Satellite Communications Requirements for a Dual Use Disaster Management Ka Band Network

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Late in 2003 we had the opportunity to work closely with a number of small communities affected by the devastating wildfires that hit San Diego county during that time. We were struck by the fact that these communities faced a very complex logistical problem, namely the near-simultaneous rebuilding of around 90% of the buildings in town, owned by a large number of individuals with no formal connection other than being residents of the same community. Traditional disaster relief responders address safety and financial issues, but offer little logistical assistance. In this paper we apply the same requirements analysis one would use for a logistics problem of this type were it part of a commercial or government project. We present a generic system design and requirements for this system as well as the communications links supporting the system. We show that current low-cost satellite links can meet some – but not all – requirements, and that recent advances in satellite and ground systems technology suggest that in the near future satellite links will be able to support the stated requirements at acceptable cost. A prototype implementation of the system described in this paper is in progress.

I. Introduction

This paper describes an innovative dual use network being proposed by the US Jaycees for disaster management and educational purposes. In the current climate of heightened homeland security preparedness, it has become clear that many communities are ill-equipped to recover from natural or man-made disasters, such as fires, earthquakes, landslides or acts of terrorism. Emergency responders and local, state, and federal government agencies have – to varying degrees – information technology systems to support their respective missions. However, most communities do not have access to equivalent resources to assist community members during the recovery and rebuilding process.

The network being constructed, dubbed ACTS 250, is composed of two network control centers, a large number of local community response centers, and a smaller number of mobile response centers. Both community and

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mobile response center are two-way high bandwidth stations deployed within the 50 states. Communities everywhere have of course had to contend with the aftermaths of various disasters for a long time. It seems appropriate, however, that the same Information Technology capabilities we use in business and government settings should also be available to the victims of these disasters to ease the recovery process and to lower the cost of recovery to the affected residents.

To insure that the network is always fully operational, and to justify the cost involved in keeping the network resources deployed, ACTS 250 is designed as a dual-use network. When the network is not required for disaster management, it is used to distribute science education material to local school systems. Sources of the curriculum material to be distributed include energy usage data from around the world, access to marine biology research stations in the Galapagos islands, as well as other unique content being developed at Ohio University and San Diego State University.

Satellite communications are required in this network to support the acquisition of real-time and archived educational content, to support the mobile response centers, and to support community response centers where terrestrial facilities are damaged, overloaded, or inadequate for the deployed applications. Many of the satellite communications applications in the network are based on systems that were developed and tested using the NASA ACTS Ka band system over the past 10 years.

In section II of the paper we first detail requirements for the Community Response Centers (CRCs) and the services that must be provided by the Network Control Centers (NCCs). Section III adds the unique requirements imposed by the dual-use design of the network. Section IV details the services that a CRC can provide as a function of its communications facilities. Sections V and VI describe the capabilities of satellite and ground systems that have been developed over the past decade. It is our expectation that commercial satellite systems of the future will need to be highly flexible, up to the point of permitting the on-demand reconfiguration of the communications payload. Section VII describes the changes that this type of system will require in the interaction between customer and satellite control personnel.

Section VIII closes the paper by describing one possible system design that meets some (but not all) of the requirements outlined in this paper.

II. General System Requirements

The response to a localized disaster can be divided into three distinct phases:

First Response: During and immediately after the disaster, the focus is on emergency response, including police, fire, and medical services, as well as relocation of evacuees into emergency shelters.

Disaster Aid: After the immediate danger has been removed, and residents start to return to the disaster site, both federal and state emergency assistance teams are deployed to arrange short-term financial assistance and to help residents file the paperwork required to obtain long-term assistance.

Rebuilding: Residents of the affected communities typically face a rebuilding period of 18 to 36 months. During this time, little organized assistance is generally available. It is this period of time the Community Response Network proposed in this paper is meant to address. This distinction is important in that it suggests that this network needs to emphasize flexibility and long-term usability over rapid-deploy features.

The community response network must give users the following capabilities:

1. Permit access to information that may aid individuals in their rebuilding efforts, even if these individuals have not yet recovered their ability to consistently access the Internet and related resources.
2. Permit the formation of community-wide groups able to organize and coordinate the rebuilding effort when a large number of individuals are affected. For example, debris removal and inspection of foundation slabs in a community hit by fires or storms may be more cost effective if neighboring property owners can coordinate their contracts with demolition teams.
3. Permit access to and consultation with outside experts. If a large number of buildings are destroyed in a small geographic area, local building resources such as architects, contractors, craftsmen, and other specialists will be insufficient. Supplies of building materials will be scarce with commensurate increases in prices. Residents will be well served by the ability to contact experts and suppliers nation-wide to supplement local expertise, help evaluate contractors who are offering their services, but who are not known to the local community, and to arrange for coordinated shipments of materials.

We map these capabilities into a number of system requirements for the community response network; in the list below, requirements for the Community Response Centers and Mobile Response Centers are labeled as CRC-n, while requirements for the Network Control Center are labeled NCC-n.

CRC-1: The CRC must be equipped with computer workstations, phone, fax, and printing capabilities. This facility must be self-contained (e.g. in an office trailer) and capable of connecting to the local communications infrastructure, as well as provide its own communications links if local communications are unavailable.

CRC-2: The CRC must be able to remain in place for 12-18 months, requiring that provisions for on-site maintenance and replacement of equipment are in place.

CRC-2a: To support requirement CRC-2, the CRC must be able to re-install the operating system and application software on all local workstations from storage on a local server, possibly under control of the NCC.

CRC-3: The CRC must provide user assistance and security (for equipment and users) for extended hours to allow users to work at the site after working hours and on weekends. Due to the long duration of deployment, security, user support, and maintenance must be provided by local personnel employed by the Community Response Network.

CRC-3a: To support requirement CRC-3, all network setup (both connection to terrestrial lines as well as satellite connections) must be automated.

CRC-3b: To support requirement CRC-3, a local server in the CRC should collect diagnostic information on both the network and the CRC equipment. This server must be accessible to the NCC via the normal network connection as well as over a dedicated dial-up port.

CRC-4: The CRC needs to permit remote consultation with experts via video and shared document space. While two-way video is desirable, only in-bound video (from the expert to the local user) is a requirement in all but the most restricted environments. Two-way interactive sharing of documents is required.

CRC-5: To accommodate a reasonable number of users and a variety of network connections, a local proxy/cache/policy server must be able to store frequently used information on-site, prioritize requests, and enforce a site policy on which information can be accessed.

NCC-1: The NCC must provide e-mail, text messaging (asynchronous and synchronous), and an electronic collaboration workspace in which community members can jointly develop planning documents.

NCC-2: The NCC must contract with subject experts during a disaster recovery deployment; these experts can be on-site at the NCC or available for consultation via video link.

NCC-3: The NCC must deploy a flexible document management and database system that can be populated for a given deployment. It must be possible to "push" relevant content to the local storage at the CRCs.

NCC-4: The NCC must monitor all systems at all deployed CRCs, and respond proactively to problems.

III. Specific Requirements for Dual Use

Historically, disaster response networks have been government (federal or state) owned. This is at least in part driven by the expense associated with maintaining the needed equipment in the face of (hopefully) very low utilization. For a privately funded response network this is an undesirable situation; the communities raising the funds to maintain the equipment should see a continuous return for that investment.

The equipment in the network we are describing here will be used for educational purposes when it is not needed for a disaster response. Several factors make this a good choice for a dual-use configuration:

- The information retrieval and collaborative workspace capabilities of the network are suitable for use in specialized subjects such as ecology, energy use, and international affairs, where the interaction with people and data located in a variety of locations is useful.
- The equipment is specialized for collaboration, audio/video interaction, and information retrieval; the equipment in many schools would not be able to duplicate these functions.
- Since the equipment is self-contained in its own temporary building, the presence or absence of this structure does not adversely affect normal school operations.

The dual-use of the equipment in the CRC places a few additional requirements on the system; however, most of them can be met with the systems and procedures needed to fulfill the requirements developed in the previous section:

1. All storage devices must be carefully re-initialized after a deployment in a disaster response role, to prevent personal information (which a resident may have inadvertently stored on one of the systems) from being found by the student users.
2. The system must have access controls that permit the school to duplicate its web access policies on the dual-use equipment.
3. The system must contain the capability (e.g. via automated network renumbering) to integrate easily into an existing school network.

Since we already required that the CRC has to be self-contained for its disaster-relief application, there is a great deal of flexibility in its placement for educational use. While many school systems will co-locate the CRC near a school building, there will be instances when placement at a more remote site will be desirable. For instance, a school system may chose a site relevant to a field experience or a community service project. The availability of integrated satellite communications with the equipment allows these placements without regard to local communications systems.

IV. Satellite Communications Requirements

Satellite communications between the on-site facility and the central response center have to support all system requirements, at least to some degree, since the satellite link may be the only connection for the site immediately after the disaster. Recognizing that cost and availability of satellite services will differ from case to case, we design for three different classes of service, which we call minimal, moderate, and optimal. The minimal case is roughly equivalent to dial-up, the moderate case mirrors low-end DSL, while the optimal case is equivalent to terrestrial T1 service.

Applications Supported vs. Available Network Service

	Minimal	Moderate	Optimal
Uplink from on-site facility	64kbps	128kbps	512kbps-1Mbps
Downlink to on-site facility	64kbps	512kbps	1.5Mbps
Voice Support	High compression, low quality codec, e.g. GSM, ITU G.729 1-2 connections	3-4 highly compressed connections, or 1 higher quality connection, e.g. G.711	Multiple low quality or a few high quality connections
Web access	Restricted to sites prepared by the NCC, uses a local cache and proxy.	Restricted to sites prepared by the NCC, uses a local cache and proxy.	Generally unrestricted.
Mail Access	Text-only mail, restricted to mail services provided by the NCC	Text-only mail, restricted to mail services provided by the NCC	Full mail access including free-mailers and ISP-provided mail.
Text Messaging	NCC provided, no file attachments.	NCC provided, no file attachments.	NCC provided, file attachments enabled.
Video	None	Inbound only, using ITU H.263 or MPEG-4	Interactive (two-way) video using H.263 or MPEG-4, high-quality (MPEG-1) inbound video.

Table 1
A comparison of applications that can be provided at various levels of network service.

The minimal configuration will in practice prove too restrictive to be of long-term use. The “moderate” configuration is in line with commercially available residential and small-office systems, and provides adequate service for the short term. It is clearly desirable to configure the CRCs in the “optimal” configuration whenever possible, especially if the satellite connection is the only available link for the long term. This is especially true for the mobile CRCs which will typically be deployed in remote areas, possibly even outside the US during the collection of educational materials. Today, the “optimal” connectivity will often not be economical for a community funded network. Fortunately, advances in both satellite systems and ground equipment promise to change this situation.

V. Advances in Satellite Systems

The Advanced Communications Technology Satellite (ACTS) has served as a national testbed since 1993, to validate and demonstrate technologies that are just now coming into commercial use. Although it is a US Government experimental satellite, ACTS used the commercial portion of the Ka band spectrum to encourage experiments for commercial sector applications. Ka band systems are now recognized for the inherent advantages that lead to higher throughput capacity per pound in orbit. The concept of a high gain, multiple hopping beam antenna system as demonstrated by ACTS has now become essential technology in the new generation of satellite systems using small inexpensive terminals. ACTS also flew an on-board digital processor, making full use of the hopping spot beams to enable bandwidth on demand and full mesh networking. Regenerative processing payloads, conceptually similar to ACTS, are now being implemented for point-to-point communications directly through the satellite, without the need for a large ground station as a central hub. ACTS implemented one of the uplink/downlink hopping beams as a one meter mechanically-steered dish antenna to allow locating a small terminal anywhere in the visible hemisphere. This enabled experiments and demonstrations such as interactive distance learning from Antarctica to the Arctic circle and tracking of airborne and shipboard terminals. ACTS also addressed Ka band rain fade issues by validating compensation techniques and collecting and evaluating propagation data over all the US rain zones. This should allow current system designers to better predict quality availability for the new services in the US.

VI. Advances in Ground Stations

Traditionally, communications via satellite has required the use of high power amplifiers and large antennas and therefore has been the purview of common carriers. In the last ten years or so, this has given way to smaller user terminals (VSAT's) that have provided the equivalent of voice telephone services in private networks used mostly for commercial applications, such as point of sale, for credit verification, inventory control and similar business applications. These Very Small Aperture Terminals have been typically fixed in a given location, equipped with antennas larger than one meter in diameter, and unsuitable for mobile applications requiring quick deployment.

NASA's Advanced Communications Technology Satellite (ACTS) demonstrated the use of Ka Band ultra-small aperture terminals (USAT's) equipped with solid state output stages, antennas of about 45 centimeters and capable of much higher data rates, making possible their consideration for mobile satellite services.

USAT's are now being built in volume for the provision of fixed user premises services not only for business but also for personal use. These terminals, capable of uplinks up to 256 kbps, are being built in large quantities (tens of thousands), are scheduled for deployment in the very near future and have the capability to make communications by satellite ubiquitous and inexpensive.

Higher data rate terminals, intended for specific applications such as gateways, are available at a much higher cost, due to the much higher cost of solid state amplifiers rated over 1 to 2 watts.

These USAT's are also being used for mobile applications, using steerable antennas and, in few cases, phased array antennas.

At the present, phased array antennas capable of a few watts output are still quite expensive, so the most appropriate solution for terminals for disaster management seems to be a terminal equipped with a manually steerable, quickly deployable antenna and a solid state amplifier in the range of 1 to 2 watts. Flyaway terminals with quickly deployable antennas made up of multiple interlocking sections, with easily mounted Ku and Ka feeds, and mounted on a gimbaled base are available commercially and most suited to the service required by the CRCs.

VII. New Demands on Satellite Operators

The experience with the NASA ACTS satellite has shown the value of a satellite system which can be reconfigured dynamically to match system capacity to end-user demand. In the case of ACTS the most dramatic example of this approach is the operation of the mechanically steered spot beam antenna. In this case the operations staff needs to configure the system (point the antenna in this case) based on a published schedule. Moreover, in many cases it is necessary to verify the final position of the antenna and to fine-tune the antenna pointing, a process that requires direct interaction between the customer and the system operator. This section outlines the requirements for operations of a "dynamic" satellite communication system.

Satellite operations requiring dynamic response to new situations and priorities will by their nature, incorporate planning for different levels of interaction with all members of the expanded service provider and customer community. This community has the potential to become more of a team than has been the case previously, as roles and responsibilities are reassigned.

A more dynamic system will transition quickly from routine background operations to special service requests with direct interaction between the end users and the satellite system controllers. This necessitates advanced planning to identify requirements, levels of interaction, means of interaction and clearly defined responsibilities for all involved parties.

A satellite system that can be reconfigured to meet changing needs will need to establish clear requirements for what aspects can be changed and under what circumstances these changes are most appropriate. All members of the control and user communities will need a good understanding of what the reconfigurations are and how they are implemented.

In order to support greater interaction it will be necessary to establish appropriate communications links between community members and rules governing when individual decision-makers must be contacted as different situations arise. Shared responsibilities for initiating communications can provide the most flexibility. For example, some situations may require that a conference call be established to link all relevant team members.

As a practical measure, the authority to initiate the conference call should be distributed to permit those who are initially available to take immediate action as soon as the situation requires. This may seem obvious, but it is necessary to recognize that a satellite system will be in continuous operation and should not be constrained by the availability of team members due to the time of day, holidays, vacations, sickness, transportation problems and so on.

Levels of responsibility need to be standardized so that the severity of problems can be recognized and additional personnel and resources brought to bear. If for example, a satellite controller notices a performance anomaly, he would have the responsibility to assess the problem and attempt a first level response. If this initial response is not immediately effective, the controller would be obligated to raise this problem with a technical supervisor. If the technical supervisor determines that the problem is of a more serious nature, the supervisor would immediately contact the customer and establish a conference call among relevant team members. Under some circumstances it may make sense for the controller to initiate contact with the customer in parallel with notification of other system personnel.

As the control and user communities become more interactive, the need for cross training and redundancy of capability will need to increase. Control staffing and capabilities will be allocated to assure consistent levels of performance and readiness to respond to customers. The system controllers will need to be cognizant of customer service concerns, as they will be dealing with the end users directly. The end users will also need to be more aware of technical aspects of system performance so as to have useful discussions with the system controllers. Rules for initiating changes to the system configuration must be understood by all parties. With distributed system resources and team members, the coordination between multiple control and user sites is essential.

The key to establishing dynamic satellite system operations will be to focus on detailed coordination through regular communications between the control and user communities. Carefully planned daily interactions will increase the sense of common purpose and lead to a shared responsibility to achieve optimal system performance.

VIII. Conclusion

In this paper we have made an attempt to apply the same work-flow and information management techniques commonly used in business applications, and apply them to the needs of a region recovering from the impact of a disaster. We have shown a general set of requirements on the support systems and communications links.

Our analysis also suggests that current satellite services can satisfy some of these requirements in a cost-effective way, and we argue that the next class of satellite services will be able to fully support all requirements at an acceptable cost.

The requirements analysis for this paper was based on first-hand observations and interviews in the San Diego area, following the wildfires in late 2003. Ohio University and Ecosage Corporation designed a prototype system that could be used to provide recovery support in this area[‡]. The back-office systems are fully implemented using open-source applications running on Mac OS X Server and FreeBSD. We are currently testing network management and monitoring procedures. Tests of the prototype using a simulated CRC environment, commercially available residential satellite internet service, and H.323 Voice over IP and video systems are planned for the near future.

[‡] No decision has been made at this time to actually deploy the prototype.

Acknowledgments

We want to thank NASA Headquarters, the NASA Glenn Research Center, Lockheed Martin, the Naval Postgraduate School, the Air Force Research Lab in Rome, NY, and Mr. John Graham for their support during various tests and prototyping operations.