has seen how lessons learned from Hurricane Katrina have helped to shape better policies and procedures for future disaster relief efforts. One example is the updating of the National Incident Management System (NIMS). An example of number two in (Denning, 2006) guide is found in the Equipment Issue section of the Hurricane Katrina (Steckler et al., 2005) AAR. Simple things such as username and password availability, dead batteries in meters and networking gear, and a lack of proper tools prevented the HFN from achieving a stable state until an exhaustive trouble shooting process had been performed. This problem was not unique to any one vendor or any one type of equipment. An example of (Denning, 2006) guide number three with regards to having a clearly defined leadership and roles is illustrated here:

In future disasters, it would be beneficial to have someone appropriately placed to manage both needs and assets to ensure the correct priorities get done first. This should be spelled out in the local disaster recovery plan. The NPS detachment should have had a liaison officer at the County EOC who would have updated the ESF-2 as to the status of the HFN as required." (Steckler et al., 2005)

Additionally, (Steckler et al., 2005) noted that there should be one central Internet authority in the area to coordinate all the ad hoc installations, with knowledge of who is up, who can share, and who is in need. It was also noted by (Steckler et al., 2005) that Further complicating issues was the lack of leadership or decision-making authority at these ad hoc sites.

One could surmise that the (Denning, 2006) guide was influenced by the real world experiences of the (Steckler et al., 2005) experiences at Hurricane Katrina.

While approximately 1836 (Hurricane Katrina FAQ, 2011) lives were lost in the Katrina disaster, the Hon. Richard G. Lugar, U.S Senator from Indiana noted (Haiti:, 2010) over 3 million people have been affected and 150,000 have lost their lives at Haiti. This catastrophic event resulted in another recent HA/DR mission where the applicability of (Denning, 2006) Guide to Effective HFN's was apparent. In his opening statements during the Hearing before the committee on foreign relations United States Senate One Hundred Eleventh Congress, Second Session, Lugar also stated "Immediate action by the United States to provide emergency assistance to Haiti was clearly warranted. The heroic efforts of American relief workers and the international teams of first responders are deeply

inspiring." An effective conversation space (Denning, 2006) is critical for this type of collaborative large scale effort to succeed.

In his NPS thesis which looked at federal resource availability during a disaster, (Heidtke, 2007) noted the importance of a rapid response is also apparent in the logistics of a HA/DR. Referring to the failure of FEMA to have a working logistics plan during the Katrina event as noted in the after action report to congress, "FEMA's logistics system failed out of the box" (Affairs, 2006), Additionally, (Heidtke, 2007) states "The direct consequence of this failure was an increase in human suffering among the victims of the hurricane. The inadequacy of the federal logistics system was manifested in a temporal gap that developed between the exhaustion of state and local resources and the excruciatingly slow development of an effective federal re-supply effort. This resource gap has been colloquially referred to as the "gap of pain"." (Heidtke, 2007) The term *Gap of Pain* was coined by Army Brigadier General Anthony Cuculo on his after action briefing on Katrina (Cuculo, 2006). An effective communication system as outlined in number 5 of the Guide to Effective HFNs would be of value to the logistics effort.

#### **D. HFN COMPONENTS**

For this thesis, the two systems of the existing HFN architecture that will be integrated with virtualization technologies are alternative power sources and communications systems. These include man portable BGAN and VSAT satellite systems, a VSAT on a trailer, and alternative power sources, which include solar, wind,

hydrogen fuel cell, and gasoline powered generators. These two components of the communications part of the conversation space will have capacities that the virtualized data center will be constrained by.

#### **E. VIRTUAL INFRASTRUCTURE**

Virtualization of computer hardware can be traced back to the IBM System 370 Mainframe of the 1960s (Creasy, 2011), and has matured to the point where it is now deployed in every Fortune 100 company (VMware, 2011) and in all branches of the military. Virtualization is a technology that is used to create virtual machines from underutilized physical resources on one or more Intel or Advance Micro Devices (AMD) x86 processor-based server(s) using a software layer known as a hypervisor. Microsoft®, VMware®, Red Hat®, Oracle®, and others are producing hypervisors with great success. However, in the Virtual Desktop Infrastructure (VDI) area, VMware is the leader. Virtualization technology capitalizes on the resources available in the Intel and AMD X86 CPU based systems and creates logical instantiations of computers known as virtual machines, which are managed as pools of resources. Users can use several types of devices as clients such as laptop computers, zero and thin clients, and even smart phones to connect to a virtual computer, which has been configured with an operating system and software, and is known as a virtual desktop. This can be done on while connected to a local area wired 802.3 Ethernet network (802.3, 2005), or on an 802.11 (ANSI STD 802.11, 2003) or 802.16 (Eklund, Marks, Stanwood, & Wang, 2011) wireless network. Access can also be achieved remotely using a

Virtual Private Network (VPN), which can leverage the public Internet, or via a wireless mesh network, which such as the one the HFN employs in response to some disaster. Figure 2 illustrates the logical view of a typical Virtual Machine architecture using the VMware model as used in their product offerings.

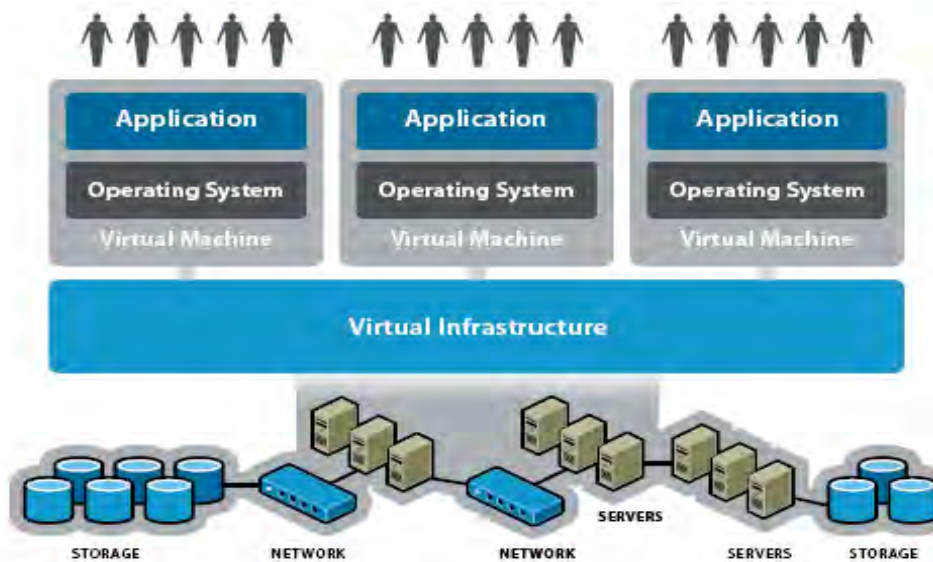


Figure 2. Architecture Logical View (From VMworld, 2008)

Figure 3 shows additional detail of the VMware virtualization layer, which adds the Symmetrical Multi Processor (SMP) (Orjan, 2000) Component as well as the Virtual Machine File System (VMFS) (VMware, 2009) component to the model. These two components are used to give the virtual desktops their processor and storage needs, both of which are managed by the hypervisor.



## VMware Infrastructure

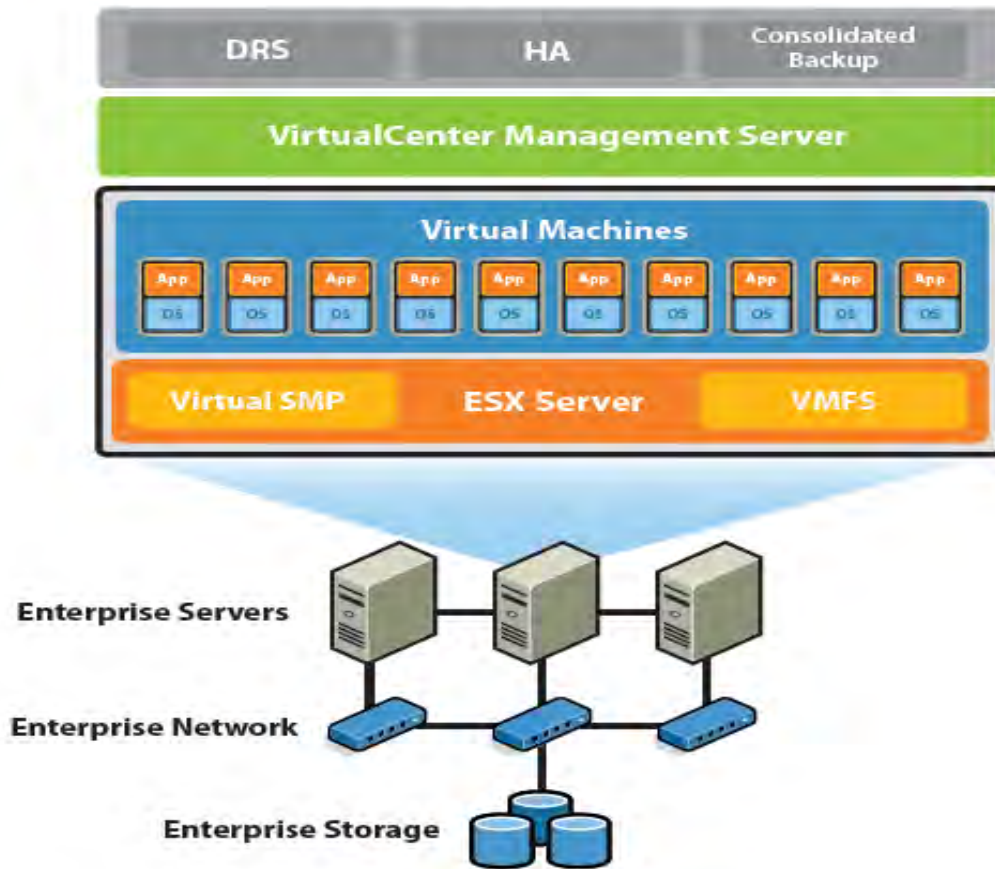


Figure 3. VMware Infrastructure (From VMworld, 2008)

Lastly, while Figures 2 and 3 illustrate how virtual machines are created on the physical server, or host, and utilize shared storage, memory, and processor resources, communication outside of the server requires the use of virtual networking technology as well. Networking is not limited to a single virtual to physical network interface card (NIC) mapping. Neither is it limited to a single virtual switch. But, it can be configured with as many physical and virtual NICs and physical and virtual switches as required for both performance and security needs.

Figure 4 illustrates multiple physical NICs, multiple virtual switches, and multiple virtual NICs which allow for security where physical and logical isolation of the network is required, and multiple NICs where performance and redundancy are desired.

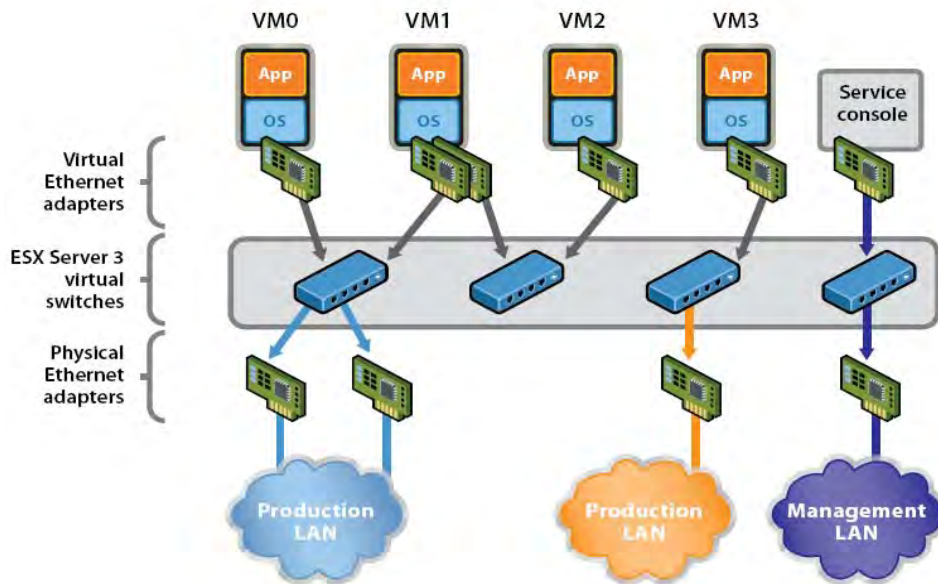


Figure 4. Network Architecture (From VMworld, 2008)

## F. VIRTUAL DESKTOP INFRASTRUCTURE

The Virtual Desktop Infrastructure being marketed by VMware in 2011 provides for an extension of server virtualization to the personal computer, or desktop as it is often referred to. For this research, a virtual desktop is defined as a computer system managed by a hypervisor which is running a desktop operating system (OS) such as Microsoft Windows or Ubuntu Linux. (VMware, 2006) These desktop operating systems are run on a computer, which is in fact a virtual computer just as virtualized servers are.

The client device, or the physical machine which is used to access the virtual desktop can be a regular desktop or laptop computer with a software agent installed, a Thin Client (Chung, Zimmerman, & Sunil, 2000) which has an operating system installed but minimal processing, memory, and storage capabilities, or a Zero Client (Madden, 2010) with no local processing, memory, or storage. Each of these solutions has their merits and drawbacks, but each allows for a user to connect to and utilize a virtual desktop across the wired or wireless network.

One major benefit of this technology is that the computer used to access the virtual machine can have any of a number of operating systems. Microsoft Windows, UNIX, Linux, or the Apple OS are compatible. Access can be via a simple device such as an Apple iPad or iPhone. Even an Android OS smart phone or any device, which can access the network via a web browser and run an agent which facilitates the communication between devices will work. The mission critical operating system and applications required by the first responders will run on virtual desktops with whatever operating system is required to run the mission critical applications and back office applications. This device agnostic reality simplifies deployment as well as reducing the requirements of the support staff to maintain common devices with common operating systems so access to the VDI can be achieved. This is a concern in number five in (Denning, 2006) Guide to Effective HFNs. Figure 5 illustrates the five-layer VDI Reference architecture used by VMware.

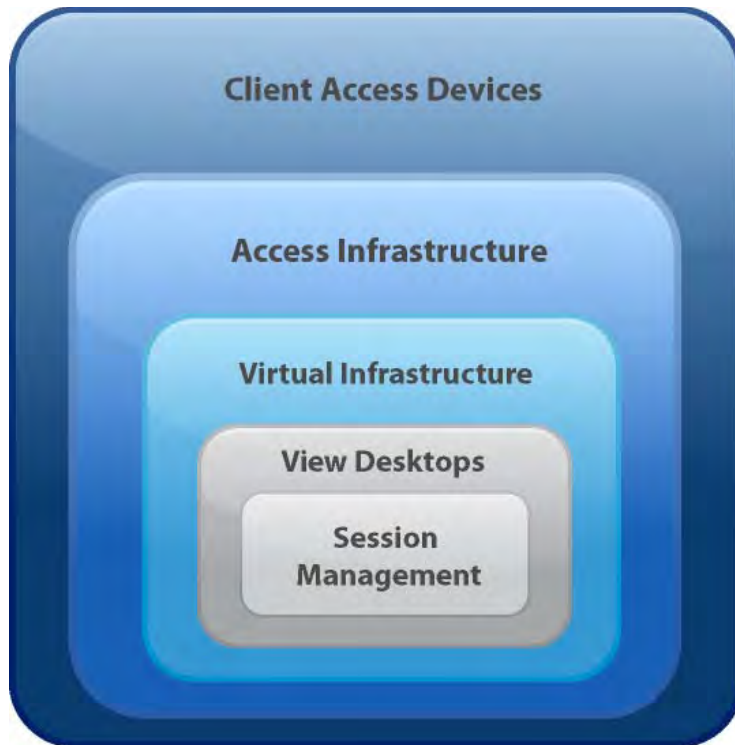


Figure 5. VMware VDI Reference Architecture (From VMware, 2010)

Summarizing the architecture (VMware, 2010), we find that each layer provides specific services

#### **G. CLIENT ACCESS DEVICES**

The client access device layer is comprised of the hardware and software components needed to deliver a PC-like experience (VMware, 2010).

#### **H. ACCESS INFRASTRUCTURE**

The access infrastructure provides network connectivity between client access devices and the virtual infrastructure that hosts the virtual desktop sessions,

including the components that manage, or broker, user connection requests to entitled desktops (VMware, 2010).

#### **I. VIRTUAL INFRASTRUCTURE**

The Virtual Infrastructure is described further as the *Virtual Desktop Management Services*, and consists of VMware View Manager, VMware View Components, and VMware View Load Balancing" (VMware, 2010).

- VMware View Manager
- VMware View Connection Server
- VMware View Security Server
- VMware View Agent
- VMware View Client
- VMware View Portal

#### **J. SESSION MANAGEMENT**

The last layer in the design consists of infrastructure components that provide a flexible, dynamic environment for managing access, user sessions, and desktops. This layer supports:

- Desktop and Pool Management
- Session Monitoring
- Active Directory Integration

Due to the need to maintain a simplified architecture of the EOC in a box model, which allows for a VDI to be implemented into the HFN, the architecture is not fully exploited. Figure 6 illustrates the high-level VMware view architecture of a more typical VDI solution as might be seen in a large enterprise deployment.

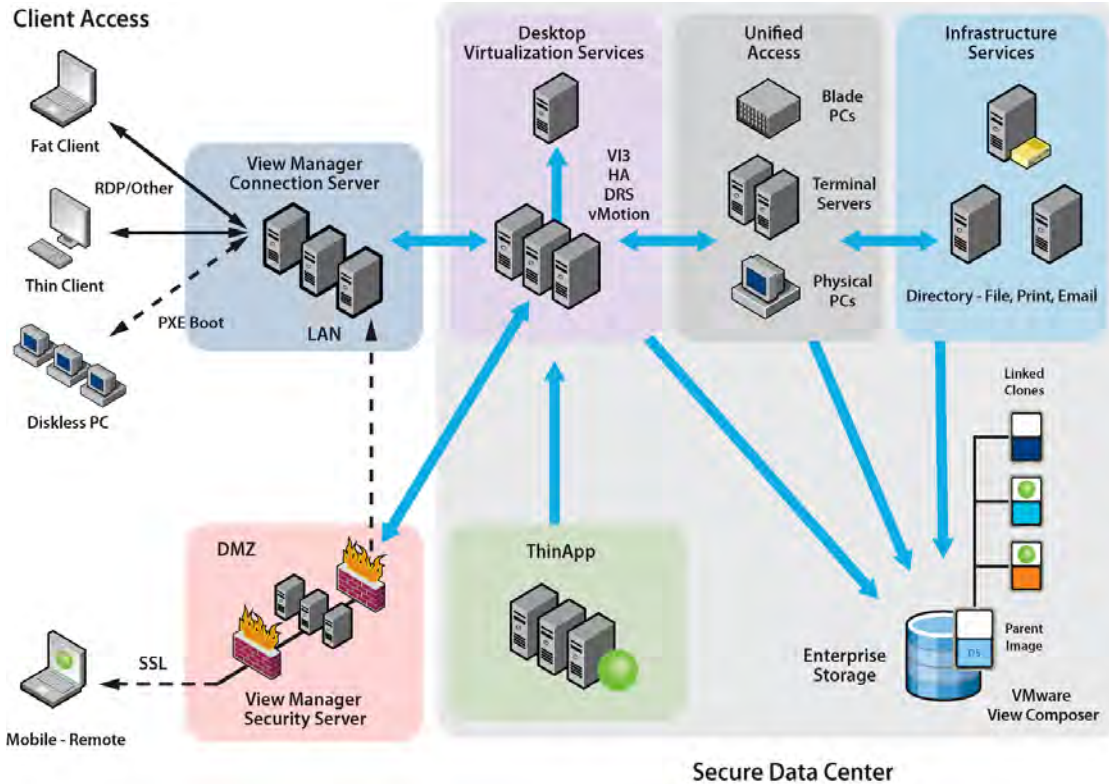


Figure 6. High-level View VMware Architecture (From VMware, 2010)

As the IPC3 EOC in a box utilizes a single physical server, there is no need to add some of the features found in an enterprise deployment. For example, the use of High Availability (HA), Distributed Resource Sharing (DRS), and vMotion (VMware, 2010), all components that provide a robust and load balanced system are not required, nor are the complex networking configurations which enable those services.

### K. CLIENT ACCESS

As one of the goals of the EOC in a box is to reduce interoperability issues, it is important to allow client devices of any kind to access the system and run a virtual desktop machine (VMware, 2010).

By supporting zero, thin and fat clients, and even certain smart phones to access the system simply by installing an appropriate View client, the dependency on a certain brand or type of device, and certain brand, type, or version of Operating System (OS), much is done to reduce interoperability concerns.

#### **L. VMWARE VIEW MANAGER CONNECTION SERVERS**

The Connection Servers act as desktop managers, providing user authentication for virtual desktops and directing incoming remote (VMware, 2010).

#### **M. DESKTOP VIRTUALIZATION SERVICES**

The main service needed from this is the actual Virtual Infrastructure itself. As noted earlier, the system will not be composed of multiple physical hosts. Rather, it will have a single robust host that will support the needs of the end users. This simplification of services, while keeping the need for complexity at a minimum, is a good compromise. A large deployment of VMware and View would require the ability to load-balance a system and have redundancy and fail-over capabilities.

#### **N. INFRASTRUCTURE SERVICE**

The normal services found for infrastructure services must be provided, even in the simplified model used by the EOC in a box. Microsoft Active Directory (AD) Services (Active Directory Server, 2011), Structured Query Language (SQL) (ISO/IEC 9075, 1992) database services, and perhaps even Post Office Protocol 3 (POP3) (RFC 1939 , 2011) and Simple Mail Transfer Protocol (SMTP) (RFC 5321 , 2011)

services will be required. Additionally, the need for print service and other features such as remote access may arise.

Three sub-systems will be integrated to create the total architecture for this research. Two of the systems are part of the existing conversation space as described in Chapter II, while the third is the new virtualized data center, or EOC in a box.



### **III. SYSTEM ARCHITECTURE**

#### **A. POWER**

The first system is the power system. Without power, the rest of the subsystems cannot function. For the IPC3 system, there are three components which have been integrated to create a complete power solution which will provide power from the sun, wind, hydrogen fuel cell, and a generator as a backup source should weather and climate conditions fail to provide enough sun and wind. Each of these systems and their capabilities are described below.

##### **1. Power Source - Solar, Wind, Hydrogen Fuel Cell**

The first component is the solar and wind generator system from Solar Stick™, and it is a PRO-Series 100 Breeze hybrid wind/solar system. Figure 7 illustrates the Breeze with its solar panels, wind turbine, and one PRO-Series 100 power pack which stores the generated energy for use when needed. This system can generate up to 1.5 kW-h of power (average) per day. It generates enough power to power communications equipment, computers, tools, medical equipment, or use it as a heavy-duty recharging station for tactical field gear. The package is designed to provide power generation for light to medium-duty applications where a small portable fuel-driven generator would typically be used and MAXIMUM power management is required. (Solar Stik , 2011).



Figure 7. Solar Stik Breeze 100 (From Solar Stik, 2011)

In order to ensure sufficient capacity and run-time, and to provide the 120 Volts clean power required by the computer equipment, the system was enhanced with the addition of one Power Pak Expander, and a PRO-Verter 1600APM which is illustrated in Figure 8 and shows all the connection points used by various devices, both Alternating Current (AC) and Direct Current (DC).



Figure 8. PRO-Verter 1600 APM (From Solar Stik, 2011)

The system was further enhanced by the addition of one PRO-Series Power Pak 100 battery pack.

The final hybrid solar piece of the power system was the addition of a PATROL Pak. This component consists of 4 fold-out solar panels which store in their own Pelican brand case, and includes necessary connector cables and its own PRO-Series Power Pak 100. A summary of the performance and capabilities for the PATROL Pak and the Power Pak from Solar Stik describes capabilities as The PATROL Pak can generate up to 2.0 kW-h of 12V DC or 24V DC power in just a

few hours with good sunlight. (Patrol Pak | Solar Stik, 2011) Figure 9 shows the PATROL Pak.



Figure 9. PATROL Pak (From Solar Stik, 2011)

The final component of the Solar Stik hybrid wind-solar-fuel cell system is the PRO CELL™ 600. This unit is a hydrogen fuel cell system which adds 600 watts per day of power to the system. It only operates when the wind and solar systems are not producing enough power to keep up with load. Additionally, it can be a standalone system for small loads, supplement larger systems, and act as a backup in inclement weather (Solar Stik, 2011).

A summary of total system capabilities is in Table 1. This illustrates the modular capabilities of the Solar Stik system, and how it can be scaled up or down to fit the demands of the system as needed. The chart provides power production and storage capacity figures, which will be used later in the analysis of system performance measures.

Table 1. Power Production/Storage Summary

Component Name	Average Power Production	Max Storage Capacity
Pro Cell 600	600 W daily Average	N/A
Pro-Verter 1600	1000 watts	N/A
100 Breeze with Power Pak 100	1.5 kWh daily average with 10 mph breeze	1 kWh/90 amp hour
PATROL Pak with 1 Power Pak 100	2.0 kWh daily average	1 kWh/90 amp hour
1 Flexi-panel	90 watts daily average	N/A
1 Expander Pak	N/A	1 kWh/90 amp hour
1 Expander Pak	N/A	1 kWh/90 amp hour
TOTAL	4.2 kWh daily average	4 kWh / 360 amp hour

As can be seen from the TOTAL row in Table 1, the total power output of the system is extremely close to the storage capacity of the battery and expander packs. Also, while the Pro Cell only produces 600 W daily average of power, it is a supplement when the wind is low or the or during periods of darkness.

## 2. Power Source - Generator

The backup power for the IPC3 system is in the form of a small gasoline powered generator from Honda. This unit is light, quiet, easy to operate, and fuel efficient, producing between 47 and 59 dBA of sound and it can run for 9.5 hours on 1.1 gallon of any pump-grade gasoline at one/quarter load, or 4.5 hours at its 1600 watt (13.3 amp) rated load. Additionally, it weighs only 47 lbs. and produces 2000 peak watts (16.7 amps) of power.

Additionally, Figure 10 shows the generators near perfect sine wave, which is ideal for computer and communications systems which are subject to failure when subjected to poor power conditions.

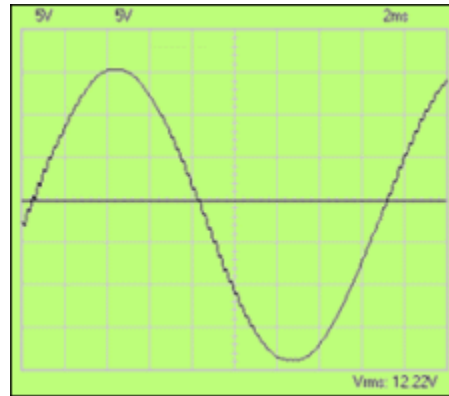


Figure 10. Honda EU2000i Sine Wave (From Honda, 2011)

The generator can produce approximately 38% of the total output of the entire hybrid wind-solar-fuel cell technology from Solar Stik, and can be used when fuel is available, and when the environment does not provide enough wind and solar power to support the system. It is also usable to charge the batteries of the system when the system is not being used should there be no convenient location to plug in all the battery packs, expander packs, and PRO-Verter components.

## **B. COMMUNICATIONS**

### **1. Broadband Global Access Network (BGAN)**

Three BGAN units were tested in this research. Two are from Harris, and one is from Hughes. The R-7800B-DU024 Land Portable BGAN Terminal from Harris was used for the initial connection to the Internet. This unit was equipped with a Subscriber Identity Module (SIM) card from Inmarsat and provided a data rate of 256 kbps. Inmarsat was bundled with the Harris BGAN unit, and is a critical component of the existing HFN for the following:

- BGAN is a global service so users are assured of connectivity wherever you are
- Establish a voice and data connection in less than five minutes
- Easy to set up and use with no technical expertise
- Availability of Inmarsat satellites and ground network exceeds 99.9%
- Highly portable terminals can easily fit in a backpack or be mounted onto vehicles for comms-on-the-move
- Connectivity still maintained even in severe weather, and is immune to failure when terrestrial or cellular communications break down in any natural or man-made disaster (Inmarsat, 2011)

Since power and communications are the two primary systems of the existing HFN architecture, the Harris BGAN coupled with the Inmarsat service is an excellent choice for voice and data communications at a limited, but reliable data rate.

A second BGAN unit is also in the inventory of the current HFN. This unit is a RF-7800-B-VU104 Land Mobile SOTM BGAM Terminal. Unlike the Land Portable unit which is designed to be in a fixed location, Satellite on the Move

(SOTM) allows for the unit to be mounted on a vehicle and maintain connectivity to the satellite at speeds of up to 70 Miles per hour (Mph). The unit has magnetic mounting feet which allow it to "stick" to the vehicle with no additional mounting requirements.

The final BGAN unit is a Hughes HNS 9201 from Hughes Network Systems, and like the Harris units, satellite Internet service is provided by Inmarsat. Capabilities and application support is also similar to the Harris units, with a form factor and similar setup and configuration process to the RF-7800B-DUO24 series BGANs. (Inmarsat, 2011) Specifications include

- Simultaneous voice and broadband data
- Global coverage
- Highly flexible
- Multi-user
- Supports both circuit-switched and IP packet data via USB, Ethernet, ISDN and WLAN interfaces
- Extremely robust
- Easy to use
- Truly portable
- Completely secure

The Hughes and Harris BGAN units may be managed using a web browser, or by using the BGAN Launchpad software provided by Inmarsat. An operator would define the BGAN system and model, and the software would then go out and search for the BGAN automatically or manually, and allow it to join the Inmarsat system and acquire a satellite by clicking on the Register button.



The use of a software tool with a common interface and operating process helps reduce the complexity of the setup of the HFN as well as reducing the amount of training required by the operators.

## **2. Monterey County, CA, Very Small Aperture Terminal (VSAT) Trailers**

The County of Monterey, CA, owns two custom-built VSAT trailers which were purchased from an out of state contractor approximately 5 years ago. The two trailers had fallen into disrepair and the IPC3 team was able to contract with a local computer consulting company to repair the trailers. At the time of this writing, one trailer is operational, but not yet field tested with the EOC in a box server, and the second is physically repaired, but not yet configured to operate with the currently contracted satellite Internet service provider.

Each trailer is constructed on an aluminum frame, single axle trailer with folding top doors, a front exposed storage area which is used to mount a spare tire, stow a generator, fuel, and power cords to allow for the trailer electronics to be powered by the grid, the generator, or for a short time from two marine grade deep cycle batteries which are integrated into the trailers along with a three phase charging system that keeps the batteries in a charged state as long as the trailer is stowed and connected to the grid. The trailers have an emergency lighting system and when it is open and operational, it has traditional California law enforcement style blue flashing lights at the sides, front, and rear. Each trailer is approximately

13 feet in length by 6 feet width, and is easily towed by any vehicle with a trailer hitch and 2" hitch ball.

The communications equipment in each trailer consists of a satellite dish and controller, a modem to communicate with the satellite, an internal router, and an external 802.11g access point plus necessary power supplies, connectors and mounting hardware. Management of the individual components is done using a laptop computer and a web browser interface to the modem, controller, router, or access point. Each trailer's satellite dish is of a .98 meter diameter VSAT type from DATASTORM, model XF2, and controlled by a MotoSAT D3 controller.

Satellite Service for the dish was originally provided by MotoSAT Mobile Satellite Systems, but is now being provided by IP Access, another Satellite Internet Service Provider (SISP).

The capabilities of the XF2 which make it a good choice for a mobile system are the ability to lock into satellites with little operator involvement in a vendor claimed time of less than three minutes, and stow to a height of 12 inches. Other features of interest are its relatively low power consumption which draws from its own 15 VDC, 8.6 Amp power supply, and its relatively low weight of 160 lbs. (Motosat, 2011) Figure 11 shows county trailer number two with the DATASTORM VSAT deployed.



Figure 11. Monterey County VSAT Trailer Number Two

Communications with the satellite and establishment of a link is facilitated by an iDirect 3100 satellite modem.

Notable features of the iDirect 3000 series are they are "Optimized for remote Internet access, the iDirect series 3000 is an ideal solution for small to medium enterprise customers with basic remote networking needs. Able to deliver broadband access of up to 18 Mbps downstream, and 4.2 Mbps upstream, the 3000 series can support all IP applications remotely, including VoIP and basic Video." (VSAT Systems, 2011)

Communications between the modem and the satellite controller is accomplished using a LINKSYS wireless router, model SRX-2000. The Linksys router provides a secure wireless 802.11g 54 Mbps cloud for managing the network, as well as providing the gateway between the DATASTORM satellite controller and the iDirect modem (LINKSYS, 2011).

The Linksys has several features, which make it a good choice for the trailers. These include Multiple-Input Multiple-Output (MIMO) (Haskin, 2007) antenna technology that increases throughput, an easy to use web interface, an integrated 4 port Fast Ethernet switch, and an inexpensive retail price of less than \$50.00 (CNET, 2011). However, one bad feature is it is designed for indoor use and that rules it out as a proper router for the environment the two trailers will be working in which will be deployed in austere environments. It was installed as a replacement to get the trailers into a working state and will be replaced at a later date with a proper outdoor rated unit.

For public or private access to the Internet, depending on need, the trailers are equipped with a proper, outdoor use rated, Cisco WAP 200E Access Point. This unit is mounted to the trailer and is equipped with a removable Omni-directional antenna.

By mounting the Cisco A/P to the left front of the trailer, and using the removable Omni-directional antenna, the Radio Frequency (RF) interference from all the other devices is reduced. The wireless cloud can be accessed from a suitable location anywhere around the trailer provided nothing interferes with the signal such as trees and brush, chain-link fences, glass windows, ponds or lakes, etc. All of these obstructions can cause degradation or complete elimination of the wireless signal through absorption, scattering, diffraction, reflection or the user may simply be outside the range of the Omni-directional antenna's coverage area (Dean, 2010). The data sheet in Figure 12 shows the specifications of the example antenna, and horizontal and vertical charts of the antenna's cloud.

(HD21058\_Specs.pdf, 2011). The two H-plane and V-plane co-polarization charts which illustrate the shape of the RF cloud and their pattern are important considerations when choosing an antenna (HD21058\_Specs.pdf, 2011). For example, if a point-to-point link were to be considered, a much more focused h-plane pattern would be desired as this would focus the antenna's RF beam and extend the distance the signal could travel. For the trailers, a local cloud was desired, and the antenna selected provided the optimal RF pattern (HD21058\_Specs.pdf, 2011). Also, by using a removable antenna, the trailers can be stowed easily simply by unscrewing the antenna, securing the water proof cap, and closing up the trailer.

# High Gain Omni Directional Antenna for 2.4GHz

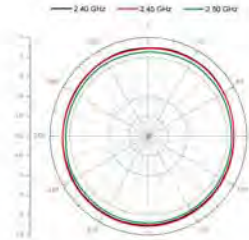
HD21058

Version 1.0

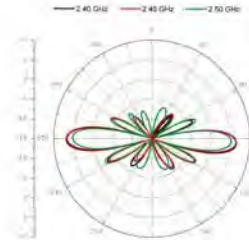
## Data Sheet



H-Plane Co-Polarization Patterns



V-Plane Co-Polarization Patterns

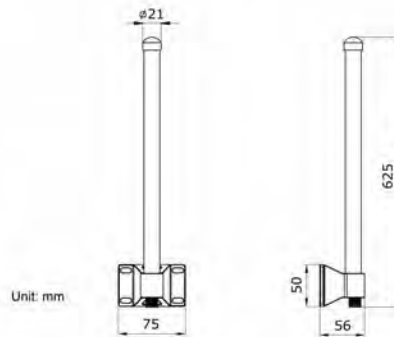


### Electrical Specification

Frequency Range:	2.4GHz~2.5GHz
Peak Gain:	8 dBi
VSWR:	1.92:1 max.
HPBW /H:	360°
HPBW /V:	15°
Impedance:	50 Ω
Polarization:	Linear; Vertical
Power Handling:	10W
Connector:	N type Jack

### Mechanical Specification

Operating Temperature:	-30°C~80°C
Storage Temperature:	-40°C~85°C
Humidity:	95% RH
Radome Material:	PC+UV resistance
Color:	White
Dimensions:	ø21x625L
Weight:	200 gfw
Mounting Function:	Pole Mount, Wall Mount.



HD Communications Corp. • Wireless Network Products Group  
2180 Fifth Avenue • Ronkonkoma, NY 11779  
TOLL-FREE (888) 588-3800 • www.hdwifi.com

Figure 12. Antenna Data Sheet (From HD Communications, 2011)

When all components are working correctly, an operator would tow the trailer to the desired location and secure it with wheel chocks and if applicable, activate the emergency flashing light system. The operator would then point the tongue of the trailer any direction but south as that direction proved to cause signal loss due to reflection from the trailer tongue and bulkhead, and then level the trailer, much like you would a motor home.

The trailer would then be opened, a laptop with appropriate web browser and iDirect software connected either to the data port located on the bulkhead of the trailer, or wirelessly to the LINKSYS SRX 200, and then powering up the trailer. Power is either by the provided on-board marine deep-cycle batteries, the included generator, connecting to the grid, or connecting to the SOLAR STIK hybrid power solution. The data port on the bulkhead is connected to one of the Fast Ethernet ports on the SRX 200 and provides access to the Internet once the system is up. Once powered on, the satellite dish would be deployed. A satellite would be locked on to, an Internet link established, and users would then be able to authenticate to the secure or open wireless 802.11g cloud as the situation warrants, and the basic link is complete.

To provide access to the Internet for the EOC in a box, the data port on the bulkhead of the trailer, which was used by the laptop for startup will be connected to the WAN port of the Cisco WRT400N. The WRT400N would then provide the public IP address, gateway, and DNS server information needed by the EOC in a box. From that point, any devices, which connected to either the Cisco switch, or

to the secured cloud provided by the Cisco WRT400N would have Internet access via the satellite.

### **3. 802.11s Wi-Fi Mesh**

An IEEE 802.11s wireless mesh network is deployed as part of the HFN communication system. (Hiertz, et al., 2008) Once a connection to the Internet is established with the BGAN or VSAT systems, the signal needs to be distributed to the local users in a secure or open manner, depending on the user's needs. This is done with Rajant wireless mesh networking equipment from their BreadCrumb® family. The units incorporated into the HFN include a fixed system, the BreadCrumb LX3, and a man-portable unit, the BreadCrumb ME3. The LX3 units are mounted on tri-pod stands and the network can be extended and expanded by simply adding additional LX3 units. One advantage of this system is it requires little operator intervention and the network is self-forming as LX3 units are added, and self-healing should a unit be removed from the network by utilizing their proprietary InstaMesh protocol illustrated in Figure 13.

The Rajant mesh network adapts to the changes caused by the movement of Node E. New links are established in real-time keeping the network available, intact, and secure(Rajant, 2011).



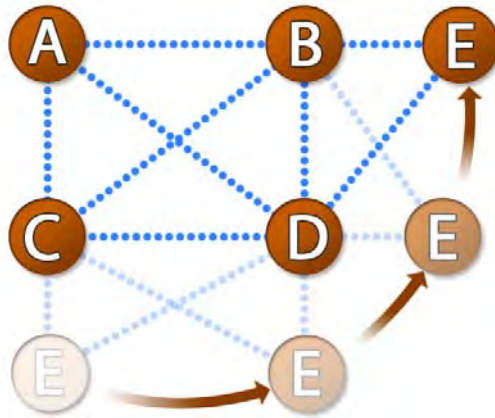


Figure 13. Rajant Mesh (From Rajant website, 2011)

The other Rajant BreadCrumb included in the HFN, the ME3, allows the network to be extended using a man-portable battery powered radio with all the features of the XL3.

Integration of the Wi-Fi mesh with the GBAN and VSAT is also illustrated in the BreadCrumb data sheet and can be seen in Figure 14. This illustrates one way the network could be deployed to supports non-secure connectivity to the Internet by some users, secure VPN between other users all on laptop computers.

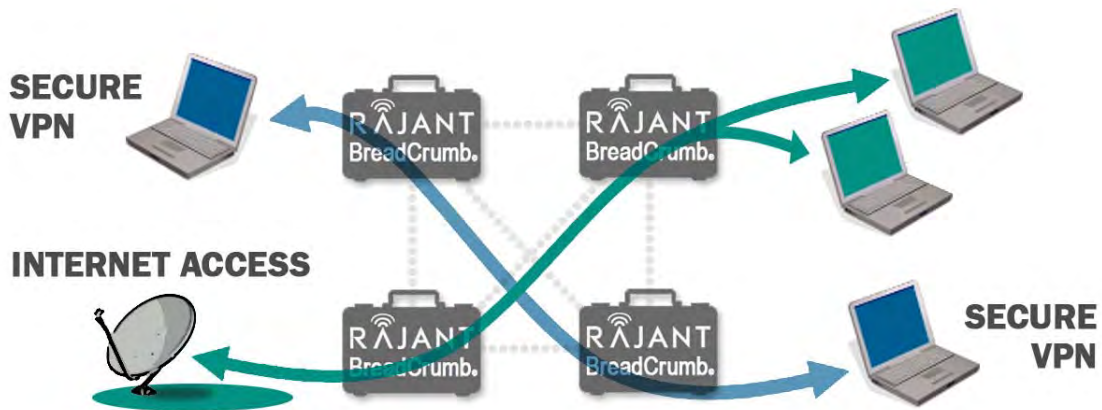


Figure 14. Rajant Wireless Mesh Sample Application (From Rajant 2011)

All management of the BreadCrumb system is accomplished using the company's BC|Commander® management tool as seen in Figure 15. This illustrates the view of the health and configuration of the network, and the relationships between nodes.



Figure 15. BC|Commander Software (From Rajant, 2011)

The following capabilities are offered by the software (Rajant, 2011).

- Topology maps show BreadCrumb and client device connections and parameters.
- BreadCrumb/client device channel, frequency, MAC address, IP address, nickname assignment, signal and noise levels and time-since-last-update.
- Channel and link speed of connections.
- Manual radio, SSID, DHCP, gateway and port forwarding, access control, security, and encryption settings

The combination of hardware and software provided by Rajant with its ease of operation and intuitive software makes the BreadCrumb Wi-Fi mesh networking solution a good choice for the HFN.

#### 4. 802.16 Wi-MAX

The final component of the communications portion of the HFN allows for the network to be extended across distances up to 25 miles in either a Point-to-Point (PPP) (RFC 1661, 1994) at data rates of up to 90 Mbps or Point to Multipoint (PMP) (Naghian, Siamak, 2004) at data rates of up to 48 Mbps configuration. The Redline Worldwide Interoperability for Microwave Access (Wi-MAX) 802.16 (Eklund, Marks, Stanwood, & Wang, 2011) AW-80i system is a state of the art high-speed WAN technology. The AN-80i is powered by Redline's third-generation IEEE 802.16 orthogonal frequency-division multiplexing (OFDM) (Eklund, et al., 2011) technology and uses hardware accelerators to achieve high throughput, low latency, and line-of-sight (LOS) and non-line-of-sight (NLOS) ranges in both urban and industrial environments (Redline, 2011).

The AN-80i has a relatively compact size, can be mounted on tri-pods, much like the Rajant BreadCrumb products, and can be configured to operate at several different frequencies within the Federal Communications Commission (FCC) licensed and unlicensed wireless spectrum including the 4.9 GHz public safety band, the 5.2 GHz to 5.8 GHz band, the 3.65 - 3.7 GHz band, and the 3.3 GHz to 3.8 GHz band (Redline, 2011).

The Redline unit also is compliant with the Federal Information Processing Standards Publication (FIPS) 140-2 standard for Cryptographic communications, which means the unit will be able to create secure WAN link (NIST FIPS 140-2, 2011).

In addition to speed, security, and ease of operation, the Redline units also support the IEEE 802.3af (802.3,

2005)Power over Ethernet (PoE) technology which is supported by the Cisco SGE2000P 24 port Ethernet switch which is a component of the EOC in a box described in the next section. In a PPP or PMP deployment, this technology allows the near side Redline radio to be powered directly from the switch simplifying installation and minimizing the need for additional power injectors or power bricks. Power is delivered from the SGE2000P to the AN-80i via a single Telecommunications Industry Association/Electronic Industries Alliance (TIA/EIA) Category 5e or higher rated Ethernet data cable (Sheldon, 2001).

### **C. EOC IN A BOX**

The architecture of the EOC in a box system consists of a few unique components, which were acquired from the open market, but still qualify as Common off the Shelf (COTS) components. The supporting sub-systems are more generic and less critical to the success of this design and research. The overall design is somewhat unique that in researching current systems, there does not appear to be any VDI solutions instantiated in the manner of this system. Power, communications, and portability were all considered in designing a complete system of systems.

In designing the IPC3 EOC in a box, four main criteria, and one constraint were identified, and needed to be considered. Primarily, the system needed to be:

1. Robust
2. Be energy efficient
3. Be two-man portable
4. Integrate with the existing HFN system

As deployed by NPS, the HFN has finite resources with regards to power and bandwidth availability.

A budget constraint was also on this project, so what may have been a better choice for some items, may have been cost prohibitive. An example of this was choosing a Linksys switch over a Cisco Catalyst switch. Both are Cisco products, but as this is a first-of-its-kind and a proof-of-concept, the value of choosing the enterprise class products versus the consumer/small business class products was not there.

### 1. Virtual Server

The core component of the EOC in a box is a VDI server from V3 Systems which utilizes a proprietary virtualization layer (V3 Systems, 2011) as seen in Figure 16, which enhances VDI performance substantially. In addition, the V3 STRATO 100 optimizes performance further by using a state of the art chassis, solid state disk (SSD) drives, 2X1 Gbps copper and 2X10 Gbps fiber network adapters all housed in a 1U rack-mountable chassis. A Unit (U), or Rack Unit, (RU) refers to "the space a component occupies in a server storage rack and can range from 0 to 10 or more RU in size. Each RU is 1.75" or 4.445 cm in height and is traditionally 19" wide" (skbcases, 2011).

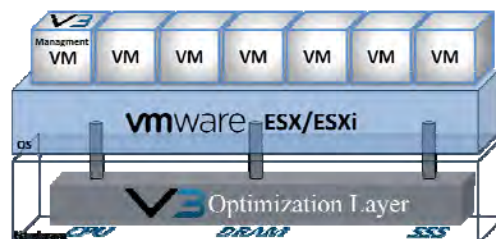


Figure 16. V3 Optimization Layer (From V3 Systems, 2011)

What is unique to this design is that the V3 system was developed as an appliance, and to provide an optimized VDI solution by integrating into an existing or new VMware ESX or ESXi environment. This research extends and modifies that design to include support for the complete server infrastructure required in a VMware deployment. This architecture includes the VMware View and ESX servers as well as the Active Directory (AD), Domain Name Service (DNS), and other supporting systems, which support user authentication, machine identification and validation, and security. In order to allow sufficient resources to make this modification to the V3 Systems model, a doubling of resources was required. For a traditional installation to support a 50 user VDI, a V3 Systems STRATO 50 would be integrated into an existing VMware system with the sole purposes of providing enhanced VDI performance. However, the system developed here uses a STRATO 100, with the additional resources normally used to support 100 virtual desktops allocated to 50 virtual desktops, and the extra RAM, CPU, and SSD storage space being allocated to the supporting AD, DNS, and other supporting services. This design extends the capabilities of the V3 Systems STRATO 100 from a purely VDI solution to a complete virtualized environment where all systems except for the end-users client devices are virtual and running on the V3 Systems STRATO 100 chassis. The weight of the server chassis is approximately 30 lbs.

## **2. Storage Attached Network (SAN)**

The next component provides for additional storage, and like the V3 Systems product, is somewhat unique due to

the protocol it uses. Access to storage is via the ATA over Ethernet (AoE) protocol (Hopkins, 2008), which is efficient and operates at layer 2 of the American National Standards Institute (ANSI) 7-layer Open System Interconnection (OSI) reference model. (Dean, 2010) Unlike low cost/low performance Internet Small Computer System Interface (iSCSI) (Satran, Meth, Sapuntzakis, & Chadalapak, 2004) storage, or high cost/high performance Fiber Channel (FC) (ANSI-CNE 704, 1999) storage, AoE provides high performance at a lower cost with simplified management as a bonus. The system chosen is a SRX3500-G manufactured by Coraid, Inc. and has a 2U rack mount size, is scalable to a total of 12 Terabytes (TB) of storage, and uses a mixture of traditional rotating disk Serial Attached SCSI (SAS) (Seagate, 2006), Serial ATA (SATA) (SATA, 2011) and higher performing Solid State Drives (SSD) which have no rotating platters and use significantly less power than traditional hard disk drives. An empty SRX chassis is 45 lbs., and a fully populated chassis would be approximately 55 lbs. depending on quantity and type of drives chosen to populate the chassis (Coraid, 2011).

For the IPC3 project, Coraid Inc. is providing an SRX3500-G chassis (Coraid, 2011) on a long-term evaluation which is equipped with 4 100 GB SSD drives and 20 500 GB SAS drives. This yields a total unformatted capacity of 20.4 Terabytes (TB) of storage which is configurable as expensive but reliable and very high-speed primary storage for applications and virtual machine storage, and secondary storage using traditional rotating disks which still give excellent performance due to the communications efficiency of the AoE protocol. The chassis is shipping with a dual-

port 10Gbps hardware initiator which will be mounted inside the V3 STRATO 100 chassis and provides dual 10 Gbps communications directly between the SAN chassis and the server chassis.

It should be noted that the Coraid SAN was not able to be acquired in time for the experiments, but data from the manufacturer's specification sheet, and familiarity with a similar Coraid SAN in the Virtualization and Cloud Computing lab was used to determine applicability and restrictions of integrating the Coraid SAN into the new HFN architecture in the conclusions section of Chapter V.

#### **D. POWER OVER ETHERNET (POE) SWITCH**

The next component, which provides for internal communication between devices, is a Cisco SGE2000P Managed 24 port switch that has 24 Power over Ethernet (PoE) (IEEE, 2003), capable ports and supports link speeds from 10 Megabits Per Second (Mbps) through 1 Gigabit per Second (Gbps), over copper links, and 1 Gbps over fiber optic links using the 4 Small Form-Factor Pluggable (SFP) ports (Cisco SGE2000P , 2011). The switch is managed via a web browser interface and supports many advanced features such as Virtual Local Area Networks (VLANs), Rapid Spanning Tree Protocol (RSTP), Internet Protocol version 6 (IPv6), and Quality of Service (QoS)802.1p (Cisco SGE2000P , 2011). The switch can be used to connect client workstations, and to connect to the wireless network infrastructure, which the system is designed to integrate with, and which provides the gateway to the Internet.



## **1. Wireless N Router**

The last communications device is a Cisco WRT 400N Wireless N router / Access Point. This unit provides several functions which allows the IPC3 system to connect to the Internet. It also provides services for the internal network such as DNS, DHCP, and an IEEE 802.11n wireless hot spot. The ability to provide these services allowed for the internal VMware IP addressing to remain static, and have the Cisco device manage the external connection. The external connection is dynamic and changes depending on what it connected to for Internet access, such as BGAN, VSAT, or a wired network infrastructure. Another feature that made this router suitable to the IPC3 research project, was its ability to support two RF radios simultaneously at the 2.4GHz and 5GHz ranges, effectively doubling the systems bandwidth.

## **2. Keyboard, Mouse, Video (KVM)**

To manage the VMware system, a Tripp-lite B021-000-19 KVM was added. This provides a slide-out keyboard with touch-pad and a 19" LCD display for logging into, configuring, and managing the V3 STRATO 100 system. It is a 1U configuration, just like the V3 STRATO 100, and integrates well with the rest of the system. Weight on the KVM is approximately 19 lbs.

The next two components of the system deal with power and monitoring.

## **3. Uninterruptable Power Supply (UPS)**

The first is an American Power Conversion (APC) SMART UPS 750 UPS, which serves two purposes. The first is to

provide a short back-up time for the system in the event of a power failure, or to allow the system to continue running should there be a need to relocate it, but keep it connected. This is not an unrealistic possibility given the nature of disasters and how much uncertainty and instability may be in the deployed area. The second is to provide for a stable power source. UPS systems not only provide for battery backup, but they also provide for surge suppression and protection from power problems such as spikes and brown outs. These are conditions where the power coming into the unit is not stable and may be above, below, or inconsistent to what normal delivered power needs to be. Each of these conditions will cause damage to electronic devices and cause interruptions in service.

The APC unit is capable of delivering 480 Watts / 750 VA of filtered power, and provides a run-time between 7 and 150 minutes depending on load (APC, 2011). As the preliminary analysis of the system components suggests a system load of approximately 250 watts, an expected realistic run time will be about 20 minutes, more than sufficient to shut-down the system, or to allow for the system to be moved or run independently, should the main power be taken off-line, such as when the back-up generator runs out of fuel, or there is insufficient solar or wind power to keep the alternative power source battery packs charged. Figure 17 illustrates the expected runtime from the APC specifications sheet.

The UPS uses standard National Electrical Manufacturing Association (NEMA) 15 outlet schemes so it will plug into a standard wall outlet, and standard

computing devices will plug into it. Additionally, the system has a claimed weight of 21.82 KG, or just over 41 lbs.

#### 4. Power Distribution Unit (PDU)

The second component is a PDU from Raritan. The Raritan PX series unit provides additional power outlets for components which require 120 volt power. However, the unit was chosen because it also has the capability of monitoring power usage and environmental conditions on an individual outlet basis, as well as monitoring individual computers utilizing the company's software.

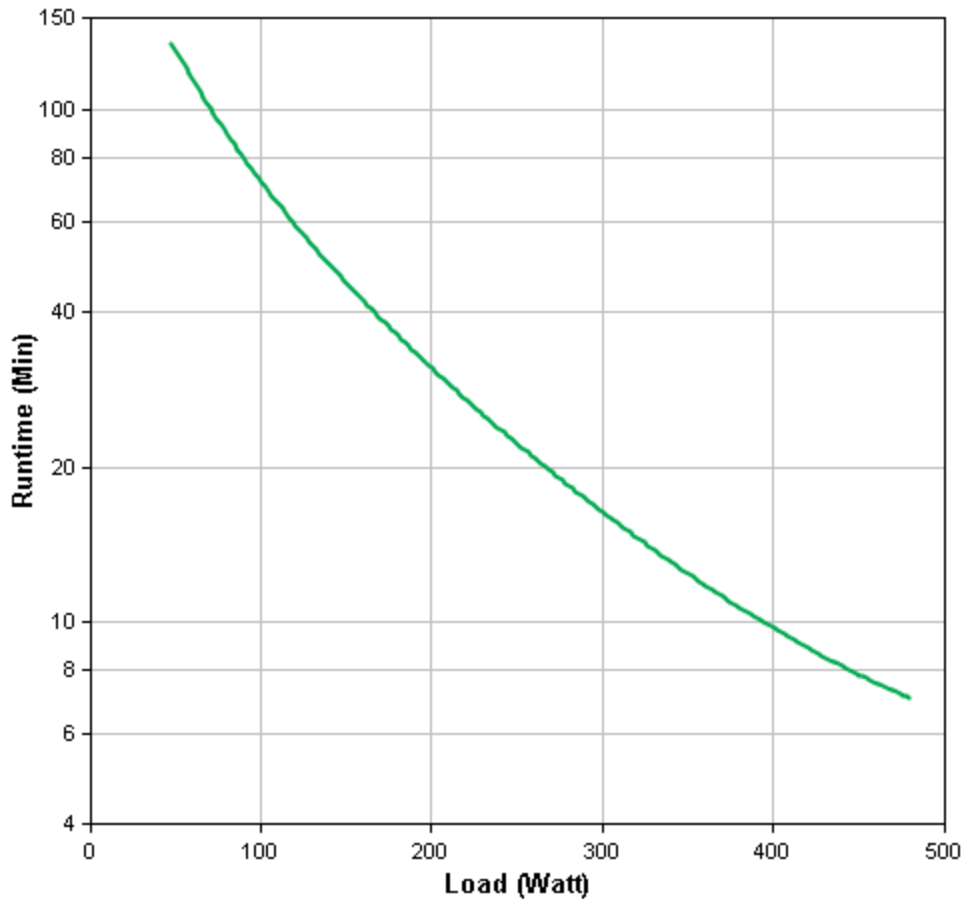


Figure 17. APC Runtime/Load Chart (From APC, 2011)

The Power IQ software used for this experiment is delivered from Raritan (Raritan, 2011) as a virtual machine image and is called Power IQ. This image is loaded onto the V3 Systems STRATO 100 and becomes part of the infrastructure. The software helps to get an accurate power consumption measure so that the deliverables of this thesis will include power utilization, peaks, valleys, total load, etc. This is critical in helping to determine which devices need the most power. It also helps ensure that when the system is deployed, sufficient power resources are available, and what systems can be reduced if sufficient power is not available, or needs to be conserved.

Each power outlet can be turned on or off, and be set to turn on or off at different times. This adds security and control by setting un-used outlets to off so someone does not connect a device, which might overload the system and reduce run-time, and allows for the staged starting of devices which reduces peak load on the system, thereby extending run-time. The software is available for free and can manage 5 outlets which will suffice for this project. If a need to monitor additional outlets arose, purchase of a licensed copy of the software which is in excess of \$1,000 would be required. (Raritan, 2011)

The Raritan Dominion PX was chosen for its 1U size, eight outlets, and ability to track system usage. For this project, the unit purchased is a 1U DPXR8-15 model and has 8 managed outlets, 5 of which are used and monitored with the Power IQ® software provided by Raritan.

## **5. Shock Rack Chassis**

The last component is the chassis or box, which is used to house the IPC3 EOC in a box. Several factors lead this researcher to the SKB 30" Deep 6U Roto Shock Rack which was chosen for its size, and its ability to withstand severe handling. The Air Transport Association (ATA) has given the SKB container its highest rating of ATA 300, Category 1 (skbcases, 2011). This means the unit can survive a minimum of 100 carrier trips.

In addition to the case being able to survive, the survivability of the contents is enhanced by the addition of a shock absorbing system, which helps to prevent damage.

The final consideration was for mobility and transportability. This was addressed by the case having removable wheels, which made it easy to move or carry, and then have the wheels removed and stowed with the unit for racking and stacking during transport. The case has a weight of 66.75 lbs., so it is a substantial unit, which should provide good protection and portability for the IPC3 system.

## **6. Components, Weights, and Power Consumption**

Table 2 is a summary of system component critical success factors. As power consumption and weight are two measures of effectiveness and measures of performance, each has been listed and a total for each computed. Note that amperage values were not available for the Raritan PDU and the Coraid SAN.

Also note that watts for the CORAD SAN are from the manufacturer's data sheet and have not been verified in field testing due to unavailability of the SAN in time for the testing phase of this thesis.

Table 2. Component Power and Weight

Component	Power Consumption (Amps/Watts)	System Weight (Lbs.)
SKB ROTO RACK	NA/NA	66.75 lbs.
V3 STRATO 100 Server	Left P/S 0.88/100.15 Right P/S 0.82/91.82	30 lbs.
Cisco SGE2000P SWITCH	0.19/20.27	5 lbs.
Cisco WRT400N Router	Outside PDU measuring range, relative < 1 watt	< 1 lbs.
RARITAN PX PDU	NA/NA	5.6 lbs.
TRIPP-LITE BO21-000-19 KVM	0.28/18.25	40 lbs.
APC 750VA/480 UPS	.86/12.95	41 lbs.
Coraid SRX3500 SAN	5.4/650 watts (manufacturers claim)	55 lbs.
TOTAL		
With	3.03/244.48	188.45 lbs.
Without Coraid SAN	43.0/894.40	244.35 lbs.

### III. RESEARCH DESIGN, BUILD, AND EXPERIMENTS

#### A. RESEARCH DESIGN AND EXPERIMENTS

Several experiments were developed, which provided the IP3C team members the opportunity to test components individually, and to integrate those components into the designed system. Table 3 lists the experiments and their dates.

Table 3. Experiment Matrix

Date	Location	Event Description
09/23/2011	Monterey County EOC	Earthquake drill
09/24-09/25/2011	Salinas, CA	California International Air show
09/30-10/2-2011	San Francisco, CA	Fleet Week
09/13/2011	Naval Postgraduate School, Monterey, CA	U.S. Army Civil Affairs School visitation
09/20/2011	Naval Postgraduate School, Monterey, CA	Monterey Chamber of Commerce Mixer

The IPC3 system is a new idea, and as such, the design of the experiments was driven by the requirements of the sponsors. The requirements as defined in the project Statement of Work (SOW) are as follows:

- Provide a report on total power consumption
- Provide a report on current alternative power sources and their applicability to the IP3C system
- Participate in exercises with other Consortium members at Camp Roberts, and others.

## **B. INITIAL SYSTEM BUILD**

For the initial configuration, the IPC3 server component was assembled into the 6U SKB Shock Rack chassis. At the time of this build, the Coraid SAN had not been purchased. Beginning at the bottom of the 6U Chassis, the configuration and build up is as follows, referring to each of the chassis RU positions from bottom to top:

- RU-1 APC UPS, mounted from the front of the chassis with outlets to the rear
- RU-2 V3 Systems STRATO 100 mounted from the front of the chassis with power and network interfaces to the rear
- RU-3 Blank (future home of Coraid SAN)
- RU-4 Blank (future home of Coraid SAN)
- RU-5 Cisco switch, mounted from the rear of the chassis, sharing this RU with the RARITAN, and with data ports facing the rear
- RU-5 RARITAN PDU, mounted from the front of the chassis, sharing this RU with the Cisco switch, and with outlets pointing to the rear



- RU-6 Tripp-Lite KVM, mounted from the front of the chassis with VGA cable and power facing the rear

Once the physical components were assembled into the rack, each devices electrical cord was plugged into the back of the Raritan PDU, and the PDU was plugged into the APC UPS. This allowed for only a single 110 outlet being needed to power the system. Also, since the APC UPS has 4 120 volts NEMA 15 outlets on the back, these could be used for additional components such as laptops and cell phone chargers.

For the physical connectivity of the data side of the architecture, the Cisco switch was the central connection point, and using TIA/EIA 565B Category 6 rated cables of various lengths and colors were used with two separate networks. One network would handle internal communication switch the ESX operating system, and the other network would handle communications for the virtual machines, which was made up of virtual servers and virtual desktops.

A third network will be used to connect the Coraid SAN to the virtual infrastructure once the SAN is acquired. However, since this traffic is direct between the V3 Systems STRATO 100 server and the Coraid SAN chassis, the cabling is direct from one chassis to the other. Although the Cisco switch and the NICs used for the two LAN connections to the STRATO 100 are 1 Gbps speed, the hardware initiators provided with the CORAI SAN allow for 10 Gbps communications between the server and storage chassis. Not only does this provide for extremely fast data transfer rates, the isolation of the SAN traffic

improves security as well by physical isolation of the networks as illustrated in Figure 3 in Chapter II.

### C. EXPERIMENTS

#### 1. Experiment One, Monterey County Offices of Emergency Services

The first experiment took place on 09/23/2011. The IP3C team, along with members of the Distributed Information Systems Experimentation (DISE) group, and one member of the Computer Science Department at NPS, deployed the IP3C network, and the DISE Joint Reconfigurable Vehicle (JRV) to the Monterey County Offices of Emergency Services located in Salinas, CA. The County's EOC is located there, and the Emergency Services Manager, Sherrie Collins, who is also the CHSC sponsor for the IPC3 project, coordinated where to set up and how to interact with the First Responder community for this experiment. NPS participants were the following:

- Brian Steckler, Albert Barreto: NPS IP3C faculty/student research team
- Ron Short, contractor for satellite trailer
- JD Fulp: NPS faculty as participant observer
- Robert Garza, Robert Schulz, and Joe Utschig: NPS DISE research team
- Oscar Antillon, Greg Gabriel: NPS students

For this experiment, the IP3C team assembled all of the command, control, and communications equipment, loaded it into a small truck, and transported it to the experiment location in Salinas. One asset, the Monterey County owned satellite trailer *Monterey County 2*, was also being

prepared to participate in the experiment to provide high speed, Broadband Internet access via satellite. However, the trailer, which had just undergone a physical cable re-wiring for the data connections, was inoperable, could not establish a link to a satellite, and was left behind for further testing and diagnosis in the hopes it could be brought to the experiment site at a later time.

The original intention was to have all the IP3C equipment in a single vehicle, with the trailer in tow, and a driver and passenger in the front of the cab to demonstrate the compactness and portability of the system.

Once on scene at the EOC, the IP3C team unloaded all the equipment in the reserved area, deployed orange safety cones at the perimeter, and proceeded to unpack and setup the equipment.

First and foremost was the unpacking, assembly, and configuration of the power system, the key component to the success of this experiment. This took approximately one hour with three people involved in the process. While this was happening, additional personnel were executing the parallel process of deploying the additional fold-up solar panels into a serial circuit which produced 4X90, or an aggregated 360 watts of electrical power.

Second, the physical construction of the communications took place. This included mounting radios and antennas onto tri-pod mounds, attaching power and data cables, and establishing a BGAN satellite link so the team could access the Internet. Again, in a parallel manner, personnel were deploying a simulated 802.16 Wi-Max link by positioning a fifth solar panel, tri-pod based 802.16 radios, and antenna. One radio was in the bed of the

truck, powered by the fifth solar panel which was also charging a portable battery pack, and the second was in the safety circle of the experiment, drawing power from the Solar Stik system.

Once the power and communications systems were unpacked, assembled, and ready to be configured, the V3 server rack was opened, connected to power, and the virtual infrastructure initialized. This process took just under 30 minutes, including the boot time of the server, and the boot time of the individual virtual machines. All told, the deployment of the system with four faculty and students was just under two hours, and which included establishing the BGAN Internet link.

For the course of the day, the researchers worked on configurations, testing of integration, and did a presentation to the participants of the county-wide disaster response exercise. Albert Barreto spoke to the capabilities of the IPC3 system, and Joe Utschig spoke to the capabilities of the JRV. There seemed to be a favorable response from the crowd with regards to the capabilities, which will be made available to them at the end of the research project, and to the additional resources which the JRV could provide if needed.

At approximately 1530, both teams broke down their systems and proceeded to the Salinas airport where the researchers were allowed to stow the equipment and prepare for the weekend experiments

## **2. Experiments Two and Three, California International Air Show**

The second and third experiment days were both at the California International Air show, which is held annually at the Salinas, CA, airport. On 09/24 thru 09/25/2011, NPS participants were the following:

- Brian Steckler, Albert Barreto: NPS IP3C faculty/student research team
- Robert Garza, Robert Schulz, and Joe Utschig: NPS DISE research team
- Stanley Wong, Oscar Antillon, and Greg Gabriel: NPS students

Brian Steckler had arranged to have the IPC3 team's equipment on display with the Salinas Police and Fire mobile command vehicles, and the gear were dropped off and partially assembled, again in an area coned off with orange safety cones. This spot also allowed for the parking of the JRV directly next to the IP3C system, giving the researchers excellent exposure to the spectators and first responders. Figure 18 is a photograph of the complete air show configuration with the two City of Salinas and JRV vehicles.



Figure 18. Salinas Air Show

The weather on Saturday was a bit foggy and cool, and the team began to setup the equipment around 0900. The order of operations for this process is to get the power system up and working, which includes the Solar Stik system, the foldable solar panels, and the generator, then bring up satellite and communications, and finally bring up the EOC in a box. As the weather on Friday was also a bit overcast, the power system batteries were not in a fully charged state, so the generator was added to the system should its capability become required. The data on Friday from the PDU diagnostics suggested the system had a peak power draw of 285 watts, and it appeared at this time that the power system could not meet this demand without the generator supplementing it, so the batteries would never be

in a fully charged state, and accurate run time values would not be available. Table 4 shows average watts and amps from the PDU for Friday, Saturday, and Sunday. Figure 19 shows the data in chart form from the Raritan Power IQ software dashboard. Notice the steady rise in power consumption as additional components were brought online.

Table 4. Salinas Air Show Power Usage

Location	Average Amps	Average Watts
Monterey County EOC	2.176	235.838
Salinas Air Show, Day 1	2.248	259.56
Salinas Air Show, Day 2	2.296	267.188

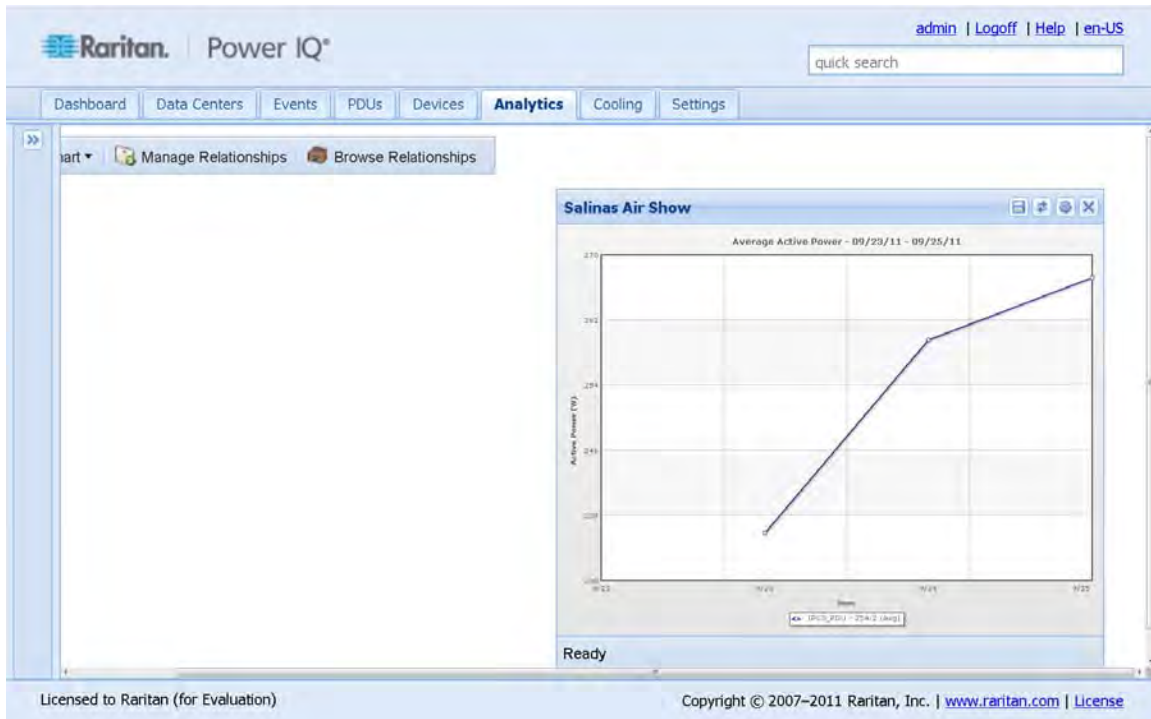


Figure 19. Salinas Air Show

The results in Chapter V detail this, along with the results of the weekend's experiments.

As there was no time between Friday and Saturday to make modifications to the system, it was known to the researchers that there would be issues with some of the systems features, so much of the day was spent working with the DISE group on communications, leveraging Robert Garza's Cisco expertise, and identifying which systems were working as expected, and which were not. There were various communications pieces capable of providing DHCP and DNS services as well as 802.11 standards and mesh networking and 802.16 networking. Ensuring that each system was providing the correct services and not competing and conflicting with the others was a challenge.



On the EOC in a box piece of the system, much of the day was spent resolving DNS and IP addressing issues. As the system was in a test mode at NPS, the addressing and name services were being provided by the school network. As the team discovered at the EOC on Friday, when a new source for those services was used, the internal communications of the virtual infrastructure failed. In order to be able to test the system and establish a link to the Internet using the BGAN satellite system, the decision was made to forego using the VMware VDI process and simply rely on the Remote Desktop Protocol (RDP) to access a virtual machine desktop. Additionally, manually assigning new IP addresses, gateway, and DNS values to the system allowed at least one user to access the Internet via the BGAN link, at least proving the viability of this design.

### **3. Experiment Four, Fleet Week, San Francisco, CA**

Fleet Week presented a unique opportunity to not only field test the IPC3 system, but to do so for an extended four day period, and in a busy setting with civilian and military visitors. This was the first time that NPS participated at Fleet Week, which took place on 09/30 thru 10/2/2011, and the theme of the event was humanitarian assistance and disaster response which fit perfectly with the two NPS team's research projects. NPS participants were the following:

- Albert Barreto, Marcelo Perfetti, Jonathan Tighe: NPS IP3C faculty/ student research team
- Dr. Alex Bordetsky, Eugene Bourakov, Robert Gruber, Steven Mullins: NPS faculty/CENETIX research team

The opportunity to work with Dr. Alex Bordetsky and Eugene Bourakov of the Center for Network Innovation and Experimentation (CENETIX) laboratory also was unique as although this was the second experiment where the IPC3 team interacted with other NPS researchers, this was the first of the experiments conducted with the CENETIX team. CENETIX brought several robot and sensor network innovations along with multi-media equipment which they used for demonstration purposes. A view of the experiment space with the two NPS teams and visitors is shown as Figure 20.



Figure 20. Fleet Week

#### **4. Experiment Five, U.S. ARMY Civil Affairs School Visitation**

On October 13, 2011, a group of representatives from the U.S. Army's Civil Affairs school, and other officials from the Pentagon, visited NPS to explore a possible relocation of the Army's Civil Affairs (CA) School to the Monterey Peninsula. Albert Barreto had been asked to present to the visiting dignitaries on the work being done at NPS with regards to HFNs and DA/HA work. It was decided by Dr. Karen Guttieri of the NPS Global Public Policy Academic Group, and Albert Barreto, that it would be another excellent opportunity to field test the IPC3 system and to show case it to the visitors.

The morning of October 13, several members of the IPC3 project and students moved and assembled the IPC3 rack in the quad area in front of Glasgow Hall. NPS participants were the following:

- Albert Barreto, Jon Tighe, Oscar Antillon, Greg Gabriel, BJ Booth, and David Huey: NPS IP3C faculty/student research team

The complete setup of the system took just over one hour. The system was used to do the presentation to the visitors via a Macintosh MacBook Pro laptop running on internal battery power, connected wirelessly to the IPC3 system, and delivering the presentation on a Windows 7 virtual machine. The actual presentation was stored on the local storage of the IPC3 server, so the entire presentation was done *off the grid*, and *off the net*. For the formal presentation to the visiting dignitaries, a virtual machine running on the V3 STRATO 100 was configured to use the Microsoft Windows 7 operating system, and was

loaded with Microsoft Office 2010, the latest Symantec Endpoint Protection Anti-Virus software, and a Power Point slide show presentation was loaded onto the local storage SSD drives. Two GB of Random Access Memory (RAM) was allocated to the virtual machine, and a 24 GB thin provisioned virtual hard drive was provisioned. This configuration allows the hard drive to dynamically allocate additional space as needed. The standard virtualized 1 Gbps network card was also configured and connected to the internal network; the video card default type was also used with video memory set to 35 MB.

This is the standard virtual machine, which will be delivered to the Monterey County EOC at the end of the CHSC project. At this time, the final and complete software load of the virtual machines is not known, but the basic machine hardware, operating system, and back office software are as used in this experiment.

The actual presentation took place in a conference room on the third floor of the Glasgow West building. GE 326 is a typical conference room with multi-media presentation capabilities, and was within RF range of the 2.4 GHz wireless cloud produced by the Cisco WRT200N access point, and the building construction and large window near the lectern did not create impediments to a successful connection by the MacBook Pro laptop which was being used for the presentation. The presentation was 13 MB in size, and would provide a good visual for how the IPC3 system performed across the wireless network.

## 5. Experiment Six, Chamber Mixer at NPS, Monterey, CA

For this experiment, a sub-set of the IPC3 system was deployed, and connected to the Internet via the Harris brand BGAN system. There are two Monterey County owned VSAT trailers available for this research, and both are being serviced and repaired as part of the CHSC consortium project that this thesis is based on. This was to be the first experiment where the IPC3 system was to have a high-speed broadband Internet connection provided by one of the trailers—with expected speeds in the 3 Mbps download and 1.5 Mbps upload range—so expectations were high for being able to access remote services and determine the effects of latency which is a normal part of satellite communications. However, the trailer planned for this exercise was not ready in time for the event.

Participants were as followed:

- Albert Barreto, Brian Steckler, Jonathan Tighe, David Huey, and B.J. Booth: NPS IP3C faculty/research team

This was the first attempt to connect the IPC3 EOC in a box to the BGAN system by Albert Barreto, and the first attempt at establishing an Internet connection from inside a building such as the Herrmann Hall complex. The connection was successful once the process of registering the unit to the network was understood, and the entire IPC3 system was able to be setup in under an hour. The location where the equipment was set up inside the ball room of Herrmann Hall would have prevented the use of the satellite trailer, so there was no detrimental affect due to the Monterey County owned trailers being non-operational.

Chapter V, Results-Remedies, and Conclusions, discusses several issues which were encountered at the first three experiments, their resolutions, and successes, and then outlines results from the next three experiments and summarizes the state of the IPC3 system.

## V. RESULTS-REMEDIES, AND CONCLUSIONS

### A. INITIAL BUILD/CONFIGURATION

As is often discovered in Research and Development (R&D), the initial configuration of the IPC3 server rack proved to be less than optimal. While the system was able to perform well while connected to the NPS intranet, and relying on the school servers to provide IP addressing, Internet gateway access, and DNS services, it was quickly learned that having the internal addressing change when relying on a satellite and its subordinating router for DNS, DHCP, and other network services was a clear oversight, and a fatal design flaw. Internal communications of the virtual machine infrastructure is dependent on reliable DNS, and by design, there are at least two networks internal to any ESX or ESXi based VMware system. Referring back to Figure 3 illustrates the multiple network interfaces and their usage in a typical VMware ESX architecture.

For the IPC3 system, the first network is used for communication to the physical server or servers which run the VMware ESX 4.1 hypervisor software, and use a static IP addressing scheme. The second network is for the actual virtual infrastructure which again uses static IP addresses for the Microsoft Windows servers; but the virtual desktop machines used DHCP addresses provided by the NPS network devices servicing the same IP network segment. These IP addresses are private, non-routable, and a range of addresses had been provided by the schools Technology Assistance Center (TAC) and the servers were assigned

static IP numbers from that pool. This model of addressing worked well until the system needed to be using IP addresses provided by the satellite service provider or another network, which invalidated the static IPs used by the virtual infrastructure, and basically created three network IP subnets using only two NICs.

#### **B. RESULTS-REMEDIES, EXPERIMENTS ONE-THREE**

While the IPC3 EOC in a box is designed to be totally autonomous with regard to power needs and local services, it is also designed to integrate with whatever system is available to get Internet access via an external IP and gateway address, and DNS servers. As it was convenient to simply plug a network cable from the Cisco switch into an available wall port to the NPS network and get access to the OSI TCP/IP Reference model Layer 1, 2 and 3 services such as ARP, DHCP, DNS, and routing, it was clear that this was not going to work in the field.

Experiment one was less than successful. While the initial setup and configuration of the system seemed to go well, taking about two hours, the system was not able to be used with the MCOES VSAT trailer as hoped since the trailers were not functional at the time of the experiment. However, access was available to a BGAN system with active satellite service, so that was used in place of the trailer. As noted in Chapter III, using the BGAN as the Internet gateway device exposed weaknesses in the original architecture.

To resolve the early issues discovered after experiments one, two, and three, a re-configuration of the system was performed, and the Cisco Wireless-N dual band



router described in Chapter III was added to the system. The system was then configured to have the Cisco router serve as the internal and external gateways to the Internet, and to provide external DNS, DHCP and wireless authentication providing secure wireless access on both the 2.5 GHz and 5 GHz unlicensed spectrum, while the internal DNS and AD user authentication provided those services to the virtual machine infrastructure. Additionally, the virtual machine infrastructure was reconfigured to allow for the virtual servers and virtual desktop machines to automatically boot and shutdown with the system. This allowed for the system to simply be turned on at the start of the day by plugging in the system, turning the UPS on with the power switch, waiting for the Raritan PDU to boot, and then pushing the server power button. The entire boot process now takes about 10 minutes to complete, and requires no operator intervention.

To shut down at the end of the day, the operator simply shuts down the server by issuing the UNIX Shutdown command with the -H parameter at the server KVM console, or shutting down the server from within the VMware Virtual Center software, waiting about ten minutes for services to stop, and then powering off the rack by turning off the APC UPS. The virtual infrastructure will do a graceful start and stop without further operator intervention, and the Microsoft Server virtual machines, which hosted the virtual infrastructure services, such as VMware Virtual Center, Microsoft AD and Structured Query Language (SQL) databases, and the VMware View connection broker, were staggered to start in a certain order to insure dependent services all started in the correct order, and finally, allowing the

virtual client machines to self-boot and become available to the users. This also allowed the system to connect to any available satellite system for reach back without requiring any further changes to the network configuration as the only changes to the IP addressing were made to the Cisco router's public facing interface automatically by the connected device.

### **C. RESULTS-REMEDIES, EXPERIMENT FOUR**

Fleet Week proved to be another step in the right direction for the EOC in a box and HFN integration. The communications issues discovered in experiments one, two, and three had been resolved by the addition of the Cisco WRT400N, and the entire system was setup and operational in less than two hours. Additionally, the automation of the virtualized infrastructure start up and shutdown processes was done prior to deployment to Fleet Week, further reducing the complexity and time required for setup.

For this experiment, an area had been secured at the Marina Green in San Francisco, and the team was surrounded by U.S. Navy and Marine Corp equipment. The weather was perfect with temperatures in the 70s for most of the day, and an 8 to 10 knot breeze in the afternoon was sufficient to engage the Solar Stik wind generation system.

Configuration and setup required the acquisition of several composite platforms roughly 3' wide by 5' long by ½" thick to set the equipment on as the display area was grass, and it had rained the night before. These were provided by the U.S. NAVY, and the team built the temporary EOC facility around several of the pads. The team also had two pop-up tents which had been provided by the NPS Public

Relations department which were festooned with NPS logos. The two tents provided a visual draw to the experiment and shelter from the elements. Two foldable tables and several folding chairs were also set up which provided a good work space for the weekend's activities and a reasonably comfortable EOC. Once the pads, tables, and tents were setup, the team unpacked all the gear and setup the Solar Stik, then the EOC in a box, and finally connected the Harris BGAN unit to the Cisco WRT400N WAN port. The generator was also setup and connected to the 120V AC input of the Solar Stik inverter should the need arise to supplement power due to weather or environmental conditions. All of the travel cases, which the equipment ships in were integrated into the display and acted as platforms for the BGANS and other equipment. Physical deployment, connection of components and acquisition of the satellite via the BGAN unit took approximately two hours. A Samsung Zero Client, a small Netbook, and a Android OS based Motorola Smart Phone were being used as client devices.

As in the previous experiments, the order of operations was to deploy the three systems in order of power, communications, and lastly the EOC in a box. The Solar Stik proved to be the most complex to setup as the team soon realized that with all the component configuration options, care must be taken to ensure the correct pieces are tied together. Additionally, the team discovered that either wind or Hydrogen could be connected to the storage, but not both at the same time. This had not been apparent at experiments one, two, and three as the PATROL Pak was being used alternately to power the Rajant

and Redline products and then provide additional charging capabilities to the Solar Stik power and expander paks. The team, on advice from Jonathan Tighe, determined that the optimal configuration was to connect the Hydrogen Fuel Cell when there was little or no wind, and to connect the wind generator when sufficient wind existed. This allowed for optimal charging as conditions warranted.

Once the system was up, a connection to the Internet was established via the BGAN. By following the manufacturer's manual aiming procedure, the BGAN unit successfully found the proper satellite, and then using the web browser interface on one of the client devices, successfully joined the network which provided the needed DNS and gateway services to the Cisco WRT200N. It should be noted that configuration of the Harris BGAN and authentication to the network could also have been performed using the Inmarsat provided BGAN Launchpad software.

This completed the power and WAN communications setup, and from that point forward, the virtual infrastructure was successfully able to access the Internet either through a wireless connection to the Cisco WRT200N or hard wired to the Cisco SGE2000P Ethernet switch. This was the first completely successful test of the base power and communications set of the HFN and EOC in a box integration and was repeated on Saturday and Sunday with increasing levels of success, particularly with power management. What were not tested in this deployment were the Monterey County VSAT trailers, which were still non-operational, the Rajant Wi-Fi mesh system, and the Redline 802.16 Wi-MAX

system. Future testing in early 2012, beyond the time frame of this thesis, will include integration testing with those devices, and the results of those will be part of the final deliverables to the sponsor. It should be noted that one Monterey County VSAT trailer was now fully operational and will be used.

When the system was first setup, there were additional components being added to the power system, which had not been anticipated. The CENETIX team had anticipated being provided with power, yet none was available at the location of the Marina Green the two teams were occupying. So, the offer was made to add the CENETIX equipment to the Solar Stik system, and this decision proved to be one which clearly overtaxed not only the capabilities of the Solar Stik, but of the generator as well. The equipment that CENTIX were attempting to use included two dual display computer systems, which were quite old. There exact configuration and age is not known, nor was the HFN team able to capture power usage of the two systems as they were not plugged into the Raritan PDU. What is known is that as soon as the CENETIX equipment booted, the generator went to full power, revving the engine to its maximum revolutions per minute (RPM) and maximum output capacity. Additionally, the Solar Stik immediately went into a discharge rate which could not be compensated for by the Hydrogen Fuel Cell. Suffice it to say that the equipment the CENETEX team brought was not designed to operate in a resource constrained environment, and immediate action was taken to find shore power.

With the CENETIX team on their own for power, further investigation of the Solar Stik inverter by Jonathan Tighe revealed several configuration and setting issues, as well as battery best practice procedures which the research team was not aware of. These are captured in Table 5.

Table 5. Solar Stik Remedies

<b>Component</b>	<b>Problem Discovered</b>	<b>Remedy/Solution</b>
Expander Pak	Improper storage after use and failure to condition	Expander Pak taken to hotel and fully charged over night
PRO-Verter 1600 APM	Improper settings for voltage, charge rate, and load	Load, shore power, storage capacity, and other settings changed to match current configuration of system
Power Pak 100	Improper storage after use and failure to condition	Power Pak 100 taken to hotel and fully charged over night

Failure to fully charge the batteries after each deployment, failure to condition the batteries per the manufacturer's guidelines, and failure to set the PRO-Verter properly could have and still may lead to premature

battery failure, reduced storage capacity, and ultimately failure of the entire system short of its expected life span. At the end of the day on Friday, it was determined that the storage and inverter systems needed to go to the "shop" in this case, the hotel, so that Jonathan Tighe could condition and charge the batteries, and adjust the settings of the PRO-Verter to match the inputs and storage that the system was equipped with.

At the end of the day, the system was shutdown using the automated procedure, and partially moved to a location inside a neighboring tent which was set up by the Marine Mobile Field Hospital team. This took roughly an hour, and the NPS pop up tents were lowered to cover the gear which was left behind, and the batteries and inverter were taken to the hotel for proper conditioning, charging, and configuration.

On Saturday, the team returned to the Marina Green with the batteries and inverter, stood up the tents, recovered the equipment from the hospital tent, and had the system up and running in less than 1 hour. It was never necessary to connect the generator to the system from that point forward, and the Power IQ software indicated that the system was drawing an average of 238 watts of power.

At the end of the event on Sunday, the equipment was shut down and stowed per the procedures developed over the first experiment cycles, and loaded into the truck for transport back to NPS. This process took just under one hour and the team overheard representatives of the Red Cross question where the NPS team's equipment disappeared too so quickly. Validation of the ability to move into an

area quickly, setup the system, and leave in a similarly expeditious fashion was starting to appear plausible. Quite by accident, the configuration of the IPC3 equipment fits the truck cargo bed perfectly. Additionally, towing the VSAT trailers is also easily accomplished using the truck which is considered to be a medium duty vehicle with a 5000lb towing capacity. (Honda, 2011)

#### **D. RESULTS-REMEDIES, EXPERIMENT FIVE**

The next test of the system was also an opportunity to showcase research activities being done at NPS. Since the presentation to the visiting dignitaries was not too far from where the IPC3 system was being stored, configured, and tested, the opportunity to use the system to deliver the presentation to the visitors seemed a valid test of the system. At approximately 0830 on October 13, 2011, the team moved a sub-set of the system, minus the generator, BreadCrumb, and Wi-MAX equipment to the quad area in front of Glasgow Hall. Once again, the team was able to get the entire system up and running in less than 2 hours. These included complete power, communications via a BGAN, and the EOC in a box with the wireless router WAN port connected to the BGAN, and establish a wireless cloud and Internet connection. Weather was partially cloudy with a slight breeze and near 70°, but there was sufficient cooperation from the sun and wind that the Honda generator was not needed.

As the storage system of the power system had been properly tended to after experiment four, the battery and expander paks were fully charged, and the system had an average draw of 229.0 Watts. The reduction from the



numbers seen at Experiments one thru four is from a decrease in external devices such as laptops, zero clients, and the Rajant BreadCrumb and Redline Wi-MAX equipment. For example, Experiments two and three saw average Watts of 259.56 and 267.188, respectively, with several laptops, the wireless mesh, and the WAN radios all connected to the Solar Stik system.

The presentation went well with the laptop able to authenticate to the wireless network without issue, and after authenticating the user to the MC-EOC domain using the VMware View client and credentials from Microsoft's AD, the View menu displayed the list of available machines. The Windows 7 virtual machine was launched from the View menu and the desktop was available in less than thirty seconds. Microsoft Power Point was selected from the menu of applications, and loaded in approximately 1 second. The slide show was loaded in approximately 5 seconds after being selected. These numbers validate the V3 Systems vendor's claims in which shows PowerPoint opening in approximately one and one half seconds (V3 Systems, 2011):

At the start of the presentation, the audience was made aware of the presentation being delivered via the IPC3 system, and the quality of the presentation was mostly excellent. The transition between slides, many of which contained large, embedded photographs, was seamless with one exception where a delay of between ten and fifteen seconds occurred between slide changes. The network analysis tools necessary to analyze this phenomenon are part of the researcher's inventory, but were not available at the time of this experiment, but such interruptions can

be a problem at multiple layers of the OSI stack and/or devices such as hard disk caching, memory swapping, or transmission errors on the wired or wireless networks. Future analysis using tools such as the Wireshark protocol analyzer and dopplerVUE network management software will make capture and analysis of such anomalies possible, as well as identifying prevention and remediation steps. Tools available within the dopplerVUE suite include monitoring, packet capture and analysis, bandwidth usage, network maps, and more. (dopplerVUE, 2011) Of use in the delay issue discovered in experiment five diagnoses would be the aggregate bandwidth utilization and performance statistics capture.

Wireshark packet capture monitors active packets on the network. The capture can see Datagram Protocol (UDP) and NetBIOS Name Service (NBNS) traffic and the source and destination ports the traffic is coming from and being directed to for example. This information is useful in determining if there is any configuration or routing issue, or rogue traffic on the network which could cause performance problems or traffic delays, or be indicative of malware or virus activity on the network. (Wireshark, 2011)

After the presentation, the system was again dismantled and returned to storage where the battery and expander paks were again connected to the PRO-Verter and allowed to charge. The dismantling process took a little over 1 hour, not including re-setting and connecting the batteries for the charging cycle, and the team felt this was a repeatable time for future deployments of the system. The team also was gaining confidence in the networking and

virtual machine management, as the startup and shutdown procedures performed as well as they did in experiment five at Fleet Week.

#### **E. RESULTS-REMEDIES, EXPERIMENT SIX**

The final experiment allowable within the time available was similar to experiment five in that it took place on the NPS campus, and was an opportunity to deploy the system without transporting it, and the team could take advantage of the proximity of the event to the Virtualization and Cloud Computing lab in room 204A of Root Hall to bring additional items as needed to the experiment site. It was also the first time which the equipment could be setup inside a building, and be powered by the grid. It had been established in Experiments 2-5 that the EOC in a box was able to integrate with the HFN power and communications systems, so a sub-set of the Solar Stik was brought to the experiment site, but was used as a static display rather than to actually power the system. The dependent variable for this exercise was going to be the Harris BGAN's ability to connect to a satellite when it was surrounded by the Herrmann Hall compound and with its 5 floors and peaked Spanish tile roof.

As with Experiments four and five, the setup of the equipment in Herrmann Hall took under two hours, and the server, a MacBook Pro laptop, a Samsung zero client, and a Motorola Smart phone with docking station were setup as clients. Following the lessons learned in the first 5 experiments, the Solar Stik was assembled, the BGAN setup on the patio directly outside the experiment location, and the EOC in a box setup, plugged into power, and started.

Once the VMware infrastructure was up and running, an effort to connect the Harris BGAN to a satellite began, and the results were successful. The Harris BGAN joined the network successfully using the MacBook Pro and a web browser, and the IPC3 system was 100% operational with Samsung zero client, MacBook Pro, and Motorola phone all able to run a Windows 7 or Windows XP virtual machine and connect to and browse the Internet. The ease with which the Harris BGAN was able to acquire a satellite was surprising due to the nature of the surrounding buildings. The location of the satellite was higher than expected relative to the horizon, and that also was a surprise to the research team.

Since the IPC3 system was not fully deployed regarding power and communications systems, and was running on shore power, the average power consumption was expected to be different than in the previous experiments. In experiment five for example, the Solar Stik system did not support any client devices, and the only communications piece was the Harris BGAN unit. Experiment six was supporting three client devices connected via a surge protector connected to the APC UPS, so slightly higher average watts utilization was expected. The average Watts was 235.3, up slightly from the 229.0 Watt average of experiment five, so there was only an additional 5.7 Watts of load produced by the three client devices.

For approximately two hours, the team entertained questions from the Chamber of Commerce members and NPS administrators, demonstrated the performance of the virtual machines, and described the capabilities of the individual

components. Performance of the virtual machines was the same as during experiment five with all the applications loading and performing at the levels stated by V3 Systems. At the end of the evening, the system was shutdown, disassembled, and loaded into the truck for easier stowing the following day.

## **F. CONCLUSIONS**

### **1. Research Findings**

1. *How will the existing independent power sources and communications channels of the HFN support the proposed VDI system?*

The IPC3 system has been field tested at six separate experiments, and improvements to the original configuration and architecture in each successive experiment have shown that in many use cases such as Hurricane Katrina and Haiti, Integration of Virtual Machine Technologies into Hastily Formed Networks in Support of HA/DR missions is both possible and feasible. Performance of the IPC3 system of systems as currently configured is exceptional regarding power consumption, communications capabilities, and EOC in a box virtual machine performance. Additionally the ability to be device and OS agnostic regarding client devices used to access the latter two systems is also good.

2. *What communications and power technologies are required to provide adequate bandwidth, network security, and power, and does the current HFN design provide those?*

While the inability of the team to bring a VSAT trailer into a working configuration was a disappointment, it is clear that the limited bandwidth provided by the BGAN systems is inadequate for remotely accessing a VDI delivered desktop. However, while accessing localized machines and applications, the system performed exceptionally well, and the virtual machines provided better performance than the laptops and smart phones being used by the first responders. As such, this question is not fully addressed, and will need to be re-evaluated in future research when a VSAT is available.

Once the power system was understood and properly tended to, the generator no longer was required. This condition remained constant for experiments four through six where the generator was never needed. However, it is expected to need the generator for times when the system needs to run 24 X 7 or when the weather is less cooperative than it was for the experiments.

Network security is addressed by the BGAN units as well as the BreadCrumb units. Additional security is available in the Cisco switch and router, which supports and works in conjunction with the security of the BGAN and BreadCrumb devices. All systems have upgradable firmware, which allows for new security protocols and capabilities to be added as they become available.

3. *What other communications and power capabilities are available to the HFN team?*

Several systems were used during the exercises, which went beyond the capabilities of the original field experiments. These included using SKYPE which is a commercially available chat program with video capabilities that also can make IP based phone calls. (Skype, 2011) Kinetic and solar power systems were tested from Goal Zero including a Sherpa 50 and Guide10 (Goal Zero, 2011) systems and nPower PEG (nPower PEG, 2011) to power personal phones, iPads and laptop computers. No formal methods were used to evaluate these tools; rather they were made available to the first responders to simply see what COTS products were available and how they could be used. Successful charging of several devices with the Goal Zero and nPower products did support the proof of concept and indicated that these two devices were promising. Future experimentation in early 2012 will have a more structured evaluation and measurement procedure in place to properly evaluate these devices.

The IPC3 system has been field tested at six separate experiments, and improvements to the original configuration and architecture in each successive experiment have shown that in many use cases such as Katrina and Haiti, Integration of Virtual Machine Technologies into Hastily Formed Networks in Support of HA/DR missions is both possible and feasible. This success is not without its caveats and restrictions, which have been determined by constraints in transportation restrictions, and on power

requirements of certain components which are identified as dependent variables below along with Independent variables.

#### Dependent variables

- System run-time
- Bandwidth
- Number of Supported Users
- System weight
- System Set-up Complexity
- System Operation-Management Complexity

#### Independent variables

- Battery storage capacity
- Generator capacity
- Solar generation capacity
- Power load
- Weather Conditions

Effectiveness is also exceptional with regard to the ability of the system to be transported in a ground vehicle such as the Honda Ridgeline truck which easily carried all the HFN gear, the EOC in a box, and tables, chairs, and personal luggage to experiment four, and is capable of towing one of the Monterey County VSAT trailers while providing transportation and shelter for the driver and one passenger; a team sufficient to unload, setup, and manage the complete HFN. Effectiveness is also exceptional regarding interoperability with the Harris BGAN communications system, the Cisco wireless cloud, and the Solar Stik power system.



As configured, the IPC3 HFN architecture provided a new model which can be successfully deployed in Humanitarian Assistance/Disaster Recovery (HA/DR) scenarios. However, all of these favorable results, defined as Measures of Performance (MOP) and Measures of Effectiveness (MOE) have been performed without the Coraid SAN, in good weather conditions, and without integration of the Rajant Breadcrumb and Redline Wi-MAX products. Further testing will occur with those technologies in the upcoming 2012 field exercise. Results from those exercises are sure to identify additional design considerations before a complete and successful integration into the new HFN architecture can occur.

With the Coraid SAN incorporated into the system, various MOE and MOP will be impacted either negatively or positively. Two immediately identifiable negative impacts are system weight and power consumption/run time. System weight will see an increase of 55 lbs. or almost 30% and power consumption will increase 640 watts, or almost a 300% increase in power consumption and beyond the capabilities of the Solar Stick will be injected. The positive impact is that the CORAD SAN, as ordered, will provide for an additional storage capability of almost 12 TB of mixed SDD and traditional disk drive storage. The additional storage allows for one or more large databases, which can be used to access existing data, collect, store, and analyze new data, and provide backup for the data stored on the SDD drives located within the V3 Strato 100 chassis. What it also does is require shore power for the EOC in a box, and additional personnel to load and unload it from a vehicle.

Integration of the Rajant and Redline technologies will also have the potential to increase complexity of the system setup and management. The Rajant products have system capabilities and offer services which are already being provided by the Cisco WRT200N such as DHCP, DNS, and a secure wireless cloud. Proper configuration of these components will be necessary to ensure the proper services are provided by the proper devices. These concerns will be addressed in the future experiments.

Table 6 summarizes the MOE and MOP used to determine the feasibility of incorporating virtualization technology into the existing HFN architecture, and provides a rating of favorable or unfavorable designated as a ++, --, or Not Yet Tested (NYT) and a brief note to the total effectiveness and applicability of the new HFN architecture and capabilities.

What is clear from this research is that depending on the nature and location of the mission the HFN is being sent to, available transportation, surviving infrastructure, and needs of the team being deployed, the new HFN model with the inclusion of the EOC in a box may or may not be an asset which the response team can benefit from.

Table 6. MOE, MOP, RATING

Independent Variable	Rating	Note
System run-time without Coraid SAN	++	Assumes suitable weather conditions, generator required in inclement weather
System run-time with Coraid SAN	NYT	Assumes suitable weather conditions, generator required in inclement weather
Bandwidth, BGAN	--	BGAN does not provide sufficient bandwidth for multiple users
Bandwidth, VSAT	NYT	Unknown, but specifications suggest favorable results
Number of supported Users, maximum of 50	++	Wired and wireless networks provide sufficient speed and bandwidth to support 50 LAN users.
System Weight	--	Not able to fly-away via commercial airliner
Setup complexity	++	Reasonable with provided instruction set
Operation-Management Complexity	++	Reasonable with provided instruction set

## **G. FUTURE RESEARCH**

Work on the IPC3 project is ongoing, and does not stop with the publication of this thesis. Additional field testing which will include the CORAD SAN is scheduled for early 2012. The results of this thesis will be incorporated with the additional results from the future experiments, and additional determinations can be made on the applicability of the Coraid SAN. Additionally, there are several EOC applications which will be tested with the system which require the capabilities that the Coraid SAN provides. These will include an application called WebEOC which is an incident management/situational awareness application which is the package of choice of the Monterey County Emergency Operations Center, and is available as a locally hosted application; it is hoped that WebEOC will be loaded onto the EOC in a box in time for the next exercises. System requirements for the WebEOC software include a web server, database server, each with four gigabytes of ram, and multiple disk drives. (WebEOC Professional, 2011) The software can be run in a virtual environment, so it looks like a good candidate as a hosted application for the EOC in a box.

Additionally, future research will allow for further development and refinement of the EOC in a box model. One hoped for outcome would be to reduce the size and weight of the EOC in a box system to a total system weight of 100 lbs. or less, allowing it to be transported on a commercial airliner along with the power and communications components of the IPC3 system or systems.

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