A STUDY OF AMATEUR RADIO INNOVATIONS FOR DISASTER MEDICINE

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ABSTRACT

Medical facilities may struggle to maintain effective communications during a major disaster. Natural and man-made disasters threaten connectivity by degrading or crippling Internet, cellular/mobile, and landline telephone services across wide areas. Communications among staff, between facilities, and to resources outside the disaster area may be lost for an extended time. A prototype communications system created by the National Library of Medicine (NLM) provides basic communication services that ensure essential connectivity in the face of widespread infrastructure loss. It leverages Amateur Radio to provide resilient email service to local users, enabling them to reach intact communications networks outside the disaster zone. Because Amateur Radio is inexpensive, always available, and sufficiently independent of terrestrial telecommunications infrastructure, it has often augmented telecommunications capabilities of medical facilities. NLM's solution is unique in that it provides end-user to end-user direct email communications, without requiring the intervention of a radio operator in the handling of the messages. Medical staff can exchange email among themselves and with others outside the communications blackout zone. The technology is portable, deployable on short notice, and can be powered in a variety of ways to adapt to the crisis' circumstances.

KEYWORDS: amateur radio, communications, emergency management, mobile command post, Internet

INTRODUCTION

Communication is essential to patient care and important for coordinating responses and allocating resources during major disasters. One consequence of major disasters is a surge in patients and requests for health care services. Yet studiesindicate that during such emergencies 10%–40% of hospital staff may be out of touch because they are incapacitated by the event, unable to contact the institution, or cannot get to it. Therefore, medical facilities may need to operate at higher service levels with fewer personnel. When communications are disrupted in a disaster, managers in health care settings may lose the ability to request help and resources,

maintain situational awareness, coordinate assistance, maintain leadership coordination, or gather information for decision making.

Although valuable communications lessons have been drawn from the severe impact of Hurricane Katrina and 9/118, disasters continue to affect the ability of health organizations to communicate during disasters. For example, in 2011 a tornado devastated the town of Joplin, MO including St. John's Mercy Hospital. Phone lines were down, electricity was out, and even emergency generators were inoperable. In 2012, Hurricane Sandy hit the coast of New Jersey and created a 250-square-mile communications blackout zone that lasted several days.

The reasons for telecommunications failures during disasters are numerous. Telecommunications relies on complex infrastructure. Maintaining redundant systems or resilient commercial alternatives is often prohibitively expensive. Damage done to a telecommunications system during a disaster may be extensive and restoration of service may be time-consuming, expensive and require specialized resources and skills. The solution developed by the National Library of Medicine (NLM), the "Bethesda Hospitals' Emergency Preparedness Partnership (BHEPP) – Army Military Auxiliary Radio System (Army MARS)-assisted Emergency Radio System" (BMERS), supports the functioning of a health care facility during major emergencies by providing emergency managers and health care staff a mechanism to communicate under extreme conditions. BMERS combines Wi-Fi, specialized software and current Amateur Radio technologies to provide an email service for medical staff when normal telecommunications systems have failed or are compromised. Through BMERS, email messages can be sent and received via the Internet by reaching beyond a communications blackout zone that may extend from a few to hundreds of miles. The system also keeps key incident management personnel at medical facilities connected via a low-cost, rapidly deployable Intranet. BMERS does not enhance communications and medical care, but it can preserve them at a time when normal communications are severely disrupted.

THE BEGINNINGS OF BMERS

Creation of BMERS by the NLM began in 2008 as a research and development project for BHEPP. BHEPP is the first military-civilian-federal partnership in the United States and comprises the National Naval Medical Center (NNMC--which was replaced in 2011 by Walter Reed National Military Medical Center), the National Institutes of Health Clinical Center (NIH CC), the Suburban Hospital-Johns Hopkins Medicine and NLM. Experts at NLM's Disaster Information Management Research Center (DIMRC) were tasked with designing an emergency backup communication system to support the three allied hospitals in BHEPP during emergencies. BMERS has much broader applications, however, because it supports the function of the Hospital Incident Command System (HICS), used by hospitals throughout the country to manage threats, planned events that present significant risks to the facility and its occupants, or emergency incidents. In emergencies, HICS

facilitates sharing of resources and management of patient surge, but coordination among the hospitals can only be effective if the organizations can communicate.

The overarching objective of the project was to develop a cost-effective, easy-to-use and adaptable telecommunications solution that can be employed by incident command staff at medical facilities for exchanging information efficiently during severe disasters. The developers at NLM/DIMRC hypothesized that digital Amateur Radio could fill a key communications gap for BHEPP hospitals because it does not have the burdens of commercial solutions and has a proven record of service during disasters. Unlike satellite-based solutions, digital Amateur Radio does not require service subscriptions or pay-as-you-go service fees for access. BMERS does not require roof-mounted equipment, as would be the case with commercial radio systems. It also does not involve additional infrastructure, institutional licensing or permits, which are typical requirements of commercial wireless telecommunications services.

Use of Amateur Radio in medical facilities is not new but rates of adoption remain low because commercial communications products and services are ubiquitous and there is insufficient motivation to maintain redundant telecommunications. However, new emergency preparedness requirements in the Centers for Medicare & Medicaid Services (CMS) rules could provide additional incentives for US medical facilities to consider Amateur Radio in their disaster plans.

The United Nations' International Telecommunications Union (ITU) and governments around the world recognize the value of Amateur Radio and allocate frequency bands throughout the electromagnetic spectrum for licensed amateurs to advance the art, science and public benefit of radio communication. Other volunteer-based radio communications services that can play a supporting role during disasters, such as Army MARS; have additional frequency allocations for properly credentialed volunteers. The BMERS system can be adapted to these other services, if necessary.

Radio amateurs must obtain a license to operate radio transmitters. Licensing involves passing an examination on radio theory, regulations, safety and operating practices. The United States has an incentive licensing structure to encourage proficiency, which typically is acquired by peer training and operating experience. Specialized training and credentialing in emergency communications is available from organizations such as the ARRL.

TECHNOLOGICAL AND HUMAN CHALLENGES

The technological disadvantages of using digital Amateur Radio for disaster communications include its very slow data rate speeds due to US Federal Government bandwidth regulations. Data rates are also limited by transmitter power and technical limitations of radio propagation through the atmosphere. Radio equipment must be operated by a Federal Communications Commission (FCC)-licensed Amateur Radio operator (informally called ham radio operator). With a unique professional collaboration and specific hardware and software, however, the BMERS developers were able to manage these limitations to provide an effective solution.

BMERS improves upon previous Amateur Radio models for providing emergency communications at hospitals. With the traditional model, the Incident Command (IC) staff at the hospital complete standard messaging forms that are handed to a radio operator for transmission. Analogously, messages that are received at the hospital via radio are transcribed by the radio operator onto a standard form that is handled to the local IC staff. Communications follow the same telegram-like protocol reminiscent of early Morse code operations, which is laborious and can be error-prone. Not all radio operators are familiar with medical terminology and logistics, which may hamper manual handling of messages. To eliminate the radio operator bottleneck, BMERS developers looked to Winlink 2000 (WL2K). The Amateur Radio Safety Foundation developed WL2K in 1999 as a free messaging system for ham radio operators. It is both a technology and an infrastructure that provides radio interconnection services, automatic routing of email with attachments, geolocation, graphic and text weather bulletins and emergency relief communications. More than 100 automatic radio access points for WL2K exist across the United States and worldwide. Although the infrastructure of WL2K is supported by volunteers, its effectiveness in real disasters has been documented repeatedly. These access points support the full range of Amateur Radio frequencies (Medium Frequency [MF], High Frequency [HF], Very High Frequency [VHF] and Ultra High Frequency [UHF]) that, as a group, maximize the data bandwidth for a given communications distance.

The WL2K system was originally designed to allow a single licensed radio operator to send and receive email messages via radio using the manual transcription process described earlier. The BMERS system re-envisioned the radio operator's role. In this new incarnation, radio exchange of email becomes a service that meets the needs of IC staff. The Amateur Radio operator becomes the manager of the service, but is not directly involved with message exchange.

The next challenge was to identify personnel who could be trained to operate the software and radio equipment required to connect with WL2K during a disaster. Most emergency personnel in hospitals are not ham radio operators. WL2K technology requires that operators have sufficient practical experience with ham radio technology and relying solely on enthusiasts from the community was not the best option, because only a minority has the necessary skills. Often, the skilled operators are already committed to other support operations during disasters. It was essential to find or create a separate pool of reliable, trained radio operators available during emergencies. The solution was to collaborate with Army MARS26 and the NIH Radio Amateur Club (NIHRAC). Both organizations committed to this undertaking and have provided experienced emergency communications operators.

Army MARS is a Department of Defense (DoD) program that trains, organizes, and tasks volunteer Amateur Radio operators with the mission of providing contingency radio communications to DoD and priority civil authorities. Through the alliance with Army MARS, the BMERS system gained access to technology usually

beyond the reach of most Amateur Radio operators. Army MARS also has its own exclusive set of WL2K resources nationwide, which became the primary resources used by BMERS.

The NIH Radio Amateur Club was founded for the purpose of providing emergency communications to NIH. The organization has a natural vested interest in supporting the project because NIH CC is part of the BHEPP organization. NIHRAC's members also brought to the project a high degree of technical expertise and Army MARS staff had significant experience building reliable custom radio communications solutions for rugged conditions using Amateur Radio technology.

BMERS COMPONENTS AND PROCESS

The collaboration with Army MARS resulted in creation of an enhanced model for use of Amateur Radio in disaster communications. With BMERS, end users send and receive emails without any direct radio operator intervention by integrating custom and commercial-off-the-shelf (COTS) software, a local Wi-Fi/Ethernet local area network (LAN), and other COTS communications devices. The BMERS radio operator establishes radio links and maintains the email service, much like other modern IT systems. Message content is managed by the user and through a rule-based system that elicits efficient use of the communications resources.

Figure 1 illustrate the service architecture of a BMERS station. A portable version of BMERS can be deployed and activated at a moment's notice to provide user accounts and web email access to laptops or other computer devices connected to a LAN provided by the BMERS system in the hospital. A ruggedized laptop powered by a gas generator, batteries, or the power grid serves as the computer server and the operator's console. BMERS operates on MF, HF (both long range) and VHF (short range/higher bandwidth) Amateur Radio and Army MARS frequency bands. Because MF and HF share a similar set of technical constrains, for most of the remaining of this article we use HF to refer to both, MF and HF bands.

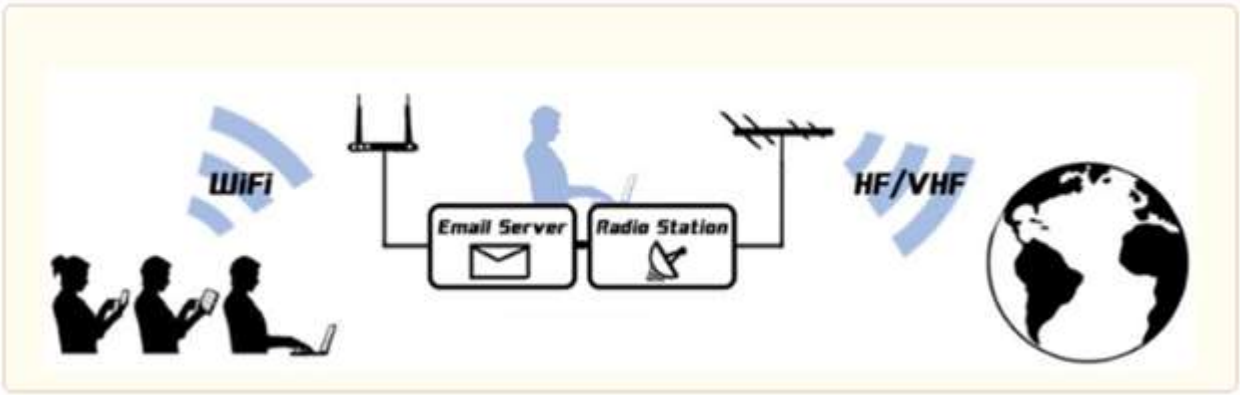

Figure 1 BMERS bridges the communications gap during disasters

BMERS also can be connected to an existing LAN to provide resilient communications services to anyone using that network. For example, at NIH, a BMERS server is connected to a private high-speed network that interconnects the three Hospital Command Centers (HCCs) of the BHEPP hospitals. The HICS staff from the

three hospitals can use the BMERS server to exchange email and text messages with each other (Intranet service), and to communicate via email with the rest of the world when institutional Internet services fail.

In advance of an emergency, the BMERS operator creates and assigns an e-mail account to each HICS role, such as the Incident Commander and the Public Information Officer. Only authorized users can access the service.

To communicate during an emergency, authorized users at a hospital‘s HCC assume their designated HICS roles, access the email accounts for those roles as assigned by the Incident Commander, and point their web browsers to the BMERS mail server. The users do not need FCC Amateur Radio licenses and they require only minimal training. The web-based design of the user interface offers a familiar web mail look and functionality. HCC personnel can access BMERS with any Wi-Fi or Ethernet-capable device (PC, laptop, tablet or smart phone) that can run a standard web browser—no additional software or special equipment are needed, only the BMERS email credentials provided by the station operator.

TECHNOLOGY LIMITATIONS

BMERS relies on the WL2K infrastructure available primarily in North America. In addition, it has a number of challenges that are inherent in Amateur Radio technology:

Antenna Placement

Placement of antennas is critical for any radio solution like BMERS. In many cases the ideal location for the radio equipment in a facility may be inadequate. Certain antennas must be kept close to the radio and other antennas require a large space for placement. For example, VHF and UHF antennas can be just a few feet long, but their efficient operation may require placement above the roof of a building. VHF and UHF operation typically reaches around 30 miles using antennas that are practical for emergency deployment. Higher antenna placement and higher radio transmission power can extend this range. In contrast, HF radio can use the ionosphere to send signals to receivers hundreds of miles away. However, practical HF antennas with good propagation characteristics typically require wire antennas of 100 feet or longer at the frequencies of interest. Smaller antenna solutions exist, but their efficiency can suffer from the reduced length. BMERS radio stations can be designed with a variety of portable antennas for different settings.

Radio Operating Skills

A trained and licensed radio operator familiar with radio equipment and the art of exploiting atmospheric radio propagation is required for BMERS. If the communications gap that needs to be bridged by radio signals is beyond the reach of VHF/UHF radio frequency bands, use of MF/HF bands (1 to 30 MHz) becomes necessary. BMERS is designed to operate on any of the bands allowed by Amateur Radio and the Army MARS service, but the vagaries of HF radio propagation require radio operators with training and experience beyond the casual Amateur Radio enthusiast. Although we collaborate with many Amateur Radio hobbyists that are highly skilled

in HF bands and eager to help during crisis situations, their availability and commitment during actual disasters can be uncertain. For this reason, we also collaborate with experienced emergency communicators from Army MARS and local emergency communications organizations.

Radio Frequency Bandwidth Regulations and Physics

Current FCC regulations regarding "symbol rates" and bandwidth allowances for Amateur Radio communications only allow for very limited data throughput in HF/VHF/UHF bands35. Radio amateurs continue to develop and utilize new digital transmission modes that maximize symbol rate while conserving radio bandwidth, along with transmission modes that are effective even with low-power signals below the level of average background noise. However, physical and technological conditions such as atmospheric phenomena, transmission power and electromagnetic interference limit the maximum information rate over a long-distance wireless channel on these bands. Practical limits are well below the maximum theoretical bandwidth (Nyquist-Shannon theorem). As a result, under the best conditions it is difficult to transmit more than a dozen pages of single-spaced text per minute using WL2K (see BMERS Performance section). Indeed, the slow communications pathway in part justified the traditional WL2K model using an operator to review each message before transmission. Unmanaged email, laden with graphics, copies of previous messages, or large attachments is not problematic on modern networks, but can overwhelm the WL2K system. With very slow connection speeds, a single e-mail with multimedia components or one requiring acknowledgement from multiple recipients would not only dominate the resource as outgoing mail, but could trigger a backlog of replies that overload the available bandwidth. To address this danger of overload, BMERS software has usage-control mechanisms that reduce the likelihood of such an event. The system also has rescue techniques to resolve this problem if overload does occur. That enhanced bandwidth management feature eliminates the need for operator intervention in each message by enforcing restrictions on the size and overall volume of messages allowed through BMERS.

Data Protection

FCC regulations do not permit transmission of encrypted messages using the Amateur Radio service. However, Army MARS does not have such a restriction and, therefore, Army MARS message encryption tools can be used to protect the content of email messages transferred through BMERS when Army MARS frequencies are used (an authorization from Army MARS is required). In some jurisdictions, health organizations may be able to obtain access to other emergency communications radio frequencies that also allow data encryption.

CONCLUSION

BMERS was developed to complement and augment the emergency communications resources of medical facilities and enable their incident management staff to remain connected during a catastrophic disaster. BMERS is not nearly as fast as typical Internet email, but when it becomes necessary to restore and maintain communications for the provision of healthcare services at a medical facility deeply affected by a major incident,

a few minutes turnaround time for brief messages are exactly what the doctor ordered. Medical organizations can use the BMERS software and involve their local Amateur Radio clubs in development of this system in their facilities. Possible future enhancements to BMERS include expansion of the number of standard messaging forms built into the system and the ability to automatically encrypt transmissions for more secure messaging. The radio station equipment can also be made more portable and easy to deploy and operate, and the email accounts defined in the system can be adapted to other IC positions and other roles, such as those needed for public health disaster response incidents. BMERS is under evaluation for use as a supplementary disaster communications resource by Emergency Management departments in Kent and Carroll Counties in Maryland. Work is also underway to add BMERS servers to the Mid-Atlantic IP Network (MAIPN), a private Amateur Radio-supported microwave network in the Mid-Atlantic region intended to support emergency preparedness.

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