Wireless Messaging for Homeland Security

Using Narrowband PCS for Improved Communication During Emergencies

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Narrowband personal communications service (PCS)[1] provides a network and technology that may be the answer for overcoming challenging communication problems that occur during public emergencies. Narrowband PCS is a two-way wireless short-messaging communication system that has had limited growth and popularity because of infrastructure deployment delays, financial weakness of key firms, and the threat of digital cellular and broadband PCS as a substitutable service. However, most recently, narrowband PCS has deployed the technology, infrastructure, and network service that provide two-way wireless messaging that is more reliable and more effective than the current voice networks used by emergency workers and public employees who respond to critical situations.[2] Narrowband PCS should be considered a primary or backup system to improve real-time communication among emergency personnel during critical periods when voice communication is not practical or fails.

Mission-Critical Communication

Communication is a critical need in any national, regional, or local emergency. It is also critical to less drastic situations, such as auto collisions, hazardous material situations, and fires. Communication is needed by the residents and visitors in the general area, emergency personnel, public employees, the news media, and anyone else at the site. Today, the primary means of communication are landline (the public switched telephone network), cellular and broadband PCS, and private radio networks. Each method has advantages but also inherent disadvantages that could be overcome with the use of narrowband PCS.

Landlines have the greatest network capacity, but their fixed location and lead time for installation make their use impractical for emergencies. Even with their redundant network capability, landlines are subject to blocking[3] when extremely large volumes of traffic occur unexpectedly. For example, after an earthquake on the West Coast, it is not unusual for residents of the area to experience busy signals for hours as the result of blocking in an overloaded network.

The fastest-growing method of communication (and an increasingly popular one) is the public cellular and broadband PCS network. Unfortunately, communication using this network is often difficult because of the high volume of users during emergencies and the inoperability of communication infrastructure as a result of catastrophes. Wireless spectrum is limited and usage is growing, so it is not uncommon to experience blocking even during normal peak periods, such as rush hour.

During an emergency, blocking is exacerbated. On 11 September 2001, in New York City, over 75% of the wireless calls were subject to blocking and not completed. In Washington, DC, 50% of the calls were affected by blocking.[4] Blocking can also occur during an emergency that is not as widespread. When TWA flight 800 crashed off Long Island, NY, the cellular and PCS network experienced blocking almost immediately. While there may be many users competing for available airtime, the news media are a major culprit in the blocking problem.[5] Upon arrival at a site, members of the media immediately place a call to their headquarters control center and keep the line open, even if it is not being used. They realize from experience that once they lose a connection, it is often difficult to get it back because of heavy usage in the network. Thus, they fully occupy one channel, preventing its use by other parties.

With the large numbers of media people at disaster sites, it is no wonder the cellular and broadband PCS network experiences blocking almost immediately. While telecommunications industry standards have implemented a cellular priority-access function for emergency responders, its actual deployment and use are not widespread enough to make an impact. The initial rollout of priority access is on one carrier using the Global System for Mobile Communications standard, and further deployment is expected to be delayed by budget issues because of the service's expected cost of $208 million over the next five years.[6]

Disasters that damage other infrastructure also can damage the telecommunications networks. According to a report released by a group of downtown executives, telecommunications networks in Lower Manhattan remain vulnerable to major failures in the event of a disaster, even one on a smaller scale than the World Trade Center attack. The report concluded that a lack of redundant telephone and digital communication networks was a factor in the loss of telephone service to thousands of residents and businesses after the attack.[7]

While landline networks have built-in redundancy and most often can reroute a majority of the traffic around a cable cut or central office failure, cellular and PCS networks are much more fragile. An inoperable tower, base station, or antenna will mean that thousands of people may not have coverage in a geographic area. The trend for carriers to split cells into micro and pico cells in metropolitan areas to provide improved coverage and increased capacity also increases the probability that a cell site will be knocked out.

On 11 September 2001, the radio transmitters and telecommunications infrastructure were devastated. Five cell sites were destroyed outright or rendered inoperable, and 160 were rendered inoperable with the loss of the landline switching office and power infrastructure.[8] Both public (cellular and broadband PCS) and private radio networks (used by the police, firefighters, and emergency personnel) were limited in effectiveness because of infrastructure damage and challenging environmental conditions. This severely limited the ability of emergency personnel to communicate. A review by Naval War College evaluators concluded that the Fire

Department lacked coordination and communication on 11 September and had tremendous gaps in command and control.[9] After a 6-month study, the *New York Times* stated that firefighters were cut off from critical communication because their radio system failed and due to lack of communication with the Police Department.[10]

Twenty-one minutes before the second tower collapsed (2 minutes after the first one had collapsed), police helicopters hovered nearby to check its condition. "About 15 floors down from the top, it looks like it's glowing red," the pilot of one helicopter radioed. "It's inevitable."

Seconds later a second pilot radioed, "I don't think this has too much longer to go. I would evacuate all people within the area of that second building." That knowledge was never relayed to firefighters.[11] In fact, earlier evacuation orders never reached them. The separate private communication systems operated by the various agencies and emergency workers contributed to the failure to inform firefighters of the tower's imminent collapse.

Mayor Rudy Giuliani was trying to coordinate the efforts of 22 agencies at Ground Zero and often had 22 radios lined up in front of him.[12] With the existing communication systems and infrastructure, it is difficult if not impossible to provide a central command and control function that can contact 100% of the emergency responders. An ideal setting would provide communication to issue commands, obtain acknowledgment of the command from personnel, and have access to location information for each person. During the critical period of an emergency, as well as during normal operations, narrowband PCS's wireless messaging may provide a viable alternative or supplemental communication method that can be used across all emergency departments and public agencies to provide mission-critical communication.

The fragility of the nation's wireless networks as shown by the blackout of August 2003 brings into question the viability of relying on cellular telephony for priority access or mission-critical communication. The networks proved unreliable, since their battery backup systems are effective only for short power outages, and many transmitters were left without power after a short time. Even after electrical power was restored, call volumes four times ordinary contributed to call blocking.

The cellular industry markets its service as good for emergencies. In reality, problems occur during emergencies, and access to the service is limited. During and after the blackout, cellular service was intermittent or not available throughout much of the Northeast and parts of the Midwest. However, customers of wireless messaging services did not experience any problems.[13]

Wireless messaging has certainly proved to be a viable replacement or supplement for voice communication in public use, and it may prove useful for homeland security. Cellular short message service consumer use has reached 9 billion messages a month internationally.[14] Government agencies have also found wireless messaging to be valuable. The Federal Aviation Administration has implemented wireless messaging in three Operations Control Centers and plans to expand it to 29 centers. The agency believes that "success with wireless messaging demonstrates its effectiveness in emergency response situations."[15] This result is further substantiated by the wide-area implementation of a wireless messaging system at the Department of Energy's Nevada Test Site (until 1992 used for nuclear weapons testing, and now used for hazardous chemical spill testing, emergency response training, conventional weapons testing, and waste management and environmental technology studies).

Nevada Test Site Implementation

The first narrowband PCS used by public agencies to take advantage of the capabilities of wireless messaging was implemented at the Nevada Test Site. It was a partnership with the National Nuclear Security Administration (a branch of the Energy Department) and two commercial vendors—Motorola and Weblink Wireless—which provided the infrastructure and the network services.

The system was installed on 10 mountaintop sites covering the test site and the metropolitan Las Vegas area. A messaging server and 14 transmitter and receiver sites (complete with 14 two-way very-small-aperture-terminal satellite link systems) were installed at a cost of about $4 million. The system provides user privacy and secure service and is flexible for future expansion. The network improves local coverage for the agencies, the Nevada Highway Patrol, and Nellis Air Force Base. People can communicate no matter where they are on the test site, and they can have nationwide, state-of-the-art, two-way messaging when outside of the test site.[16]

The system is expected to provide the mission-critical communication required across agency and department boundaries and improve communication within departments. Narrowband PCS's messaging capability will supplement existing public and private voice networks to ensure that mission-critical information reaches stakeholders in a timely manner.

The Narrowband PCS Network

A narrowband PCS system comprises the following:

- A network backbone
- An air interface
- End-user devices

Figure 1 depicts a typical system.[17]

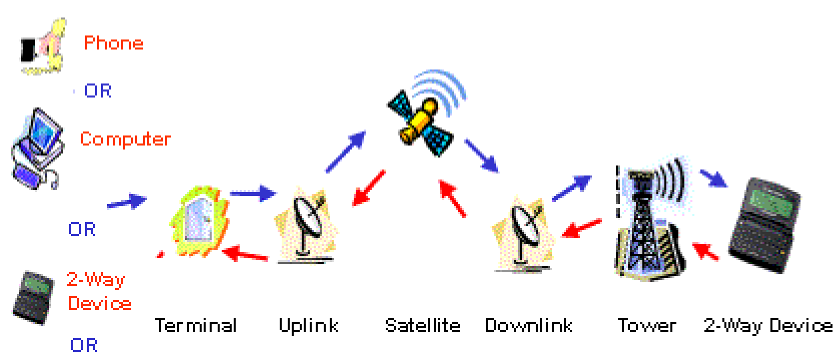

Figure 1

Messages enter the narrowband PCS system through any Internet Protocol interface into a messaging server. The messages may originate in three ways: (1) from a user who dials a narrowband PCS customer service operator, who will type the message for the caller; (2) from an Internet or email user who keys a message and addresses it to the narrowband PCS mobile user's address; or (3) from one mobile user to another using a two-way messaging device. The messaging server performs functions similar to those of a cellular network's mobile switching center, home location register, and visitor location register. The messaging server authenticates users, tracks their movement among base stations, and manages the delivery and receipt of messages. The Global Positioning System (GPS) is used at the sites for timing the forward and reverse channels of the air interface.

A telecommunications data backbone is required to transmit the message from the messaging server to the appropriate tower(s) for transmission. Most narrowband PCS systems use a satellite backbone, but transmission can be accomplished using any combination of transmission methods. Satellite systems are a favorite because of the speed and ease with which they can be deployed.

The narrowband PCS network uses an industry-standard air interface, developed by Motorola, called Reflex to manage communication between the base stations and user devices. The air interface is asynchronous, so it is well suited to handling the larger amounts of data broadcast from towers compared to the smaller volume that originates from a user's mobile device. Narrowband PCS networks are deploying encryption of both personal and broadcast messages based upon the National Institute of Standards and Technology's Advanced Encryption Standard.

The battery life for narrowband PCS devices is 3 to 4 weeks for an AA battery or up to 2 months for a lithium battery (depending on the device) under normal operating conditions. A narrowband PCS device can be designed to trade battery life against message latency. This trade-off can be accomplished throughout a service area for all mobile devices or for a specific subset of devices. Narrowband PCS already provides this capability, which was one of the recommendations for wireless carriers based on the 11 September 2001 Ground Zero rescue effort to maximize the chances of locating survivors.[18]

Narrowband PCS has a far reduced dependency upon wireline telephony, since it uses satellites for both network communication and GPS timing and therefore is less subject to service outages from telephony infrastructure failures caused by a catastrophe. Service restoration is limited to bringing a power supply online, and the systems can use mobile base stations in emergencies if base stations are not operating. Blocking during emergencies is basically non-existent since narrowband PCS, as a packet data service, does not require a connection to be set up the way cellular or private radio systems do; at most it will experience latency in message delivery. Wireless packet data was the most reliable service used on 11 September by first responders and emergency managers.[19]

Narrowband PCS Capacity

Narrowband PCS networks achieve capacity growth similar to cellular systems' growth by reducing the area covered in a serving region. In cellular telephony, this is called cell splitting; with narrowband PCS it is referred to as dividing a simulcast zone into sub-zones. The sub-zones do not have to have equal capacity. The number of channels can be adjusted for each sub-zone to accommodate traffic volumes and user density. The narrowband PCS forward channel is now at 6400 bps. The reverse channel from any given mobile device may operate at 800, 1600, 6400, or 9600 bps. Since sub-zones can support multiple forward channels, capacity is not a limitation of the service. Narrowband PCS can support 40,000 users on a single forward channel for the typical short messages that are sent on the system.

Data rates on forward and reverse channels do not have to be the same in a sub-zone. The forward channel (from the base station transmitter to the mobile user) most often operates at a faster rate than the reverse channel (from the mobile user to the base station receiver). This accommodates the need of most mobile users to have a large amount of data sent to them but to respond with only an acknowledgment or a short message. Most mobile devices (with small keyboards) are not conducive to creating a long, voluminous message; therefore, a short return message most often suffices.

If a user has a long inbound message, the network will usually reserve time on a reverse channel for transmission of the inbound message within the device's sub-zone. Those base stations associated with other sub-zones will still be available for other traffic, increasing the overall network capacity. In the latest versions of the narrowband PCS Reflex protocol (v2.1.1 and higher), networks can allow devices to effectively schedule their own long inbound messages and resolve any contention among devices that may be competing for the same inbound channels and time allocations. This increases capacity and reduces latency, especially for the messages using Instant Messaging or Internet Relay Chat.

Using narrowband PCS provides better capacity than using cellular and broadband PCS to transmit data or using a private radio network. Police in the United Kingdom studied and tested General Packet Radio Service (used by existing cellular systems for data) and found that it's "too subject to overload at the time of a major incident, which is just when its needed."[20] Third-generation cellular systems will improve data rates, but it will be years before they are deployed, and they will still be subject to overload and network failure conditions similar to what the current systems experience.

Emergency Personnel Specific Network Functionality

Narrowband PCS has network features that introduce improved reliability to the network.[21] Features such as incommunicado delay, mesh networking, simulcasting, group messaging and broadcast, and GPS aid in overcoming the problems inherent to an emergency. These features provide a greater probability that mobile users will receive mission-critical communication and be able to react in coordination with central command and with other emergency personnel in the field.

Of particular interest to emergency personnel is a messaging server's feature called incommunicado delay time, which will force registration of the mobile user until the message is delivered. If the mobile end user's messaging device loses contact with the network for longer than the incommunicado delay time (set by the system administrator), the mobile device contacts the network and registers itself, allowing the pending message to be sent. If the user's device loses contact for a period less than the incommunicado delay time, the network searches for the device until it finds it and then sends the pending message.

With a private radio or cellular system, by contrast, a voice call might be made to an emergency worker in the basement of a building. If the radio signals cannot penetrate to the worker's location, the radio or cellular phone would not recognize the failure. The call would simply not be received, and the worker would have no idea that someone was trying to communicate. When the worker emerges from the basement area, in range of the radio or cellular system, there still will be no indication of a failed communication attempt.

In a narrowband PCS environment, the system or the user's device forces registration, and the user will receive the message.

Another narrowband PCS system feature that helps provide always-connected service and extended coverage reliability is mesh networking, which permits mobile devices to communicate with multiple base stations simultaneously. Users who move out of the coverage area of one base station will not experience any service downtime, since they are served by multiple base stations. Also, if a single base station were inoperable due to catastrophic failure, the end user would still have uninterrupted service from other base stations. This creates significantly better coverage than a single link with a single base station, although it does use more network capacity. However, since messaging can experience more latency than voice networks, the additional capacity is not an issue.

Simulcasting covers a given geographic area with radio frequency that is transmitted from multiple locations, increasing the probability that a mobile user will receive the signal. This is important in difficult environments characterized by the many buildings that create shadows in urban areas, heavy foliage that may absorb signals, and rolling terrain that creates troughs that signals bypass. Simulcasting is particularly effective in achieving excellent in-building penetration, since signals originate from different locations and have a better probability of penetrating structures at various angles through windows, doors, and walls.

In-building penetration is aided by the 900 MHz frequency used by narrowband PCS and by its transmission power and height, which are greater than those of cellular systems and broadband PCS. The 900 MHz short wavelength has excellent penetration ability but is large enough to reflect and propagate once inside a building, so its coverage is more complete. This is an advantage over wireless services using the higher bandwidths, such as 1900 MHz, which is subject to absorption. Narrowband PCS simulcasts are made from multiple transmitters at 1000 ERPs (effective radiating power) that are up to 300 feet above the ground, versus cellular and broadband PCS's single-tower transmission at only 60 ERPs and a height of up to 100 feet.

The transmission redundancy of simulcasting also enables communication even when a specific transmitter is not operational, since the remaining transmitters will still be transmitting and providing coverage. One fewer transmitter will provide less overlap in the simulcast coverage and possibly some pockets of poor coverage, but overall it still will provide significantly stronger radio-frequency coverage than the non-simulcast coverage of cellular, broadband PCS, and private radio systems.

Narrowband PCS's group messaging and broadcast (sometimes called information services) allow immediate communication from one source to many mobile users. Each mobile device has a unique personal forward channel address and may have broadcast and group messaging addresses that are shared with other users or used by all. The users may be predefined in groups and the messages sent to one group or multiple groups. A message may also be broadcast to all mobile users. A central command and control operation can send the messages, or individual mobile users can do it.

Confirmation of message receipt can be requested to ensure that the communication was successfully received or, if necessary, to resend the message. Message confirmation may be broken down into two features: (1) message delivery to the mobile device and (2) message read by the user.

Narrowband PCS provides enhanced location ability using the Snaptrack GPS technology.[22] The system provides GPS fixes in difficult environments, such as in buildings, with as much as 25 dB signal attenuation compared to the 5 to 10 dB attenuation of most GPS receivers. The system also provides a location fix without the acquisition time associated with other classes of GPS receivers. The timely location of mobile users can be a critical feature for emergency personnel working in hazardous conditions. With this assisted GPS technology, there is no startup time for satellite acquisition. Rather, information about GPS satellite positions is obtained either from network broadcasts or by request. Also, the device is not required to make GPS calculations, which are offloaded to network-based servers. This yields a tactical ability to locate devices with GPS accuracy using a network server without the intervention of the device user. The result is a unit that has exceptional battery life for several weeks and exceptional signal penetration for both the GPS fix and the narrowband PCS communication pathway. Such features can be critical in the tactical location of missing, imperiled, or unresponsive personnel.

Summary

Narrowband PCS has demonstrated compelling benefits in terms of functionality, geographic coverage, in-building penetration, and the ability to support reliable delivery in difficult environments. It is positioned to be extremely helpful to emergency personnel for public safety and other homeland security applications through its wireless instant messaging, broadcast messaging, email, and location capabilities. The Nevada Test Site is a successful implementation of narrowband PCS by several government agencies and departments and will serve as the model for future implementations. The inherent strengths of narrowband PCS features and functionality will provide an excellent means of communication as a primary or backup system for emergency personnel and homeland security.

References

1. PCS "encompasses a wide variety of mobile, portable and ancillary communications services to individuals and businesses," according to the Federal Communications Commission, which "broadly defined PCS as mobile and fixed communications offerings that serve individuals and businesses, and can be integrated with a variety of competing networks. The spectrum allocated to PCS is divided into three major categories: (1) broadband, (2) narrowband, and (3) unlicensed."

2. Jim Dwyer, "Radio Problem Could Last Years, Fire Dept. Says," *New York Times*, 18 Sep. 2002.

3. Blocking is the "inability to establish a new call because of the inaccessibility of facilities in the system being called"—Glossary of Telecommunication Terms.

4. Cellular Telecommunications & Internet Association, report to the Network Reliability Interoperability Council: "Network Impact and Recovery Efforts—September 11, 2001," 23 Oct. 2001, pp. 1–2.

5. Wireless Services Task Force, "Cellular Priority Access Services Subgroup Report," the President's National Security Telecommunications Advisory Committee, Sep. 1995, p. 2.

6. Jeffrey Silva, "GSM Leads Fed's Priority Access Plan," *RCR Wireless News*, 16 Sep. 2002.

7. Jayson Blair, "Downtown Phone Network Is Vulnerable, Report Says," *New York Times*, 6 Aug. 2002.

8. Kathryn Condello, "Letter to the Chairman of the Network Reliability and Interoperability Council Regarding CTIA Report on 9/11," CTIA, 23 Oct. 2001, p. 2.

9. Simon Ressnor, "Fire Dept., on 9/11," *New York Times*, 26 July 2002.

10. Jim Dwyer, Kevin Flynn, and Ford Fessenden, "Fatal Confusion: A Troubled Emergency Response; 9/11 Exposed Deadly Flaws in Rescue Plan," *New York Times*, 7 July 2002.

11. Jim Dwyer, Kevin Flynn, and Ford Fessenden.

12. Dan Caterinicchia, "Lessons Worth Remembering," *Federal Computer Week*, 16 Sep. 2002.

13. Andrew Sorkin and Matt Richtel, "Cellphone Failures Cause Many to Question Systems," *New York Times*, 16 Aug. 2003.

14. Cellular Online, "Latest Global, Handset, Base Station, & Regional Cellular Statistics," Sep. 2002.

15. "Emergin Expands FAA Installation of Emergin WirelessOffice," Cellular Telecommunications & Internet Association, 6 Aug. 2002.

16. Mary Manning, "New Wireless System Improves Agencies' Communications," *Las Vegas Sun*, 13 June 2002.

17. Weblink Wireless, "Reliability of Reflex," 2002.

18. Wireless Emergency Response Team, "Final Report for the September 11, 2001 New York City World Trade Center Terrorist Attack," October 2001, p. 8.

19. Institute for Security Technology Studies at Dartmouth College, "The First Line of Defense: Tools and Technology Needs of America's First Responders in the Aftermath of September 11, 2001," 28 May 2002, draft, p. 19.

20. BWCS, "UK Emergency Services Voice Concerns Over Radio Systems in Face of September 11th Scale Disaster," Cellular Telecommunications & Internet Association, 16 Sep. 2002.

21. Allan Angus and N. Ross Buckenham, "Reflex Wireless Data Technology," 5 Sep. 2000.

22. Snaptrack, "An Introduction to Snaptrack Server-Aided GPS Technology," 2002.