Rapidly-Deployable Broadband Wireless Networks for Disaster and Emergency Response*

Scott F. Midkiff and Charles W. Bostian
Center for Wireless Telecommunications
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061 USA
{midkiff, bostian}@vt.edu

Abstract

Researchers at Virginia Tech's Center for Wireless Telecommunications are investigating a rapidly-deployable broadband wireless communications system for disaster and emergency response. Our goal is to provide a 120-Mbps backbone network to connect a hub and up to eight field units that can be operational within a matter of hours and can support a diverse set of applications. We describe the need for such a system for disaster and emergency response, the current environment for investigating and deploying broadband wireless systems for this purpose, and the philosophy that is guiding our research. We describe our technical approach including, what we believe, are important innovations for advancing communications capabilities for disaster and emergency response. We also describe demonstrations of an early prototype system.

1. Introduction

Like most workers in government and industry, responders to disasters and other emergencies are becoming increasingly reliant on information technology. However, in the hours and even days following an event, communication is often limited because existing infrastructure was destroyed or the event occurred in an area without infrastructure. Voice service may be severely restricted. Further, it is often impossible to access remote databases, use web sites and web-based applications, and communicate with agency headquarters and other field command centers, for example using video conferencing and other collaborative tools. We and others believe that such capabilities can significantly improve the safety of responders and the effectiveness of the response.

To address this need, researchers at Virginia Tech's Center for Wireless Telecommunications (CWT), in collaboration with industry partner SAIC and with funding from the National Science Foundation’s Digital Government program, are investigating a rapidly-deployable wireless communications system for disaster and emergency response [1, 2]. Our goal is to provide a 120-Mbps backbone network to link a hub and up to eight field units. The hub can connect to existing network infrastructure or use a satellite earth station to provide connectivity to a global network, or the system can be used to provide connectivity only within the disaster area. The field units provide generic 100-Mbps Ethernet access to network devices and can be extended through wireless and/or wired local area networks at remote sites. Using virtual private networks, security can be provided just over the wireless backbone or from users back to agency networks.

In addition to a high data rate, the system features three innovations to enable rapid deployment and robust operation. First, a Geographic Information System (GIS) based tool generates coverage estimates, or “viewsheds,” to evaluate options for initial placement of the hub and field

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units [3]. Second, a unique, low-cost broadband channel sounder is integrated into the hub and field units to allow "on-the-fly" channel measurements [4]. Information from the sounder can be used to optimize the final placement of the hub and field units. Used together, the GIS tool and the sounder enable the system to be quickly put in place without first conducting a time-consuming site survey. A third innovative feature of the system is an adaptive data link protocol that adjusts error coding and error recovery schemes during operation [5]. This proactive scheme utilizes sounder information to adjust link configuration based on observed channel conditions, thus making the system more robust to sub-optimal deployment and a changing environment.

The full system is currently under development. However, we have successfully demonstrated an early prototype system – two stations connected by a 10-Mbps link operating in the Local Multipoint Distribution Service (LMDS) band – to prove the basic concept, investigate integration with off-the-shelf networking equipment and Internet Protocol (IP) based applications, and collect feedback from potential users.

In Section 2 of this paper, we describe the need for a rapidly-deployed broadband wireless network and, in Section 3, we provide our opinions on the rapidly evolving environment for meeting this need. We indicate the philosophy that is guiding our work in Section 4 and describe our associated technical approach in Section 5. We briefly describe demonstrations of the early prototype system in Section 6 and provide a summary in Section 7.

2. The Need for Broadband Wireless in Disaster and Emergency Response

Broadband wireless connectivity can provide significant capabilities at a disaster or emergency site to increase the safety of the responders and to increase the effectiveness of the response. A number of related factors are increasing the need for high data rate network connectivity for disaster and emergency response. We briefly summarize these factors below and provide further details about key drivers for broadband wireless.

- The disaster and emergency management community has, over time, developed effective processes to respond to crises. An Incident Command System (ICS), customized to the scale and nature of the event, is used by federal, state, and local agencies responding to a crisis. As discussed in Section 2.1, this process should be enabled by an underlying information technology (IT) infrastructure and, we believe, high data rate networking can be utilized to significantly improve the enactment of the ICS.
- Existing communications support is focused on voice. Land mobile radio (LMR) systems can provide local and regional connectivity, while cellular telephone systems can provide national connectivity. However, data connectivity is becoming increasingly important as part of the IT infrastructure required for the ICS.
- Communications is required locally within the disaster site, within the local region, and nationally (or even globally in some cases). Thus, there is a need for at least three tiers of communications infrastructure: (i) local connectivity, e.g., using wired and wireless local area network (LAN) technology; (ii) backbone or backhaul connectivity, which is the focus of our work; (iii) and wide area network (WAN) connectivity in the form of the global Internet or a private network. The backbone network may connect directly to the WAN or a fourth component – realized using satellite communications or terrestrial wireless – may be needed to connect the backbone to the WAN.
- Responders cannot rely solely on the public communications infrastructure. It may be destroyed or largely destroyed by the disaster, it may be non-existent as is the case in many rural areas, or it may be saturated by public safety users, the press, and others.

- There is an increasing need for interoperability to support multi-agency response. Large scale disasters require response by agencies in adjoining jurisdictions. Many incidents also require the involvement of multiple federal, state, and local agencies with different charters. The lack of interoperability is most evident today with LMR systems where, for example, fire fighters from one city cannot communicate directly with fire fighters from an adjoining city who are trying to assist.
- The communications infrastructure must be flexible to satisfy a variety of situations. Different locations and different types of emergencies and disasters may require use of different applications, connectivity for different types of end-user equipment, support for different types of users, operation in different environments, etc.

Clearly, all equipment used for emergency and disaster response must be rugged to survive transport and harsh conditions and easy to use by responders who need technology to be "transparent" so that they may focus on life-critical tasks. It is also important to note that responders are focused on their immediate and critical mission. Technology that shows clear, immediate, and significant benefits will likely be adopted. Technology that is confusing, ineffective, or requires significant training will likely be ignored.

2.1. System Needs for Incident Response

Six key elements are needed for incident response as part of the ICS [6]:

1. Status, to develop a common operational picture for decision makers;
2. Collaboration, to enable collaborative decision-making;
3. Plans, to allow situation-dependent planning;
4. Tasks, to enact procedures and ensure completion through checklists;
5. Resources, including accounting for and tracking for resources; and
6. Documentation, in the form of records and logs.

These elements can be enabled by various components of an IT infrastructure. This infrastructure must include integrated computers and communications, must be rapidly deployed to the field, and must tightly integrate plans, resources, and management. Table 1 lists the six elements, critical functions needed to provide the incident response element, and IT tools that can potentially be used to enable those critical functions.

Table 1. Response Elements and Enabling Applications

Response Element	**Functional Needs and Examples of Enabling Applications**
Status	• Common operational awareness – streaming video from event site • News – streaming video to event site • Access to GIS and other databases – web and other client-server applications
Collaboration	• Collaborative and distributed decision-making – web-based and other tools, electronic mail, video conferencing, voice over IP, virtual private networks
Plans	• Access plans – web and other client-server applications • Real-time plan integration – web and other client-server applications • Automatic task event generation – web and other client-server applications
Tasks	• Entry, tracking, and updating of process tasks – web and other client-server applications
Resources	• Inventory management and accounting – web and other client-server applications
Documentation	• Document access and updating – web and other client-server • Automatic event recording – web and other client-server

2.2. The Role of Broadband Wireless Connectivity

Table 1 highlights the data-intensive applications that are necessary to fully realize elements of the ICS or that can substantially increase the effectiveness of those elements. In today's environment, responders are guaranteed few of the communications services that are necessary for the IT tools listed in Table 1. Voice service, perhaps limited, is common. Limited data connectivity, for electronic mail and slow web access, is often available, although often late in the response. Broadband network connectivity can support a much richer set of applications, such as electronic mail with large attachments, high-speed web access, voice over IP (VoIP), streaming and interactive video, interactive GIS access, and a variety of specialized client-server applications. Broadband wireless can provide the capacity needed for these applications and can be deployed in a rapid manner.

There is a recognized need for wireless communications, including high capacity wireless, for emergency management. The following is a quote from the Information Technology Architecture, Version 2.0, developed for the Federal Emergency Management Agency (FEMA) [7].

> *The FEMA IT Architecture calls for improved mobile and nomadic computing and communications (wireless) support for FEMA operations including: high-bandwidth deployable wireless communications in the field; increased use of existing networks; support for Personal Communications System (PCS) communications, messaging, and notification for the public and deployed FEMA Emergency Response Team (ERT) personnel; integration of Global Positioning System (GPS) with digital maps for inspections; increased utilization of wireless laptops and Personal Digital Assistants; improved support for digital photography and data transfer.*

This statement explicitly recognizes the need for "high-bandwidth deployable wireless communications in the field" and the cited applications implicitly dictate the need for high data rate networks, at least if deployed on a medium to large scale.

3. The Evolving Landscape

We began work on our current project in September 2000 with the goal of developing and demonstrating a rapidly-deployable broadband wireless system that links to existing networks to meet the needs identified in FEMA's IT architecture [7] and discussed in Section 2. We have also focused on support for and demonstration of applications that enable the ICS elements discussed in Section 2 and that utilize GPS, digital maps, and personal digital assistants (PDAs) as cited in FEMA's IT architecture [7].

We wrote the proposal that led to funding in 1999. At that time, the wireless networking industry was largely focused on the IEEE 802.11b wireless LAN standard and products offered 11-Mbps solutions for indoor office environments. Only a few companies offered radio modems that worked above 100 Mbps and these were intended – and priced – for satellite communications. Transmission over wireless at data rates of 155 Mbps was largely an expensive laboratory demonstration. The IT industry – hardware and software – was focused on the "dot-com" market; most vendors were uninterested in the public safety and disaster response market. And, the tragic events of September 11, 2001 were still two years away.

The environment for this and similar research has significantly changed in many ways since we began working on our project. The following changes, some expected and some not, have occurred.

- As expected, the importance of IP and the use of network-centric incident management have continued to grow.

- Interoperability has become more and more important. The need for interoperability extends to LMR voice communications, data networking, and applications.
- Wireless technology has improved significantly, perhaps at a rate that exceeds what many expected. Of particular significance is the availability of high data rate wireless communications over long ranges, especially in 2.4-GHz and 5-GHz license-free bands.
- Perhaps unexpected by many was the recent precipitous decline of the telecommunications industry. Broadband wireless service providers and "dot-coms" have substantially reduced acquisitions of wireless equipment and many have gone out of business. Equipment vendors are vigorously pursuing new markets, including "homeland security."
- The unexpected events of September 11, 2001 have increased awareness of the need for effective disaster and emergency response, made providing more effective response a national imperative, and led to plans for substantial reorganization at the federal level.

4. Our Philosophy for Rapidly-Deployed Broadband Wireless

While we have adapted our strategies to the changing landscape described in Section 3, we are confident that our approach is still sound and that the need for this work has only become more important. We believe that the following features of our rapidly-deployed broadband wireless network are necessary to successfully meet the needs of disaster and emergency response.

- By linking a disaster site to existing network infrastructure, our system provides responders and emergency managers with information resources that are available locally and globally.
- Our system provides just one tier of a three or four tier system, but, by using IP and standard network interfaces, it seamlessly interoperates with Ethernet and IEEE 802.11 LANs, the Internet and other IP-based WANs, and satellite or terrestrial wireless systems, if needed.
- Our system provides high capacity service. We believe that demand for bandwidth will grow quickly as responders adopt the applications discussed in Section 2.1.
- Our system is based on IP and, thus, can support a wide variety of applications. Technology trends in general point to the widespread adoption of IP as the foundation for a variety of services including voice and video.
- Most traditional broadband wireless systems cannot meet the demands of rapid deployment. We explicitly consider this requirement in our system. We have developed GIS tools, a built-in broadband channel sounder, and an adaptive data link protocol to enable site planning, rapid initial deployment, fine tuning, and real-time automated adaptation in the field.
- A traditional fixed broadband wireless system is deployed to achieve optimal operation. In an emergency, any connectivity is likely better than none. Therefore, our system is designed to operate in an opportunistic manner. For example, the built-in channel sounder allows the system to identify non-line of sight paths of opportunity. Also, the data link protocol can tradeoff data rate and error rate to achieve an acceptable operating point.
- Rapid deployment requires not only rapid placement, but also rapid network configuration. Future work will focus on a "zero configuration" approach to network administration and management.
- Security is, of course, critical. We believe that a flexible, end-to-end security system based on IP Security (IPSec) and virtual private networks (VPNs) is a more promising approach than protection that covers only the wireless link.

- Our initial research focused on use of LMDS spectrum because of the tremendous capacity offered by its bandwidth and because the Virginia Tech Foundation owns LMDS spectrum in much of southwest and southern Virginia. However, our innovative features are largely "spectrum agnostic." We are pursuing the integration of our techniques into equipment for license-free bands to leverage the advances made in that market segment. There are some basic tradeoffs between use of licensed and license-free bands. Licensed bands may not be available for use and equipment will likely cost more since it is not a commodity product. But, licensed spectrum, if available, is protected and, in the case of LMDS, offers huge bandwidth. Spectrum-agile systems that can operate in a range of bands offer an alternative, albeit at increased cost and complexity.
- IP network services may offer an opportunity for LMR interoperability in addition to supporting a variety of data applications. Packetized voice, coupled with simple signaling, could provide a common basis for LMR interoperability.

5. Technical Approach

The approach described in Section 4 has led to the design and partial implementation of a rapidly-deployed broadband wireless system. Figure 1 illustrates the concept of operation and some key features of the system. A hub or base station "illuminates" the disaster area with high data rate connectivity using broadband wireless technology. Remotes or field units placed within the illuminated area connect to the base station to send and receive data. A GIS-based tool that computes "viewsheds" is used for initial site planning. In Figure 1, the magenta (shaded) region within a sector represents the area visible from a hub placed at the position indicated. Remote field units can be placed at any location in the covered zone. Additional coverage using non-line of sight paths can also be considered.

The hub provides connectivity to the remote units and, ideally, to a global network such as the Internet, using either existing infrastructure or a satellite connection. The remote units provide connectivity to personal computers, notebook computers, PDAs, VoIP terminals, and other networked devices using wired and/or wireless LANs.

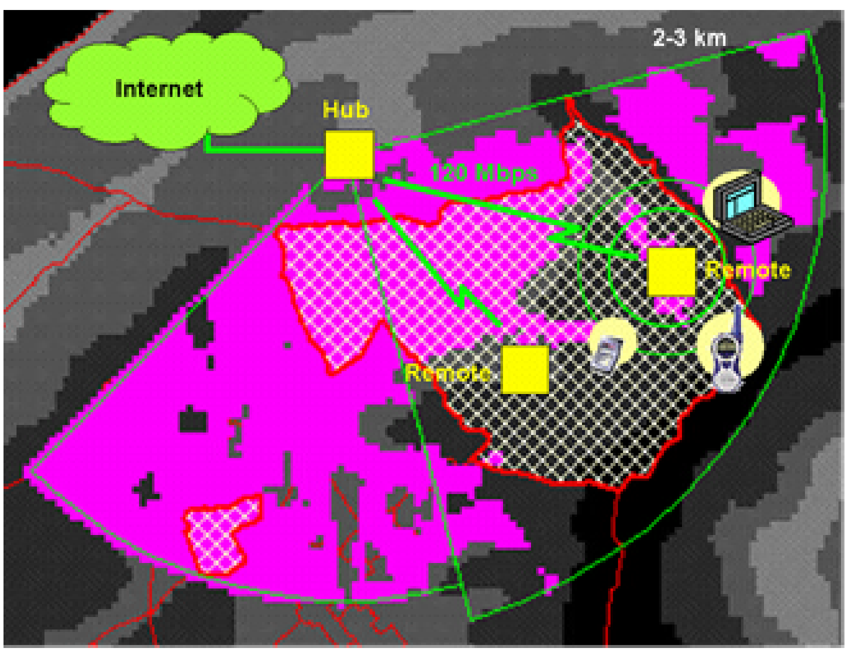

Figure 1. System concept of illuminating the disaster area with broadband wireless.

Our objective is to provide a data rate of 120 Mbps. We are initially using radio frequency (RF) spectrum in the licensed LMDS band, which is between 28 and 31 gigahertz. In theory, this band can support data rates of one gigabit per second. The system we are developing has a range, or maximum distance between the hub unit and a remote unit, of 2 to 3 kilometers. This range limitation is due to our use of off-the-shelf radios that were donated to us. Radios designed specifically for this application could achieve a range of 10 to 15 kilometers.

The logical network formed by the hub and remote units has a star topology and is designed to transport Ethernet frames. The hub and remote units include a full-duplex 100-Mbps Ethernet interface. Ethernet frames sent to a remote unit by hosts or network equipment at a remote location are delivered to the hub unit and sent to network equipment – typically an Internet Protocol (IP) router – at the hub site. Ethernet frames sent to the hub unit by network equipment at the router are delivered to all remote units, which deliver the frames to hosts and network equipment at the remote site. This simple logical behavior and use of Ethernet as the basic link-layer service allows the use of common Ethernet-based network equipment and IP-based applications. The broadband wireless backbone is transparent to other network equipment and to standard applications.

Security is of particular concern in wireless networks. The band that is utilized for our system greatly reduces the vulnerability to casual eavesdropping, which is a significant concern with more common IEEE 802.11 wireless WLANs. For stronger security, VPN approaches are an appropriate solution. A VPN provides secure end-to-end transport, thus protecting traffic over wireless link as well as over the public network that is likely to be used to carry traffic back to agency networks. In addition, multiple VPNs can isolate traffic and network resources belonging to different agencies that are sharing a common wireless network.

Our approach incorporates three unique and innovative capabilities that enable rapid deployment and robust operation for emergency and disaster response applications.

- A Geographic Information System (GIS) “viewshed” analysis tool can be used for “on-the-fly” site planning to determine coverage within the disaster area and to indicate optimal locations for the hub and remote units [3]. Viewshed analysis is especially important given that LMDS and other nearby bands require line-of-sight connections between the hub and remote units. The opportunity also exists for viewshed analysis to use measurements from the built-in sounder to improve its prediction and to suggest alternative locations.

- The hub and remote units include an integrated broadband channel sounder [4]. More precisely, this unit is a “sampling swept time delay short pulse sounder.” Sounders are commonly used for site planning to assess RF channel characteristics, but they are expensive. We have developed a novel sounder design that lowers the cost to a point where it is feasible to build the sounder into the hub and remote units. A built-in sounder simplifies initial equipment set-up and allows for continuous monitoring of the RF environment that may change, for example due to the movement of trucks or heavy equipment at a disaster site.

- The communications link between the hub and remote units can adapt to changes in the quality of the connection. Based on current conditions, as indicated by the built-in sounder and detected errors, an automatic retransmission request (ARQ) function is selectively enabled or disabled and forward error correction (FEC) coding is dynamically set to different levels of protection against bit errors [5]. The goal of this data link adaptation is to achieve optimal operation based on run-time versus design-time conditions.

6. Early Prototype Demonstrations

While development of the full system is not yet complete, we did successfully demonstrate an early prototype system to federal, state, and local government officials in November 2001 and January 2002. The system consisted of two stations, a hub and a remote, connected by a 10-Mbps link using LMDS. The prototype system used off-the-shelf networking equipment, modems, up/down converters, and 28-GHz radios. There was some custom hardware to interface the radios to the modem. The hub was connected to the Internet. Access at the "remote" site was extended using both an IEEE 802.11b wireless LAN and a 10-Mbps Ethernet LAN. Applications included in the demonstrations were VoIP telephony using off-the-shelf VoIP telephones, VoIP push-to-talk communications using a PDA running Microsoft Pocket PC, H.323 video conferencing, instant messaging between PDAs and notebook computers, access to the commercial E-Team web-based emergency management system, and generic electronic mail and web access.

Figure 2 shows the system configuration for the January 2002 demonstration, held in Chatham, VA. The "Unified Command Center" in the left portion of the figure is the remote site. The configuration for the November 2001 demonstration, held in Blacksburg, was similar. The radios, up/down converter, modem, and networking equipment for the remote unit are shown in Figure 3. The photograph in Figure 3 was taken at the November 2001 demonstration. The same equipment was used at both demonstrations and at both the hub and the remote sites.

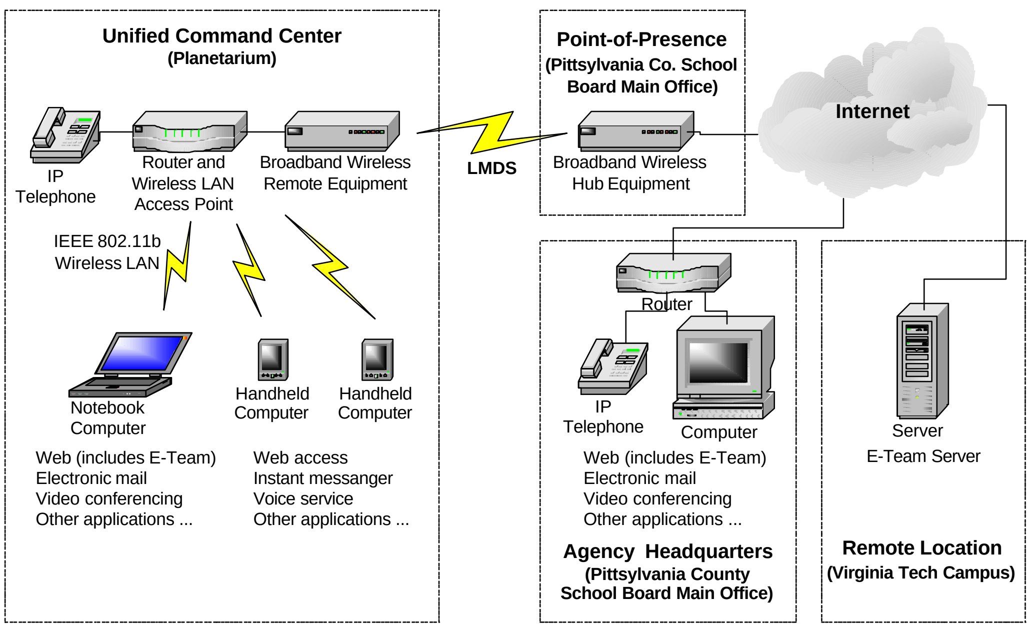

Figure 2. System used for January 2002 demonstration.

7. Conclusions

We are designing and developing a novel wireless communications system that can be quickly deployed to provide an onsite broadband backbone network for emergency and disaster response. Significant outcomes from our work include: (i) a GIS tool for rapid site planning; (ii) a novel, low-cost, built-in sounder to assess channel quality; and (iii) an adaptive data link protocol that configures error coding and retransmission strategy based on channel quality as indicated by the sounder.

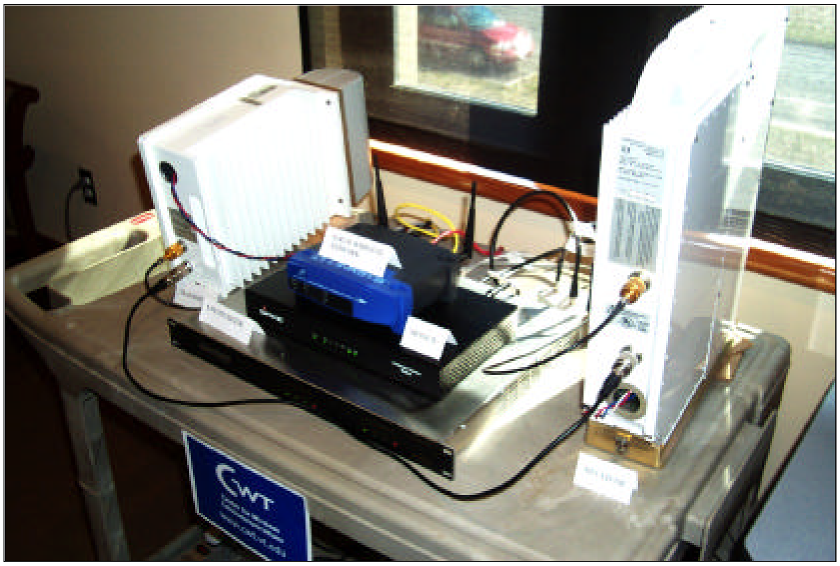

Figure 3. Demonstration system with radio, modem, and networking equipment.

We have successfully demonstrated a prototype 10-Mbps system and are developing transportable hardware and software to create a rapidly-configured 120-Mbps backbone network. We are integrating this system with commercial IP-based applications suitable for emergency management.

Acknowledgments

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