RAPIDLY DEPLOYABLE BROADBAND WIRELESS COMMUNICATIONS FOR EMERGENCY MANAGEMENT

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Abstract

This paper preliminary results and status for a project that is investigating a rapidly deployable "last mile" wireless high-speed communications system to support emergency management. The system is intended to utilize surviving network infrastructure to provide network connectivity to emergency management field workers for applications such as Geographic Information System (GIS) access and audio/video conferencing. Virginia Tech, in conjunction with partner SAIC, is designing the system architecture, developing and/or integrating radio, link, network, and application level hardware and software, and exploring GIS applications. The system will be demonstrated through construction and test deployment of a base station and two field units. An important element of the work is rapid deployment, so equipment must be portable, easily configured, and able to access remote databases and GIS engines. Innovative features to support rapid deployment and robust operation, including a built-in channel sounder, adaptive link layer protocols, and use of GIS for viewshed analysis, are being investigated.

1. Introduction

1.1. Problems and Motivation

When an emergency occurs, such as a chemical spill, hurricane, or other natural or man-made disaster, personnel are sent to the field to assess the situation, plan a response, and execute and monitor that response. In carrying out these emergency management functions, field workers should be able to rely on the same means of communications and tools that they use every day. And, since an emergency presents new problems, workers should have new tools to cope with the emergency and to work remotely. In today's information technology-centric environment, emergency management personnel rely on IT tools such as electronic mail, document sharing, and web and database access to do their jobs. In an emergency situation, a variety of IT tools can be utilized to improve management. For example, GIS databases can be accessed to enable damage assessment or to locate critical infrastructure such as natural gas lines that may need to be inspected and secured. GIS data can be processed using GIS engines at remote data centers and accessed using "thin client" software. Audio/video conferencing can be used to allow field workers to interact with personnel at an agency headquarters or with field workers in another area of a large-scale disaster. High-resolution images or video sent from a remote location can allow experts to assess damage. IT presents significant opportunities to greatly improve the effectiveness of emergency management.

However, IT-centric applications require substantial network infrastructure. Indeed, many of the applications, such as video conferencing, transmission of high-resolution images, and control of remote GIS engines require broadband network access with a capacity of 10 megabits per second (Mbps) or more. Even more capacity is needed to support multiple network users.

Such network access is becoming commonplace in the workplace and even the home. Our challenge is to provide this level of network access in the field for emergency management.

Table 1 summarizes features and differences of traditional network access and that required for rapid deployment. As indicated in the table, rapidly deployable networks introduce numerous challenges for network equipment and deployment strategies.

Table 1. Summary of Features for Traditional and Rapidly-Deployed Networks

Traditional Networks	Rapidly-Deployed Networks
• Wireline technologies, i.e., optical fiber, coaxial cable, or digital subscriber lines, can be used for high capacity links.	• Wireline technologies are likely to not exist or not function and cannot be quickly deployed. Wireless technologies are typically the only viable option.
• A lengthy planning process increases the likelihood of a good network deployment.	• Planning must be "on-the-fly." There is little opportunity to do traditional site planning for wireless systems.
• Operation is robust due to use of wireline technologies and/or careful advance planning.	• Sub-optimal deployment and a frequently changing environment can decrease reliability.
• Security may be available through limited physical access, encrypted links, or security gateways.	• Use of wireless implies the potential for eavesdropping. Key management is difficult in a rapid deployment.
• System designs and deployments are usually highly sensitive to cost per user.	• Total system cost is still important, but cost per user is less important.

1.2. The Virginia Tech/SAIC Approach

Virginia Tech's Center for Wireless Communications (CWT) is investigating novel solutions to the problem of rapidly deployable broadband wireless network access as part of a project funded by the National Science Foundation's Digital Government program, "Testbed for High-Speed 'End-to-End' Communications in Support of Comprehensive Emergency Management." The CWT is responsible for developing the wireless network and supporting hardware and software. Our partner, SAIC, is responsible for crafting scenarios for the system's use, for helping to ensure that it will be useful to a broad range of federal agencies, and for developing concepts of operation. SAIC will also facilitate integration into future disaster relief exercises and determine the effectiveness of the system in these exercises. The primary partner agency is initially the National Response Center (NRC), which is responsible for responding to chemical spills, toxic agent release, and related environmental problems. We are confident that other agencies will also be able to realize significant benefits from this work.

The first objective of the project, which is our current focus, is to develop and demonstrate a transportable high-bandwidth wireless backbone network capability. We are presently working toward designing and building at least one base station and two remote units that will operate in a star topology with connectivity between the base station and the remote units. The base station is designed to connect to surviving telecommunications infrastructure, for example via an existing 10/100 Mbps Ethernet, DS3, or OC-3c network connection or via a dedicated wireless connection to an existing connection. The base station connects to multiple remote units that can be deployed to serve an appropriately wide geographic area. The aggregate data rate will be at least 45 Mbps in each direction, i.e., from the base station to remote units and from remote units to the base station. We expect that the aggregate data rate will approach or exceed 100 Mbps. The field units will provide network connectivity to portable computers and network equipment through either 10/100 or 1000 Mbps Ethernet connections. Computers in the field can execute a full range of applications that use the Internet Protocol (IP).

To take advantage of lowered prices and increased availability of commercial Local Multipoint Distribution Service (LMDS) equipment, we will build the initial wireless network to operate in the LMDS bands where Virginia Tech holds licenses covering approximately 40% of Virginia. Once the broadband wireless concept is demonstrated and proven, users may wish to operate in a nearby unlicensed band (25 GHz, for example). We will insure that later versions of our design may be operated in such bands, either by modifying the transmitting and receiving equipment, or by adding external up/down converters to the LMDS units.

The system will demonstrate several innovations that overcome the problems of rapid deployment cited in Table 1 and that support emergency management applications.

- The base station and remote units include a channel sounder that assesses the capacity and quality of the wireless channels between the base station and remote units. This capability is coupled with a Global Positioning System (GPS) and GIS to provide rapid resource estimation and the ability to recommend relocation of the remote units. This enables "on-the-fly" site planning to reduce the need for pre-deployment wireless planning studies.
- We are developing techniques that allow the wireless network to adaptively utilize the full bandwidth that the sounders designate is available. Rather than designing for a worst-case deployment, the system can take advantage of favorable conditions to increase capacity.
- Software development for field units emphasizes remote access of GIS engines and databases both to support the wireless network's own deployment and operation and to support disaster mitigation and emergency management. In particular, we are focusing on the mission of the NRC in dealing with environmental problems.

An overview of the system organization is provided in Section 2. Section 3 describes the design of the system, including the built-in channel sounder, radio, modem, and multiple access. Section 4 discusses support for GIS applications. Section 5 summarizes our status and plans.

2. System Overview

The network, shown in Figure 1, consists of a base station and one or more remote units connected via a broadband wireless backbone. The test bed will consist of a base station and two remote units that use LMDS frequencies. The base station and the remote units can contain routing, security, and other network service functions, as well as a radio, modem, built-in channel sounder, and GPS unit, as shown in Figure 2. The remote units can provide connections to hosts on a remote local area network (LAN), using, for example, a 10/100 BaseT Ethernet and/or IEEE 802.11 wireless LAN. The base station provides a connection to a wide area network, such as Net.Work.Virginia, via a high-data rate connection. End hosts can access remote GIS and other networked servers using the backbone and existing infrastructure.

The wireless backbone network can be viewed as a "virtual Ethernet" in that Ethernet frames are input and output at the endpoints (the base station and remote units). By placing an Internet Protocol (IP) router at each endpoint, the rapidly deployable network can be viewed as a "virtual IP network" in that IP transport and related services are provided at the endpoints.

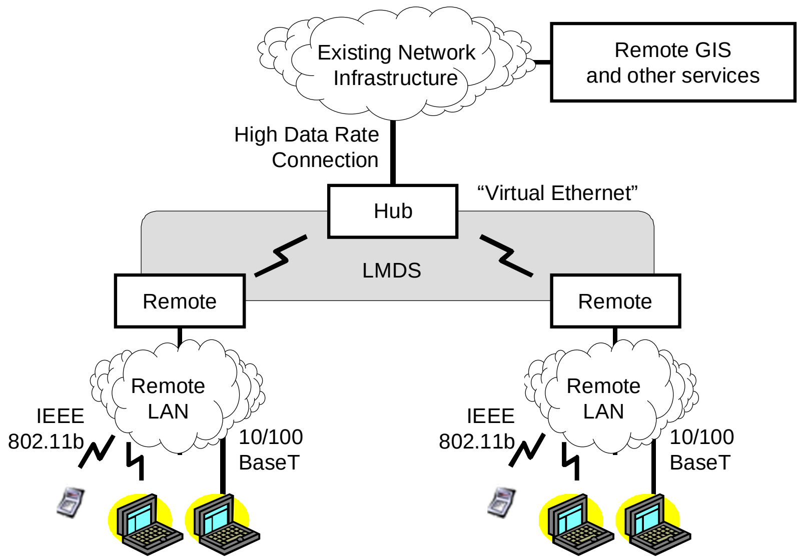


Figure 1. High-level view of the system.

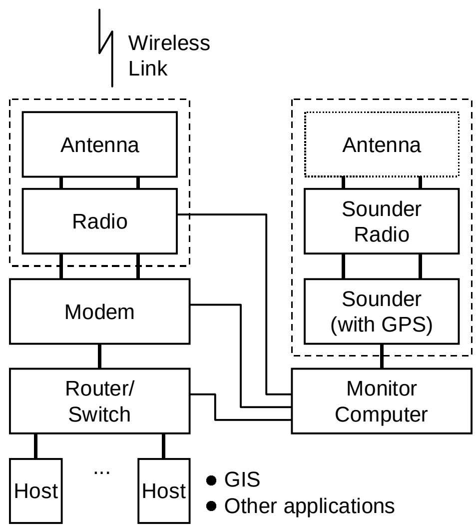


Figure 2. Subsystems for a base station or remote unit.

Figure 2 shows the subsystems that constitute a base station or remote unit. The designs of the two different types of units are almost identical, although subsystems will exhibit different behaviors in the different types of units. The subsystems are described in Section 3.

The network supports bidirectional transfer between the remote units and the base station in a star architecture. For the current baseline design, the capacity from the base station to the remotes is 120 Mbps. The division of the capacity between the different remotes is implicit in the addressing of packets sent to the remotes. In fact, the transfer of packets from the base station to the remote units is logically and physically a broadcast. The aggregate capacity from the remote units to the base station is also 120 Mbps in the current design. The division of capacity from remotes to the base station must be controlled by a multiple access scheme. For the baseline network, a fixed assignment time division multiple access (TDMA) scheme is used so that the capacity per remote unit is approximately C/N, where C is the aggregate capacity and N is the number of remote units. More efficient multiple access schemes will be considered later. The actual available data rate will be lower than 120 Mbps due to framing and other overhead.

3. Design Overview

3.1. Broadband Wireless Channel Sounder

The performance of any wireless system is inherently limited by usable channel bandwidth. Our prototype system will include a digital vector wireless channel sounder capable of characterizing wireless spectrum in the 28-GHz LMDS band. The sounder will characterize the behavior of the communications channel, thus providing information needed to (1) rapidly locate equipment for improved operation and enabling "on-the-fly" site planning, and (2) adapt link level operation to optimize performance under changing channel conditions.

Typical wireless channel measurements are conducted using sliding correlator pseudo-random noise (PN) spreading code sounders because of their robust performance in the presence of noise. One limiting factor of such systems is board-level noise produced by the high frequency chipping rate signals of the sliding correlator circuitry. Another limitation of this approach is the data processing and storage requirements required for high-sample rate digital instruments.

The sounder being developed in this project is designed to avoid these complexities, allowing the system to continuously monitor the wideband wireless channel and provide real-time performance metrics such as the mean excess delay, RMS delay spread, and coherence bandwidth. These metrics are derived from the digital power delay profile, or impulse response, produced by the system. The system was designed with three modes of operation: (1) continuous channel monitoring, (2) single instant channel snapshot, (3) and data logging. In contrast to high sample rate sounders that may require 2 billion samples per second to achieve multi-path resolution of less than one foot, each data acquisition channel requires analog to digital (A/D) conversion rates ranging from 48 thousand to 1 million samples per second. These lower performance A/D converters are more common and, therefore, less expensive, reducing the overall cost of the system. The combination of a lower sampling rate and the novel digital signal processing algorithm allows the system design to achieve multi-path resolution of less than one foot, while dramatically reducing the memory and data logging storage requirements.

Figure 3. Packaged GPS-disciplined oscillator for the sounder.

3.2. Radio Subsystem

A radio is associated with the base station and each remote unit. As shown in Figure 2, the radio is the subsystem located between the wireless link and the modem. It includes the hardware to transmit and receive a signal at the proper radio frequencies as well as to interface with the modem. The radio equipment includes the antennas and appropriate up-converter and down-converter hardware needed to maintain a connection between the modems at the base station and the remote units.

To save money and development time, we are adapting radios that were originally designed for a frequency band that is slightly higher than the LMDS band to be used in this project. These radios are being modified to operate in the desired band. Bench testing and simulation indicate that the existing radio hardware will permit operation with the desired fidelity up to a distance of at least 2 km. The radios must operate with a modem input/output center frequency of 140 MHz, output power level of +4 dBm, and input power level of –15 dBm. The acceptable input power range for the modem is unclear at this time and resolution of this question will determine whether automatic gain control (AGC) is needed. The frequency band for the wireless link is the portion of the LMDS band from 27.5 GHz to 28.35 GHz. The radio hardware will be modified to operate with a maximum bit error rate (BER) of 10^{-6} up to a distance of 5 km.

The modem operates such that the occupied signal bandwidth is 84 MHz. The 850 MHz LMDS frequency band is divided into 8 channels, each 100 MHz wide. Since the radios were designed for a frequency band slightly higher than this project's requirement, it was decided to utilize the highest channel for the demonstration. Work is currently underway to replace portions of the radio hardware with parts that will allow the radios to operate appropriately in any of the channels.

As shown in Figure 4, the uplink is designated to be the frequency band at which a remote unit transmits and the downlink is the frequency band at which the base station transmits. The base station will transmit to all remote units at a center frequency of 28.3 GHz (in a 28.25–28.35 GHz band). All remote units will transmit at a center frequency of 27.85 GHz (in a 27.80–27.90 GHz band) and will share the uplink channel using TDMA.

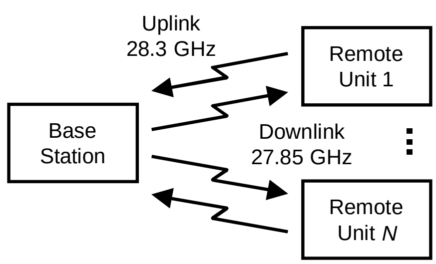


Figure 4. Uplink and downlink frequencies to be used in the demonstration.

3.3. Modem Subsystem

The modem subsystem consists of two physical components, the actual modem and a modem interface card (MIC). The modems, which are acquired from Lockheed Martin Global Telecommunications (LMGT), were designed for use in a satellite communications system and support a data rate of 120 Mbps (60 million symbols per second) using quadrature phase shift keying (QPSK) modulation. The MIC, being developed at Virginia Tech using field programmable gate array (FPGA) technology, is the modem controller and serves as a bridge between the network and the modem. It is responsible for the following functions.

- The MIC provides data and control signals to the LMGT-supplied modem.
- The MIC provides the physical and data link layer functions for the Ethernet interface to the network.
- The MIC interfaces to the monitor computer using a serial connection to provide operational status and performance information and to receive configuration information that selects operating modes based on dynamic channel and application conditions.
- The MIC implements the TDMA scheme that permits multiple remote units to share a single uplink channel.
- The MIC realizes Reed-Solomon encoding and decoding to support forward error correction (FEC) coding. The level of coding will be dynamically adjusted to optimize a tradeoff between data rate and error rate for given channel conditions.
- The MIC implements an optional link layer automatic retransmission scheme to minimize end-to-end retransmissions by TCP.

3.4. Multiple Access Scheme

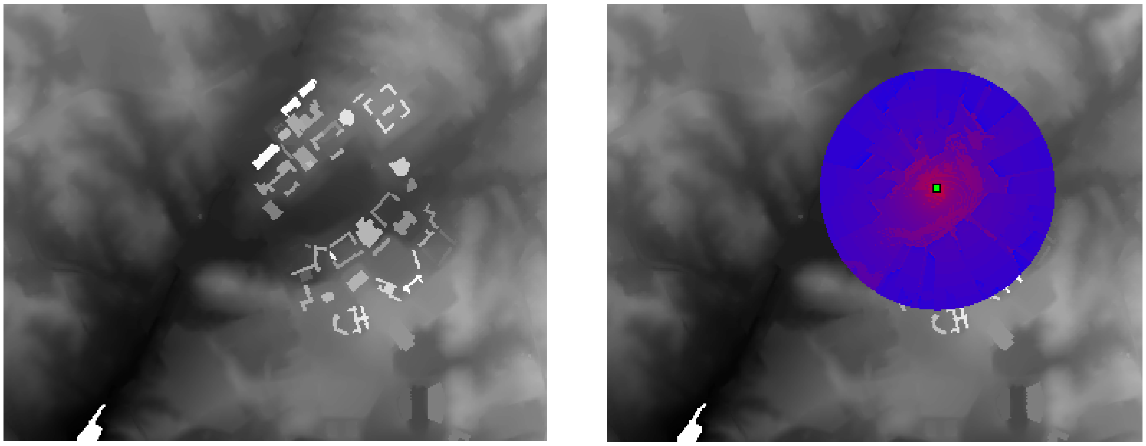
A multiple access scheme is required to allow multiple units to share the wireless medium. As shown in Figure 4, frequency division multiplexing (FDM) separates the downlink and uplink transmissions or streams. Since all remotes transmit on the same uplink frequency, a second multiple access scheme is required beyond the FDM scheme. A TDMA scheme will be used with the uplink stream. To maximize commonality in hardware and software between remote units and the base station, the downlink stream will also use a (trivial) TDMA scheme with all data slots assigned to the base station.

Transmissions in each direction will be structured as a set of consecutive frames separated by interframe gaps. Each frame will include a synchronization field to allow all receivers to synchronize to the frame transmission, a header control field that will carry link protocol and TDMA assignment information, data slots, and a sounder slot. The data slots carry the actual data and include header and trailer fields to provide information for Ethernet frame reassembly, time slot encoding, and link layer retransmission.. The sounder slot is used to provide a “dead” period during which time the sounder can transmit and take readings of the channel.

4. GIS Support

Geographic Information System technology plays multiple roles in the system. Emergency management personnel can use standard GIS applications in the field and access remote databases or GIS engines via the broadband wireless network. Two other roles support rapid deployment of the broadband wireless system. Given GIS data and radio information, “viewshed” analysis can be used to quickly plan initial sites for the base station and remote units. An extension of this function is to link information from the broadband channel sounder with GIS-based viewshed analysis to consider actual measured channel conditions into the viewshed prediction. This more advanced capability, which is to be investigated in later stages of the project, will allow units to be moved to better sites with a minimum of setup time.

The first version of the GIS-based viewshed analysis has been completed. The user is able to change the radio characteristics, base station tower and remote unit heights, and effective radii of the area of interest. The user can graphically enter locations for the base station and remote units or this information can be read from files if the locations have been previously specified. An example viewshed analysis for a portion of the Virginia Tech campus is shown in Figure 5. The system can also generate individual line of site data. The model incorporates free space losses and diffraction gains. At this point, however, the model only concerns itself with the highest blockage point along a line of sight. It currently works with band sequential (BSQ) file formats and produces BSQ images of the results for both viewshed and line of sight. It also produces a text file for the line of sight results to be used in future studies.



a) Image of an area of the Virginia Tech campus (10 m resolution). Brighter pixel colors indicate higher elevations for terrain and buildings.

b) Analysis output for theoretical tower placed in the center of buildings (green dot). Red indicates higher decibel strength.

Figure 5. Example viewshed analysis images.

5. Status and Future Plans

Work on the rapidly deployable broadband system is underway with pieces of various subsystems complete or nearly complete. It is anticipated that a functional baseline system will be ready for early testing in late summer 2001 and for a full demonstration in fall 2001. Future work will extend the baseline design to improve scalability and performance. Future work will also consider lessons learned from the demonstration to further improve the system and, especially, its utility for emergency management agencies.

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