EXECUTIVE SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) commissioned this study to identify and address specific deficiencies in firefighter radio communications and to identify technologies that may address these deficiencies. Specifically to be addressed were current and emerging technologies that improve, or hold promise to improve, firefighter radio communications and provide firefighter location in structures.

Introduction

One of the most significant problems facing firefighters within a structure on the fireground is the ability to communicate reliably between the firefighters themselves and between the firefighters and the command post or communications center. In an ideal world, firefighters would be able to communicate with one another and the command post at all times, regardless of where they are or what they are doing. However, this is not the case. Firefighter radio communications to, from and within structures can be unreliable, thereby compromising the safety of firefighters on the fireground.

Over the past decade, incidents involving firefighter injuries and fatalities have demonstrated that, despite technological advances in two-way radio communications, important information is not always adequately communicated on the fireground or emergency incident scene. Also, the events of September 11, 2001, and other emergency situations in recent years have highlighted the need not only to improve firefighter radio communications, but also the communication systems available to law enforcement personnel, emergency management officials, and other public-safety responders.

The continued incidence of firefighter fatalities where communications are cited as a contributing factor as well as the industry-wide lack of consensus on the appropriate frequencies to use in fireground communications have prompted NIOSH to more thoroughly investigate fire communications and the problems associated with communications within, as well as into and from, structures.

Methodology

To begin the project, the team members compiled a comprehensive set of communications issues that affect radio communications in the fire service from several sources – an initial literature survey, knowledge of the project team members, and discussions with fire service leaders, NIOSH project team, engineers, and others. Team members refined this comprehensive set of issues with NIOSH project personnel to identify critical issues that could be addressed by improvements in radio communications. A prioritized list of communication and personnel location problem areas was developed. In general, the primary focus was clarified to be the identification, status, and research recommendations for technologies that could improve in-building communications or provide firefighter location within structures. Furthermore, the effort was to focus on the radio communications and radio location problems found in large structures such as high-rises to include radio transmissions into and out of the structure to the command post. Buildings such as these present the most difficult communication problems because of their floors both high above the ground as well as basement levels. The list of the high priority topics is shown in Table 1.

TABLE 1: PRIORITY TECHNICAL AREAS AND RELATED TOPICS ADDRESSED IN STUDY

Area	Example Issues
Accountability	• Integrating Personal Accountability Systems (PAS) with communications • Electronic accountability • Automatic vehicle location • Electronic command boards
Communication Planning and Coordination	• Through building (into/out of) • Underground • In building
Monitoring Firefighter Welfare and Location On-Scene	• Role/responsibility of dispatchers • Use of field communications units and communications coordinators • Remote monitoring • Vital signs • Location
Reliability	• Line-of-sight limitations • Underground (subways, parking garages) • Confined space rescue • Communication into and out of buildings (especially high rises) • Intermittence • Communication coverage/dead spots
Interference	• Building construction and materials (such as concrete, metal, and Lexan) • Radio propagation through fire, heat, and smoke • Cell phone towers (e.g., Nextel) • Terrain
Unsuitable Equipment	• Frequency band unsuitable for structure/ground penetration

The first phase of the project was an extensive literature search for research and product information. The literature search covered a wide variety of government, engineering, and scientific databases. The Internet was also used to identify current products as well as the abundance of unpublished research posted by various companies and universities.

The next phase of the project included two areas: identifying communication problems experienced by fire departments and investigating the current state of technology research and development. This research was used in the third phase of the project to identify gaps between the problems and issues of firefighter communications and the technologies to address these issues.

In final phase of the project, recommendations were made for areas of research, which if completed, could lead to improved firefighter communications in structures. The technologies identified in this phase included current applications, potential applications, and how these potential applications could be relevant to firefighter communications.

This phase is addressed in Chapter V, "Current Technology Status, Knowledge Gaps, and Research Needs". Past and current research is described as well as important issues remaining to be overcome if the technology area is to be feasible for firefighters.

Communication Issues

Communication problems commonly encountered by firefighters (and others) can be broadly divided into two categories. First are mechanical or technical issues related to unsuitable equipment, system design, inadequate system capacity (too much radio traffic), and building construction, among others. The second category of problems relates to human factors.

Fire departments consistently have problems maintaining effective communications while operating in large structures, such as high-rise office buildings and apartments, and warehouses. Similar issues exist in structures with a large number of windows (or areas of glass) with reflective coatings. Communications from areas below grade (e.g., basements, parking garages, subway systems, tunnels) tend to be uneven. For the typical home, communications are generally not a problem. The technical issues associated with the physical structures themselves (building materials, height, etc.) are discussed further in the body of the report. Communications problems encountered by fire departments are discussed further in the body of the report. Solutions currently used by fire departments range from increasing the number of repeaters to migrating to trunked communications systems.

Human factors, such as radio discipline, training, and tactical decisionmaking, also affect firefighter radio communications. These factors, while not technical issues themselves, adversely affect communications, especially when combined with technical and equipment issues. These issues, while not under the scope of this report, are discussed as background in the body of the report.

Technology Summary

The literature search identified a number of technologies that could contribute to solving firefighter communications problems. Some of these technologies can be used as standalone technologies while others are technologies that enhance performance of wireless links. Mobile area networks (MANet), ultra wideband (UWB), bi-directional amplifiers (BDAs), power line communications (PLC), medium frequency (MF), very low frequency (VLF), and radio frequency over heating and ventilation materials (RF over HVAC) all can be used standalone to build a communications system. Smart antennas, spread spectrum modulations, channel coding and interleaving, and automated electronic status systems are enhancing technologies.

The ideal technology would provide robust in-building firefighter communications without equipment setup or equipment beyond personal communication devices (e.g., a handheld radio, personal tag, or the like). For providing a practical communications system, this technology does not yet exist. Current firefighter communications suffer from inconsistent in-building performance and may require additional equipment such as repeaters. Untapped technologies provide other opportunities, but have limitations as well. VLF signals have been used to penetrate hundreds of feet through the earth in mining applications but the band is so narrow it can carry only one analog voice channel. MF through-the-air-signaling was tested in England as a means of communicating with firefighters in high-rises. This application used antennas that were looped around the entire building, making the antenna size a serious drawback. Furthermore, neither VLF nor MF has spectrum allocated for this use. A MANet does not require any infrastructure, but it does require that a firefighter always be with in range of a sufficient number of other firefighters who act as a network of repeaters. In practice, this may be impossible as firefighters may be out-of-range of each other in high-rise stairwells or building basements. Other technologies have similar issues.

The next best choice to provide robust in-building fire communications would be one that couples personal communication devices with standard infrastructure found throughout a building (e.g., ac power lines and telephone lines) and little or no portable infrastructure (e.g., repeaters). Such a system would require some setup to interface the personal communication devices with the infrastructure. Using a PLC system would require the firefighters to plug a wire access point (WAP) into the building ac outlets to connect to the building's ac power lines. It may also require a portable range extender to placed as needed. A MANet may require additional fixed wireless nodes (similar to a repeater) to enhance its range.

Another choice would be one that couples the personal communication devices with specially engineered, permanently installed building infrastructure. BDAs and RF over HVAC are examples. If these systems are in place and designed correctly to give the firefighters the coverage required at the frequencies required, they work well.

Using these criteria, the top technologies potentially suitable for firefighter communications are shown below in Table 2. A summary of each of these technologies follows. A complete discussion of these and other technologies investigated is presented in Chapter V.

TABLE 2: SUMMARY OF STANDALONE TECHNOLOGIES WITH POTENTIAL TO IMPROVE IN-BUILDING RADIO COMMUNICATIONS

Technology	Existing Structure		Portable Add-on Equipment for System Enhancement	Limitations	Potentially Applicable Enhancing Technologies
	Built-in Infrastructure Required	Modifications Required			
MANet	—	—	• Fixed wireless nodes • PLC wireless access point (hybrid system)	• Network size (number of radios) • Wireless range	• Smart Antenna • Spread Spectrum • Channel Coding • Elec. Status
UWB	—	—	• To be determined based on outcome of FCC final rulings	• Current FCC restrictions	• Smart Antenna • Spread Spectrum • Channel Coding • Elec. Status

Technology	Existing Structure		Portable Add-on Equipment for System Enhancement	Limitations	Potentially Applicable Enhancing Technologies
	Built-in Infrastructure Required	Modifications Required			
PLC	• Uses existing ac power lines	—	• Range extender	• Range	• Smart Antenna • Spread Spectrum • Channel Coding • Elec. Status
MF	• Uses existing telephone • Uses existing ac power lines	—	• Undetermined	• Limited research on in-building propagation	• Spread Spectrum • Channel Coding • Elec. Status
BDA	• Cable, antennas	• Installation of cable, antennas if not built-in	—	• Pre-installation required • Frequency must match that of fire department	• Smart Antenna • Elec. Status
VLF	—	—	—	• Narrow frequency band limits usefulness	• Channel Coding • Elec. Status
RF on HVAC	• HVAC ducts	• Modification to existing HVAC	—	• Pre-installation or modifications required • Duct size must accommodate/pass frequency used by fire department	• Elec. Status

STANDALONE TECHNOLOGIES

MANet

Mobile area networks could provide firefighters with voice and data communications as well as supporting radio location technology. MANets for commercial applications is a field of intensive research and product development.

In a MANet, each firefighter carries a networked radio. As soon as two radios are within range of each other they form a network over which voice and data can be sent and received. As more radios move with in range they automatically join, too. If two radios are out of range of each other but on the same network, the networked radios between them relay the voice and data from one radio to another until the destination is reached. National Institute of Standards and Technology (NIST) has demonstrated this networked radio approach to communication and location on its first responder test bed. [**189**] A MANet can also include the use of wireless access points to a local area network (LAN) such as the HomePlug LAN (described below) to provide range extension into especially difficult coverage areas.

There are no regulatory issues with MANet but there are technical areas to be addressed. Currently, quality of service measures (e.g., the time delay from source to destination) and communications capacity degrade rapidly as the network adds radios. Extensive research is needed to improve routing protocols to address this and other issues.

Ultra Wide Band (UWB) Communications

UWB technology addresses in-building communications and locations needs. UWB can propagate better through materials and is degraded less by multipath than narrower band communications techniques.

This is a field of intensive research because of its in-building propagation characteristics and the high data rates that can be achieved. For communications, the majority of the research is directed at using UWB as the wireless link technology in LANs such as MANets.

The major barrier to this field is regulatory. The FCC has restricted both the band and transmitted power level resulting in severely reduced range and data transmission rates. The fire service should evaluate this technology, develop requirements, and encourage the FCC to implement rules so that fire services needs can be met. Despite this barrier, UWB holds much promise.

Power Line Communications (PLC)

A PLC communication system could provide improved firefighter communications wherever power lines run. There are two types of PLC, HomePlug and Access PLC. Both use standard ac power lines for propagating high frequency (HF) signals. HomePlug is the only power line LAN standard used within structures and products are widely available in stores. There are several proprietary Access PLC standards in the trial stage competing to deliver Internet service to end-users.

Standard HomePlug devices provide the ability to quickly setup a fully functional LAN. One available device of particular interest is a wireless-access-point-to-HomePlug interface. In this type of application, the HomePlug network is used for range extension of a wireless network. Firefighters equipped with a MANet communication system could carry these devices into a building with them and plug them into ac receptacles as needed to provide coverage in areas where they are out of range of the MANet. Their radio communications would be carried by the ac lines to other identical wireless-to-HomePlug interfaces plugged into other areas of the building and where firefighter MANet radios would be able to receive and relay the communications.

HomePlug devices do not have regulatory issues, as HomePlug is an accepted standard. There are technical issues, however. The ability of these devices to provide range extension for a wireless communications system such as a MANet needs further study. Studies to-date have been technology demonstrations for home use. These have found that a percentage of the ac receptacles do not support adequate network performance.

This effort needs to be expanded to cover additional structure types and their ac distribution schemes.

Alternative Frequencies (MF and VLF)

These frequencies are not currently used for firefighter communications but are used in underground mines for voice communications because of their unique propagation characteristics.

The MF band has been used in underground mines because of its ability to couple with conductors in tunnels and propagate for several miles on the conductors. In this system a base station takes exterior communications (e.g., a phone system), converts it to an MF radio frequency signal and couples it onto a conductor such as the ac power lines. Miners use portable radios and wear portable antennas built into a vest or worn bandolier style to receive and send voice communications.

Frequencies in the VLF band can propagate through hundreds of feet of earth. The entire VHF band is about the same bandwidth as a single trunk radio channel, which severely limits the capacity for voice and data communications. One practical use of VLF is as a one-way emergency evacuation pager to miners. The transmitter and antenna can be located on the surface and still reach miners equipped with portable emergency receivers.

VLF based systems have been used to locate miners below ground as well but the inherent lack of location accuracy may not provide performance sufficient for firefighter applications.

These technologies' applicability to firefighter communications and location need to be tested as their use has been limited to underground mines where the propagation is heavily dependent on the tunnel characteristics. In addition, commercial developments in this area appear to be at a very low level as the bulk of the research and testing was performed over 10 years ago. There may be spectrum regulatory issues as these bands are currently allocated for other uses.

TECHNOLOGIES USING BUILDING INFRASTRUCTURE

Bi-directional Amplifiers (BDA)

BDAs provide improved in-building communications. This approach installs cable and interior antennas for distributing radio signal throughout a building to provide extended in-building coverage. They are difficult to retrofit into existing buildings, costly to retrofit or include in new construction, and require special RF engineering expertise when designing each installation, as each installation will be unique. BDAs also require periodic maintenance to ensure the system continues to function as designed.

These systems have been installed in a large number of buildings and face no technical or regulatory issues. Use of them as a standard firefighting tool has been resisted because of implementation costs. Local jurisdictions are reluctant to require them by code, as they must compete with other areas for business. A nationwide or regional approach should be investigated requiring these systems in new construction.

RF Distribution Using HVAC Ducts

This approach could provide better in-building communications. It takes advantage of existing heating and ventilation ducts as RF waveguides for distributing radio signal throughout a building. It would potentially provide a low cost method for distributing radio communications analogous to BDAs.

For this approach to work, the ventilation system must be modified to enable RF signals to bend around obstacles, such as fans and dampers, found in ducts. Also, room vents would need to be replaced with ones that would be RF-friendly. Very little research is being pursued in this area and has attracted little commercial interest as well. This technology should be monitored; if commercial interest develops it could provide a lower cost alternative to BDAs.

ENHANCING TECHNOLOGIES

The following four technologies can also be used to enhance the function of existing digital communications system regardless of the system architecture. All are being intensively researched and all should be considered for inclusion in firefighter communication systems. Smart antenna technology can be applied to both analog and digital systems.

Smart Antennas

Smart antennas are under intensive research for many communications applications, including use in wireless LANs such as MANets and commercial cellular systems. They promise to significantly extend the range and data rate that wireless links support. This may help address the data rate shortcomings in MANets as radios are added to the network. Smart antennas products have been announced for inclusion in wireless access points.

Channel Coding, Interleaving and Encryption

These techniques are present in almost all digital communications systems. Systems using these techniques function well indoor as they are less susceptible to conditions, such as multipath and interference, that cause errors. Firefighter radio systems cannot be retrofitted with these techniques and new radio systems would need to be developed.

Spread Spectrum Modulation

Spread spectrum modulations provide improved communications because they can mitigate reception problems caused by multipath and interference from narrow band radios. Again, firefighter radio systems cannot be retrofitted with this and new systems would need to be developed.

Electronic Status Systems

The newly announced electronic status systems automatically track firefighter status to address the difficulty faced by Incident Commanders in tracking personnel on the fireground. Radio channels are assigned to incident command sectors and the system tracks them and displays status on a laptop. Future enhancements will include the ability to poll individual firefighter radios to determine if they are in a coverage area. If they are out of coverage for too long a warning will be displayed. If the ability to determine radio location were integrated, it could further enhance firefighter safety.

Conclusion

Current firefighter communications systems were chosen more for mobility or availability of spectrum than for suitability to the job of providing robust, reliable communications into, from, and within structures. It is not surprising that they can fail to provide adequate communications in buildings, which are the most challenging of radio communication environments.

The technologies discussed in this report offer the possibility to significantly improve radio communications in large structures as well as in basement and other below grade areas. But it also appears that one technology alone will not be sufficient. Combining technologies together to make a hybrid system may be necessary. A MANet system provides the firefighter the mobility he needs; when coupled with a PLC or MF communications system, a MANet system may provide coverage even into difficult areas where radio waves cannot penetrate. Enhancing technologies can be integrated into this hybrid system to give even further improvements.

Many of the technologies considered in this report are undergoing commercial development at a fast pace. This promises to keep the underlying cost of the technology reasonable, although the special requirements of the fire service may impose additional costs. Commercial development should be encouraged, as the benefits of these technologies will improve fireground communications.