A NPSTC Public Safety Communications Report

The National Public Safety Telecommunications Council is a federation of organizations whose mission is to improve public safety communications and interoperability through collaborative leadership.

Public Safety Communications Assessment 2012-2022

Technology, Operations, & Spectrum Roadmap

Final Report, June 5, 2012

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Public Safety Communications Assessment, 2012-2022:
Technology, Operations, & Spectrum Roadmap

Foreword

Ambassador Philip Verveer, Deputy Assistant Secretary of State and U.S. Coordinator for International Communications and Information Policy, U.S. Department of State, and Former Chair, PSWAC Steering Committee

More than 15 years ago I participated in the Public Safety Wireless Advisory Committee (PSWAC) that attempted to identify public safety spectrum needs through the year 2010. I submitted the formal Report of the Advisory Committee on September 11, 1996, 5 years before the events of 9/11. The *PSWAC Report* stated, "*The effectiveness of police officers, fire fighters, emergency medical services personnel, and other public safety officials is inextricably tied to communications capability. The lack of sufficient, quality radio spectrum suitable for public safety use deters technological innovation, diminishes the responsiveness and effectiveness of public safety, and ultimately compromises the safety of the responding officers and of the very individuals seeking their help."* This statement continues to be true.

I am very pleased the National Public Safety Telecommunications Council took on the challenging task of updating the *PSWAC Final Report* with the *Public Safety Communications Assessment, 2012-2022: Technology, Operations, & Spectrum Roadmap,* which identifies public safety communications requirements for the next 10 years, and assesses the impact on technology and radio spectrum. When we completed the *PSWAC Final Report,* we had no idea broadband would become available to public safety so soon. I commend NPSTC for their work of the last 10 years which has recognized the potential of broadband for public safety and helped move the public safety communications community in its current direction. I commend the members of the public safety organizations who created a united front in Washington, D.C., and who succeeded in acquiring the necessary spectrum to accomplish the building of the nationwide public safety broadband network.

A number of statements, observations, and findings were listed in the PSWAC *Final Report*. Many continue to be valid more than 15 years later: *The PSWAC Report stated, "The currently allocated Public Safety spectrum is insufficient to meet current voice and data needs, will not permit deployment of needed advanced data and video systems, does not provide adequate interoperability channels, and will not meet future needs under projected population growth and demographic changes."*

The *Public Safety Communications Roadmap* says, "The AFST Working Group received many comments on the need for additional narrowband spectrum to support public safety operations, including the need for additional interoperability spectrum assignments. There is a need for additional VHF narrowband spectrum to support existing and future public safety communications needs. Many rural agencies compete with statewide public safety agencies for access to VHF spectrum, which is highly desirable spectrum due to its ability to cover very wide areas at lower costs."

The PSWAC Report stated, "Data communication needs are becoming as varied as voice needs, and are expected to grow rapidly in the next few years. New services and technologies (e.g., data systems enabling firefighters to obtain remote access to building plans and video systems for robotics-controlled bomb disposal) that are critical for Public Safety users to continue to fulfill their obligation to preserve life and property are now becoming available."

The *Public Safety Communications Roadmap* reports: "The public safety community reported that one of their greatest challenges was the implementation of effective data services to support mission critical applications including mobile dispatch, automatic vehicle location, and access to state and national databases. Reliability, data speed, coverage issues, and lack of priority access were all cited as roadblocks to implementation of additional applications such as Geographic Information Systems (GIS) and access to building plans. ..Public safety agencies are increasingly aware of the growing demand for broadband services and applications and the new role this technology is playing in the public safety communications arena."

The *Public Safety Communications Roadmap* is a valuable document, based on extensive research, with many of its recommendations taken directly from public safety first responders. NPSTC conducted a national questionnaire that collected capability shortfalls across the full range of public safety communications needs. A series of operational focus group sessions held across the United States and law enforcement, fire/rescue, EMS, and other emergency services personnel provided invaluable insight into their daily operations regarding broadband data. This information was coupled with a nationwide assessment tool sent out to thousands of public safety agencies across the country. The technologies needed to meet public safety's operational requirements were developed from that operational information. Technical information was fed into an internationally accepted spectrum model from the International Telecommunication Union (ITU) to calculate the spectrum needs of first responders.

In closing, I would like to recognize the hard work of the authors of the *Public Safety Communications Roadmap*, which took over a year to complete as did the earlier *PSWAC Report*. Hundreds of people contributed to this report, but it takes a champion to complete a huge project like this. NPSTC was fortunate to have Joe Ross, Chair, AFST Working Group, who guided the work, indefatigably assembled representatives of the public safety community to participate, and who authored the Technical Section of this report. Barry Luke, Chair, Operations Task Group, developed questions, analyzed the data from the questionnaires, and led and analyzed input from the nationwide focus groups. Dave Buchanan, Chair, Spectrum Task Group, former Spectrum Chair of the PSWAC, turned the public safety requirements into the actual numbers that reflect the spectrum that will be needed in the next 10 years.

More work remains as the nationwide public safety broadband network is built and technology continues to evolve. The *Public Safety Communications Roadmap* will prove to be a valuable resource as public safety communications continues to evolve.

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Executive Summary

In August of 2009, the National Public Safety Telecommunications Council (NPSTC) chartered the Assessment of Future Spectrum and Technology (AFST) Working Group to identify public safety communications requirements for the 10 year period, from 2012 to 2022, and assess the impact on technology and radio spectrum. This report is a follow up to the *Public Safety Wireless Advisory Committee's (PSWAC) Final Report*[1] of September 11, 1996. The PSWAC was established on June 25, 1995, by the Federal Communications Commission (FCC) and National Telecommunications and Information Administration (NTIA) to evaluate the wireless communications needs of local, tribal, state, and federal public safety agencies through the year 2010, identify problems, and recommend possible solutions.

The Working Group conducted extensive research and based many of its recommendations on inputs taken directly from public safety first responders. It conducted a national questionnaire that collected capability shortfalls across the full range of public safety communications needs. A series of operational focus group sessions was held across the United States and law enforcement, fire/rescue, EMS, and other emergency services personnel provided invaluable insight into their daily operations regarding broadband data. This information was coupled with a nationwide assessment tool sent out to thousands of public safety agencies across the country. The technologies needed to meet public safety's operational requirements were developed from the above information. Technical information was fed into an internationally accepted spectrum model from the International Telecommunication Union (ITU) to calculate the spectrum needs of first responders

The Public Safety Communications Assessment, 2012-2022: Technology, Operations, & Spectrum Roadmap provides an overview of public safety communications and emergency operations as they exist now and as they are envisioned to be in the future. A number of public safety applications have been identified in this report that are deemed critical for on-scene operations. The Report is organized into five main sections: Executive Summary/Introduction, Operations Report, Technology Report, Spectrum Report, and Appendix.

> *Separate narrowband and broadband spectrum allocations should continue until broadband technologies and the network as deployed can be proven to replace narrowband mission critical voice and data capabilities and until the technologies/network meet the needs of all public safety agencies using that particular spectrum.*

One of the most urgent operational issues raised in this report relates to how existing public safety mission critical voice communications may be transitioned to the emerging broadband technology. It was very clear that public safety communications managers are extremely concerned over how their executive officers and elected officials will view funding and upgrades of their existing Land Mobile Radio (LMR) systems based on a belief that broadband systems may replace the existing LMR infrastructure in the next few years.

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[1] *Final Report* of the Public Safety Wireless Advisory Committee issued September 11, 1996. See http://www.ntia.doc.gov/legacy/osmhome/pubsafe/PSWAC_AL.pdf

This report concluded that while there is a technological potential for mission critical voice to be managed over a broadband network, much work remains to be done to determine if this is the correct long-term solution for public safety communications. As a result, narrowband and broadband spectrum allocations must continue to be made available to public safety agencies.

Many public safety agencies indicated that they continue to have interoperability challenges which prevent them from communicating with adjoining agencies or with more distant mutual aid partners. Many of these barriers are based on the continued use of proprietary systems or lack of proper planning and training. A review of the Department of Homeland Security's (DHS) SAFECOM Interoperability Continuum provides a path with multiple solutions to resolve these issues. Public safety agencies also indentify lack of funding for system upgrades and installation of needed interoperability solutions as a significant impediment to interoperability.

Public safety agencies should provide initial and recurring training on operability and interoperability to their first responders.

Improving Existing Operations

Several important points were raised by the public safety community regarding needed improvements with infrastructure and operations. First, all emergency services personnel need to be initially trained in the use of their subscriber radio equipment and should receive ongoing training in its use. Next, future designs for interoperability solutions and subscriber equipment should focus on ease of use with minimum complexity and decision making required by the first responder. In some cases, there are simply too many choices confronting an Incident Commander regarding the need to stay on a trunked system versus switching to a conventional simplex frequency, or deploying a portable repeater or gateway or other interoperability device. Finally, public safety agencies should be continually encouraged to embrace the role of the Communications Unit Leader (COML) position within the Incident Command System (ICS) structure. As public safety communications become more complex and as more choices are made available, it is critical that personnel who are trained in public safety communications be available to assist the Incident Command team.

NPSTC should work with appropriate standards bodies to improve cell edge spectral efficiency to accommodate incidents occurring in non-ideal locations.

Questions about Emerging Broadband Technology

Significant emphasis was placed on the issue of broadband technology and spectrum needs to support public safety communications. A number of critical issues were identified by the Working Group. Of major concern was the need for broadband technology and application standards to promote interoperability between first responder agencies. While this statement seems quite obvious there are dozens and dozens of technical and operational issues to be resolved during the proposed creation of a nationwide public safety broadband network. Some of these elements are significantly complex, including the need to improve cell edge spectral efficiency to accommodate incidents occurring in non-ideal locations and to enhance the usability of broadcast and

Next generation public safety broadband systems should be designed to automatically assess the available network options and automatically create the needed and approved communications paths.

multicast capabilities using Long Term Evolution (LTE) technology, the standard chosen for the nationwide public safety broadband network.

Public safety will also need to closely monitor the emerging development of new and innovative technologies that may assist or hinder emergency communications. It is envisioned that as technologies mature public safety should see more robust applications that require smaller amounts of network bandwidth. However, the growing demand for applications and image resolution are expected to offset such improvements.

Broadband networks and applications must affordably satisfy all of the requirements of public safety LMR systems before it can replace them.

Other factors include the need to balance quality of service with the priority of the request. The nationwide public safety broadband network will need to prioritize individual transactions and consider situational context of applications, not just the relative priority of a particular user based on their agency affiliation. The network may need to be aware of a user's particular assignment at the scene or whether a user in the area of the incident is not associated with the emergency that requires high-priority network access. Discussions are under way to determine how these priorities should be assigned. An Incident Commander should have the capabilities (with support from a COML) to influence network priority rather than having this responsibility fall to an overwhelmed public safety dispatcher or to the individual radio user. It must be noted that this report does not attempt to quantify the additional volume of broadband data that is likely to be transmitted to field units as a result of the Next Generation 911 project.

These next generation public safety broadband systems should also assess the available network options and automatically create a viable communications talk path for the user. The network should be designed to provide mission critical service and should provide all users with a common set of applications and features. It should be constructed to support the needed applications and services for public safety agencies, including appropriate levels of quality and security. The communications device of the future should provide the user with more information such as confirmation that it is successfully attached to the nationwide public safety system.

The report findings and evolving issues indicate the need for continued support to identify broadband solutions and impediments to the provision of mission critical push-to-talk (PTT) over LTE. As mission critical PTT voice is being developed, it must include the ability for nationwide roaming to allow for total interoperability between and among public safety first responders. Before it can replace LMR systems, a broadband network and associated applications must be able to meet all of the requirements of existing LMR systems. This is meant to say that public safety agencies should not sacrifice any of their existing capabilities when switching to a broadband system. The AFST Working Group recommends NPSTC continue work with the Broadband Working Group (BBWG) and its Task Groups to fully document public safety's requirements and path forward in this critical area.

Long-term and short-term opportunities should be identified with regard to mission critical voice over broadband. Short-term benefits such as nationwide application access, integrated applications, and others should not be held up by the longer term goal of replacement of LMR with broadband. Instead, the public safety community should create parallel paths to accomplish both long-term and short-term objectives.

More Spectrum Is Clearly Needed

The AFST Working Group received many comments on the need for additional narrowband spectrum to support public safety operations, including the need for additional interoperability spectrum assignments. A review of available spectrum coupled with full implementation of the SAFECOM Continuum using open standards solutions indicates that sufficient talk path capabilities do exist to support multi-jurisdictional incidents, assuming public safety maintains access to its existing spectrum.

> *Public safety agencies need additional VHF spectrum. Consider requiring Part 22 to be narrowbanded creating 12.5 kHz channels; freeze non-public safety licensing in Part 22; and making certain lightly licensed Part 22 channels available for public safety use. Request that the FCC audit use of the VHF spectrum and recover any unused frequencies. Make those frequencies available for public safety licensing.*

However, the same analysis shows the need for additional VHF narrowband spectrum to support existing and future public safety communications needs. Many rural agencies compete with statewide public safety agencies for access to VHF spectrum, which is highly desirable spectrum due to its ability to cover very wide areas at lower costs. Additional VHF frequencies might be found if the FCC conducted a spectrum audit of this band to identify active users of the spectrum and to determine what VHF frequencies might be made available to public safety. A review of the FCC Universal Licensing System (ULS) also shows that many channels are available in the FCC Part 22 allocations which were primarily used for older style mobile telephone interconnect services.

There are various opportunities available in this band, including potentially adding a new requirement for Part 22 users to narrowband their systems from 25 kHz to 12.5 kHz channel level, freezing new licensing of non-public safety users in the Part 22 band, and, additionally, by making some Part 22 channels which are used infrequently available to public safety. Following narrowbanding, the FCC should also be asked to audit use of the UHF spectrum (450 to 470 MHz) to determine if any recovered channels could be designated for interoperability on a regional basis.

NPSTC recommends the establishment of a new working group to study the impacts of the Middle Class Tax Relief and Job Creation Act of 2012 (Spectrum Act) on UHF capacity. The Spectrum Act establishes relocation of public safety users between 470 and 512 MHz (the T-Band) around the year 2023. This band is heavily used in major metropolitan areas of the United States. The new working group should study potential solutions for the relocation of these public safety users.

It is clear from the operational interviews and the spectrum calculations that public safety agencies will need priority access to 20 MHz of broadband spectrum allocated to public safety in the Spectrum Act. The medium-scale incidents discussed in the focus group required more than 10 MHz of total spectrum while the large-scale incidents required more than 20 MHz of spectrum. These findings firmly support the additional allocation of 10 MHz granted to public safety in the 2012 Act. Given inadequate spectrum access, public safety could experience frequent congestion. Public safety will have to manage quality of service and priorities within its demands for large-scale incidents.

Broadband systems and networks also require a significant amount of backhaul capacity to connect on-scene operations with the larger public safety fixed network. Fiber and fixed microwave communications provide the most viable pipeline for this activity. A review of existing systems and spectrum indicates that additional microwave spectrum may be needed by public safety agencies. A variety of options are available to address this shortage. First, public safety should maximize the use of broadband fiber in place of microwave. This would include partnerships with private companies. Microwave systems should be engineered to use shorter hops where possible to maximize the available bands and therefore the total spectrum available for each link. The FCC should also be advised that current microwave spectrum allocations in Part 101 may be insufficient in areas where fiber is not available, affordable, or not feasible to install. The Commission should conduct a study to determine if new spectrum should be made available and identify potential solutions if appropriate. Public safety agencies may also desire to increase their use of the 4.9 GHz band for backhaul when no other options exist.

Public safety agencies need additional microwave spectrum. Recommended: Use broadband fiber in place of microwave, including partnerships with private companies. Use shorter hops where possible to maximize frequency options. Encourage FCC to monitor issue and to be aware of concerns that current microwave (Part 101) spectrum allocations may be insufficient in areas where fiber is not available or not feasible to install. Increase use of the 4.9 GHz band for backhaul when no other options exist.

Introduction

The National Public Safety Telecommunications Council (NPSTC) authorized the creation of a Working Group within its Technology Committee to assess the future spectrum and technology needs of first responder organizations. This group was chartered as the Assessment of Future Spectrum and Technology (AFST) Working Group in August 2009. The Working Group was tasked to provide an update to the Public Safety Wireless Advisory Committee's (PSWAC) *Final Report* of September 11, 1996. The PSWAC *Final Report* documented public safety's spectrum and technology needs through 2010. The AFST Working Group was tasked to identify the public safety communications requirements for the 10-year period, from 2012 to 2022, and assess their impacts on technology and radio spectrum. The Working Group was charged to deliver a final report that identifies spectrum and technology needs to help drive policy (spectrum, funding, and other), standards development, and the public safety vendor community to meet those needs. This document represents the final report of the Working Group.

This report is organized in four main sections:[2]

- Executive Summary/Introduction: An overview of the findings and recommendations of the AFST Working Group;
- Operations Report: The Operations Task Group focused on the communications needs of the public safety community.
- Technology Report: The Technology Task Group focused on the resulting technology needs that stem from the public safety operational needs.
- Spectrum Report: The Spectrum Task Group focused on the net wireless spectrum impact resulting from the operational needs of the public safety community and the host of technologies that will meet the need.

1.1 Operations Needs Assessment

The Working Group focused its initial efforts on capturing public safety communication requirements. In the spring of 2010, the Operations Task Group issued a web-based questionnaire to seek input from the public safety community on its needs. NPSTC received responses from the local, tribal, state, and federal communities as well as the vendor community. Responses represented urban, suburban, and rural public safety agencies, and spanned all functional groups within the public safety community (e.g., emergency medical services (EMS), fire/rescue, law enforcement, mass care, etc.). When the feedback period ended, on July 15, 2010, a total of 291 comments had been filed for consideration. A review of the agency demographics revealed a mix of urban, suburban, and rural responders had participated representing local government operations from those respective areas.

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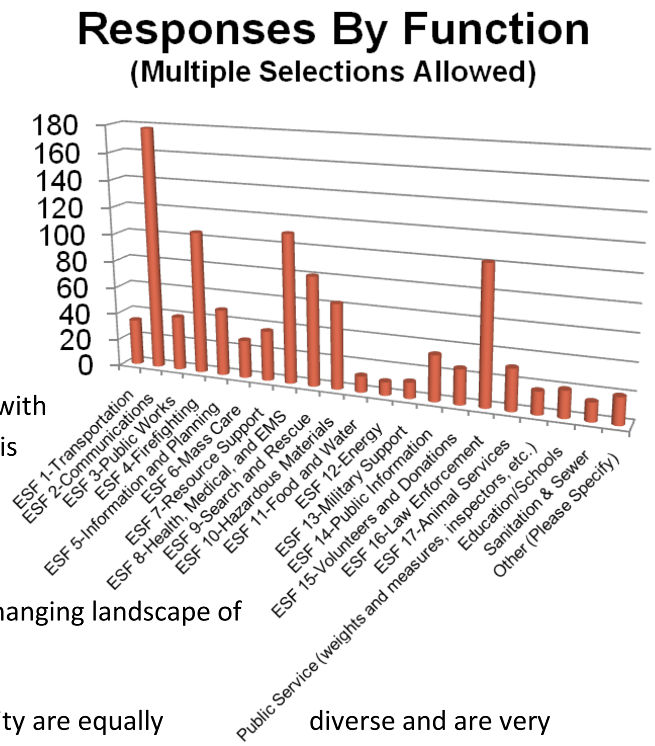
[2] Additional information used in the development of this report such as questionnaire results, spectrum calculations, and other reference materials can be found on the NPSTC website at www.npstc.org/AFST.

Feedback was requested on a wide range of topics including perceptions about spectrum availability, use of broadband systems, and progress toward achieving interoperability. To supplement the feedback received via the Internet, a series of focus groups were held across the U.S. during September and October of 2010. These meetings allowed for a structured and comprehensive review of data communications needs at the scene of a unique emergency in their area. Focus groups were hosted in the following locales:

- Southern California, September 8, 2010, Wild Fire
- Houston, Texas, September 21, 2010, Chemical Plant Explosion
- Washington, DC, September 27, 2010, Toxic Gas Leak
- Orlando, Florida, October 25, 2010, Hurricane



Public safety communications are diverse. The public safety community interacts with the public via 911, the media, and with mass notification systems. However, the focus of this report is communication within the public safety community. This includes communication from dispatchers, field personnel, emergency operations centers, hospitals, and other facilities, but not the general public. This report does not ignore the changing landscape of communications for public safety.

The communications needs within the public safety community are equally diverse and are very unique. The nature of public safety operations requires that frequently a dispatcher, commander, or first responder in the field communicate with tens or hundreds of other public safety personnel. Communication needs include voice, video, text, images, and other data critical to fulfill the public safety mission. While voice communications represents the most critical form of communication media, the remaining forms are growing dramatically in their importance.

The AFST assessment showed public safety agencies voice communications needs are largely met with existing technology and continued availability of public safety spectrum, but financial and relationship barriers continued to slow their ability to achieve interoperability with other agencies. Voice communications for "day to day" incidents were also deemed to be mostly adequate, but were completely insufficient in a large-scale incident when a formal National Incident Management System (NIMS) Incident Command structure was implemented. In 2010, the core issues regarding voice communication included cost, insufficient capacity, multi-band interoperability, roaming, tactical to wide-area communications, and training. These issues are explored fully throughout this report.

Major improvements have been made to enable interoperability between agencies and many of the nation's first responders are now able to communicate with neighboring jurisdictions. In spite of these advancements, the interoperability solutions have a variety of deficiencies that hampers their effectiveness. These include patching system issues, which may not carry radio IDs; encryption; and voice latency as well as time delays to activate deployable solutions. In many cases, first responders must select between several available interoperability solution choices when arriving at the scene. Training continues to be problematic in that first responders need a significant amount of training, and retraining, to maintain a working knowledge of the solutions and the appropriate use of each type of device. Incredibly for the single piece of equipment that most responders carry and use most frequently (typically many times on every call) – their Land Mobile Radios – they receive the least amount of training. Respondents to the web questionnaire reported that less than half of them have met their interoperability needs or that interoperability solutions are cumbersome. Existing communications solutions are insufficient at the scene of a major incident due to the number of channels and talkgroups that need to be cross connected, voice latency with console patching, and problems created when agencies migrate to different frequencies/frequency bands.

The public safety community reported that one of their greatest challenges was the implementation of effective data services to support mission critical applications including mobile dispatch, automatic vehicle location, and access to state and national databases. Reliability, data speed, coverage issues, and lack of priority access were all cited as roadblocks to implementation of additional applications such as Geographic Information Systems (GIS)[3] and access to building plans. The operational needs assessment found that public safety agencies were increasingly aware of the growing demand for broadband services and applications and the new role this technology was playing in the public safety communications arena. The most common communication shortfall identified in the web questionnaire was broadband communications.

The Operations Task Group recognized the importance of capturing the broadband requirements of public safety. And because of the lack of familiarity within the public safety community regarding the broadband applications and the lack of use in real-world operating environments, the Task Group opted to collect broadband requirements via focus groups. The focus groups enabled the Task Group to fully explore how public safety operations could benefit from broadband communications. Furthermore, they provided a detailed review on the quantity of data that would be shared within the public safety community. Based on feedback from the Technology Task Group, the focus groups were isolated to major public safety incidents, where the diversity and density of broadband communications were anticipated to be most representative of the public safety community in general.

1.2 Technology Needs Assessment

Voice communication needs have been predominately met by Project 25 (P25) equipment and standards. P25 provides the one-to-many voice communication capability necessary for public safety communications and delivers the interoperability needed via open standards. The impetus of P25 and the national voice interoperability deficiencies were underscored in the PSWAC *Final Report* and national efforts since 1996 have dramatically improved public safety interoperability. Funding and relationships remain the primary impediment to voice interoperability needs. However, the Operations Task Group did identify several

[3] A Geographic Information System (GIS) digitally creates and "manipulates" spatial areas that may be jurisdictional, purpose, or application-oriented for which a specific GIS is developed. In a general sense, the term describes any information system that analyses, displays, edits, integrates, shares, and/or stores geographic information for informed decision making. (Source: Wikipedia).

functional areas where technology may play a role in addressing public safety's voice communications needs more comprehensively.

A frequent complaint was the lack of effective management of wide-area and tactical communications simultaneously. Today's equipment allows public safety agencies to manage these transitions to a significant extent. The Task Group identified opportunities for technology to play a role in improving these transitions using broadband packet communications whereby the public safety communications equipment ensures public safety can always communicate in the most effective, efficient, and transparent means.

The operations assessment also shed light on roaming and interoperability deficiencies for voice communications. Many of these issues are addressed by changes in system configuration and existing interoperable P25 products available on the market. These solutions do not, however, provide comprehensive national interoperability. The solution to this issue may involve improvements in technology leveraging a nationwide public safety broadband network with a push-to-talk application that incorporates nationwide roaming service.

NPSTC should continue supporting work to identify impediments and broadband solutions for the provision of mission critical push-to-talk over LTE.

The Technology Report provides an analysis of the operational requirements of the public safety community against the available wireless technologies and spectrum bands. The Task Group found that both narrowband and broadband spectrum allocations must be maintained for the foreseeable future. NPSTC also supports a Broadband Working Group focused on Mission Critical Voice, which identified a number of public safety voice requirements that are simply not achievable today nor are there known solutions in the near future to deliver push-to-talk (PTT) voice to fully replicate narrowband solutions over a broadband Long Term Evolution (LTE)[4] system. While this report's focus is on mission critical PTT voice, this is not intended to exclude the need for traditional full duplex voice calls that are supported by current cellular networks. This focus on PTT voice simply recognizes that the major challenge is developing a mission critical PTT voice application for LTE that replicates the functionality of public safety's current Land Mobile Radio Systems. As a result, the Technology Task Group recommends continued planning for separate narrowband and broadband spectrum allocations until broadband can be proven to replicate narrowband capabilities.

The AFST Working Group learned public safety's wireless broadband data communications needs are largely met or under development by today's broadband technologies. In 2012, the foundation for the public safety community to achieve its functional requirements for broadband data communications was largely met by the selection of LTE for the proposed nationwide public safety broadband network. Once regulatory and policy decisions are finalized, public safety should begin to have broadband capabilities as the network is deployed. While commercial-based technologies such as LTE are capable of meeting many public safety requirements, commercial networks do not currently meet the availability requirements of public safety broadband wireless services. The federal government set a roadmap for addressing these deficiencies

[4] LTE is a standard for terrestrial wireless broadband communication developed by the Third Generation Partnership Project (3GPP). It is a trademark of the European Telecommunications Standards Institute (ETSI).

through the Spectrum Act, which allocates spectrum, funding, and governance for a nationwide broadband network.

Despite the tremendous capabilities of LTE and the numerous other advances in broadband technologies, a number of gaps remain. The Task Group identified several gaps associated with the delivery of mission critical push-to-talk over LTE. Enhancements to technology will be critical in closing this gap. And while the selection of LTE provides network interoperability, the Task Group identified a number of areas where application interoperability will be critical to provide useful interaction between public safety agencies. Public safety needs national standards prior to the deployment of these applications to avoid patching workarounds that could disrupt interoperability in the next 10 years. Finally, broadband technologies need to improve and public safety must move forward on standards that will enhance the capacity of broadband networks in public safety environments.

1.3 Spectrum Needs Assessment

The Spectrum Task Group was tasked with assessing the public safety radio spectrum allocation based on the findings of the Operations and Technology Task Groups. The Task Group leveraged spectrum models provided by the International Telecommunication Union (ITU) to calculate the amount of spectrum required to meet public safety's wireless communications needs.

The Spectrum Task Group provided a full assessment of the wireless spectrum available to the public safety community and an assessment of the required spectrum allocations. Importantly, public safety requires a variety of spectrum allocations for economic and functional reasons. The Task Group highlighted the propagation differences between low and high frequencies, resulting in a need to plan Very High Frequency (VHF) and Ultra High Frequency (UHF) spectrum allocations separately. As a result of this analysis, the Task Group modeled public safety's spectrum needs for VHF and UHF systems as individual needs. Furthermore, as highlighted in the Technology Report, the Spectrum Task Group separated broadband from narrowband needs as each technology delivers unique public safety communications needs.

From the time of the PSWAC *Final Report* until this updated report, public safety has received significant spectrum allocations. Yet the nature of public safety operations and the growing need to better manage day-to-day operations and response to large complex incidents still leave public safety short of spectrum in key areas.

The 700 MHz nationwide narrowband allocation and specific UHF TV sharing allocations in large urban areas have helped meet public safety mission critical voice needs in most areas. Some areas are making large investments in new 700 MHz voice systems as that band and available radios that cover both 700 MHz and 800 MHz help to provide interoperability across multiple jurisdictions and/or agencies in a city, region, or state.[5] In some rural areas, reported through the operations questionnaire, jurisdictions experience a

[5] At the time of this report, the AFST Working Group is aware of large 700 MHz systems in operation or being built out in Houston, Texas; the State of Maryland; the County of Riverside, California; the State of Louisiana; the State of Colorado; the State of Arkansas; and many other jurisdictions across the country.

shortage of VHF spectrum for growth. The VHF band is ideally suited for rural areas and is cost effective to implement for smaller cost-constrained agencies.

Public safety agencies can license spectrum in seven separate frequency bands where the FCC has allocated spectrum for public safety use over the years. Those bands and the spectrum available in MHz are listed below Table 1. The 30–50 MHz (high band), 150–174 MHz (VHF), 450–512 MHz (UHF), 800 MHz, and parts of the 700 MHz bands are used for narrowband voice and low speed data systems.[6] The 758-768/788-798 MHz frequencies are allocated for the nationwide broadband public safety network. The 4.9 GHz band is available for short-range broadband data and point-to-point data links. Each voice band has unique propagation characteristics and each band is good or bad for different types of systems.

Table 1: Public Safety Spectrum[7]

Frequency Band (MHz)	MHz[Approximate]	Useage
25-50	6.3	Narrowband Voice
150-174	3.6	Narrowband Voice
220-222	.1	Narrowband Voice
450-470[8]	3.7	Narrowband Voice
809-815/854-860[9]	3.5	Narrowband Voice
806-809/851-854[10] 758-763/788-793[11]	6 10	Narrowband Voice Wide Area Broadband
763-768/793-798[12]	10	Wide Area Broadband
768-769/798-799[13]	2	Guard
769-775/799-805	12	Narrowband Voice[14]
4940-4990	50	Short range Broadband
Total	107.2	

[6] The Spectrum Act allows the FCC to permit flexible use of broadband in 700 MHz narrowband spectrum (769-775 and 799-805 MHz), but any move to do so would first need to consider the potential for interference between broadband and narrowband systems.

[7] Recent Congressional action authorizing the D Block also directs that the FCC reclaim public safety channels in the T Band (470-512 MHz)

[8] Also available in 11 market areas are TV-sharing frequencies in parts or all of TV channels 14 to 20. See the Spectrum Section 4.3.1.4 for more details.

[9] This allocation was altered by the ongoing 800 MHz reconfiguration. Some additional channels are being made available to public safety as the reconfiguration completes and total the number varies per geographical region. These additional channels are not included in the table count. See FCC 90.615.

[10] The National Public Safety Planning Advisory Committee (NPSPAC) band moved to the low end of the band with no change in the size of the allocation due to the 800 MHz band reconfiguration. See FCC 90.677.

[11] Allocated as part of the Spectrum Act in February 2012. Also known as the D Block. It should be noted that this spectrum can be offered to non-public safety users on a secondary basis, however, Section 6212 of the Spectrum Act prohibits the First Responder Network Authority from the direct offering of telecommunications service directly to consumers.

[12] This does not include the 1 MHz internal guard band.

[13] This is a two MHz guard band between the broadband and narrowband allocations.

[14] Pending potential flexibility by the FCC as part of the Spectrum Act.

The 30-50 MHz band is primarily used in some statewide systems to provide mobile coverage of highways. The VHF band is a good band for rural areas, while the 450 and 700/800 MHz bands are used in urban and suburban areas where good portable coverage is needed. The 700/800 MHz bands are best suited for trunking systems and increasingly are being used for large regional and statewide systems to provide improved communications and interoperability across multiple agencies and jurisdictions.

The Spectrum Task Group sought an appropriate spectrum model that would be suitable to determine the spectrum required for public safety needs. The Task Group found an ITU model based on an ITU cellular model but enhanced it to include narrowband voice in the spreadsheet implementation. The model is flexible and specific to public safety spectrum modeling. The model leverages four fundamental variables to determine the amount of spectrum required: Demand for a given area, number of sites/cells covering the area, spectral efficiency of the technology providing the service, and the amount the technology is able to reuse frequencies. The Task Group was able to implement the model for the 4G LTE technologies in addition to the already included narrowband voice in the spreadsheet implementation. It is important to note that spectrum modeling is an imprecise exercise. The results should not be used to determine absolute spectrum allocations but rather to validate and confirm other indicators of spectrum needs.

In interviews and Working Group calls, the need for additional VHF spectrum, particularly in rural areas was brought forth. To validate that need, modeling was conducted using five rural Arizona Northern Counties. Table 2 below provides the key spectrum modeling parameters while Table 3 summarizes the VHF model results. For more information regarding spectrum modeling assumptions and inputs, please consult the Spectrum Report.

Table 2: Arizona (VHF) Area Spectrum Modeling Parameters

Parameter	Value	Notes
Total Police Personnel	1344	Based on Census data
Total Fire Personnel	2881	Based on FEMA data
Total EMS Personnel	1350	Based on Census data
Total Study Area Size	51255 km^2	Represents the three county area
Cell Radius	30 km	Results in 18.1 sites to cover the study area
Total Width of Frequency Band	3.6 MHz	The VHF spectrum
Guard band and reserved channels	5%	Results in 7.2 channels
Average Call Duration – Voice Uplink	7.5 seconds	
Average Call Duration – Voice Downlink	26.5 seconds	

Table 3: Arizona (VHF) Spectrum Results

Service	Uplink (MHz)	Downlink (MHz)	Total (MHz)
Narrowband Voice	.93	5.9	6.83
Narrowband Data	.08	.15	.23
Narrowband Status	.004	.006	.01
Total		7.07	

An additional modeling exercise was performed to assess the need for spectrum in more urban areas. Very large urban areas like Los Angeles and New York were excluded because these areas have additional spectrum resources from UHF TV sharing that was added since the PSWAC *Final Report* was issued. That spectrum, known as the T-Band, was targeted for reallocation in the Spectrum Act. In 2010 and 2011, public safety had presumed this spectrum would be maintained, and therefore, did not see the impending need to study these major metropolitan areas. Instead, the Working Group decided to model Seattle and the surrounding area. Seattle is a large urban area that is impacted by spectrum sharing with Canada. The voice systems are mostly in the 800 MHz bands using trunking technology with some expansion using the 700 MHz narrowband spectrum. There is a high degree of interoperability on the trunking systems. Agencies operating trunked systems in these bands will have to find additional 700 MHz narrowband channels for any needed system expansion. Table 4 below presents the key input parameters for UHF modeling and Table 5 provides the results of the analysis.

Table 4: Seattle Area (UHF) Spectrum Modeling Parameters

Parameter	Value	Notes
Total Police Personnel	5847	Based on Census data
Total Fire Personnel	5114	Based on FEMA data
Total EMS Personnel	2371	Based on Census data
Total Study Area Size	6203 km^2	Represents the three county area
Cell Radius	7.7 km	Results in 33.3 sites to cover the study area
Total Width of Frequency Band	5%	Represents 70.2 channels (most of these are in the 700 MHz band
Guard band and reserved channels	5%	Results in 7.2 channels
Busy Hour Call Attempts – Voice (Uplink and Downlink)	13	Per the PSWAC voice model
Average Call Duration – Voice (Uplink and Downlink)	13.9 seconds	This average call duration delivers the average busy hour Erlang result from the PSWAC model (0.0502 Erlangs per user)

Table 5: Seattle (UHF) Spectrum Results

Service	Uplink (MHz)	Downlink (MHz)	Total (MHz)
Narrowband Voice	8.33	8.33	16.66
Narrowband Data	.1	.189	.29
Narrowband Status	.005	.007	.012
Total Unpaired Requirement	16.96		

Broadband spectrum modeling used data from the focus groups as inputs to the model (see Table 6). This modeling is intended to show broadband spectrum needs based on large incidents rather than focusing on day-to-day needs. Commercial broadband systems tend to overload and fail when a large incident occurs. Having the broadband data resource is expected to greatly improve management of the large incidents that impact safety of life and property, therefore the broadband spectrum needs should be based on incident management needs.

Table 6: Broadband Modeling Spectrum Needs Summary

Notes	Toxic Gas Leak Washington, DC		Hurricane Event Orlando, Florida		Chemical Plant Explosion Houston, TX		Wildfire Southern California	
	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink
Sum of all required application throughput (kbps)	10,263	7,516	6,974	4,085	7,479	4,564	12,936	10,443
Percentage of total from video sources	97%	92%	97%	92%	98%	94%	94%	87%
Percentage of total from downlink	58%		63%		62%		55%	
ITU Traffic Multiplier	150%							
Overhead and Signaling Factor	115%							
# of Serving Sectors	2		2		2		1	
Spectral Efficiency (bps/Hz)	1	0.47	1	0.47	1	0.47	3.34	1.55
Spectrum Required (kHz)	8,852	13,792	6,015	7,497	6,451	8,376	6,681	11,622
Total Spectrum Unpaired (MHz)	22.6		13.5		14.9		18.3	
Total Spectrum Paired (MHz)	27.7		15.0		16.8		23.2	

The table above shows the vast majority of the traffic from expected incidents in the year 2015 will come from real-time streaming video. Furthermore, the study shows that uplink transmissions, and specifically, uplink video streaming is the primary driver of the overall spectrum due to lower spectral efficiency on the uplink. The table also shows that 10 MHz of spectrum is insufficient for the moderately sized incidents in Orlando and Houston. These incidents required 13.5 and 14.9 MHz of spectrum respectively; however, this assumes unpaired spectrum. Given that likely spectrum allocations that are complementary to commercial technologies would be paired, the more likely spectrum scenario would be 15.0 and 16.8 MHz of spectrum for the hurricane and chemical plant explosion scenarios respectively.

The large-scale incidents required nearly double this amount of spectrum. In the case of the toxic gas leak scenario, a total 27.7 MHz of spectrum would be required. Upon closer inspection of the figures, a 20 MHz allocation (of 10 MHz uplink and 10 MHz downlink) for this incident would be nearly 4 MHz insufficient on the uplink. This would require that public safety ration the available uplink bandwidth and employ quality of service measures to ensure the top priority traffic is successfully received. Likewise, the Southern California wildfire incident required more than 20 MHz of total spectrum in the paired scenario due to an 11.6 MHz uplink requirement. Again, Incident Command would need to ration the available bandwidth for this incident with only 20 MHz of total available spectrum. The layout of the 700 MHz band would prohibit public safety from flexibly assigning uplink transmissions to downlink resources without causing harmful interference.

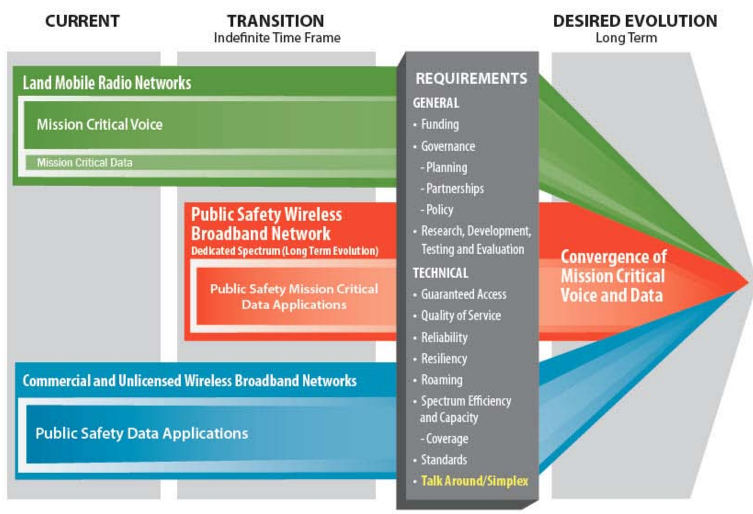
This report does not attempt to model backhaul needs. Wireless backhaul using microwave spectrum is an important tool for public safety voice systems. There may be a need to increase the use of microwave backhaul for the build-out of the broadband network, especially in rural areas. While fiber will be used for most urban data connections, suburban and rural areas will, in many cases, not have cost-effective access to fiber connections. In rural areas environmental conditions and regulations may prevent any use of fiber. The resulting need both for commercial and public safety broadband backhaul will strain existing FCC Part 101 microwave allocations. The degree to which additional microwave spectrum will be required will depend on public safety's level of access to fiber through its own assets as well as those of private partners.

1.4 Key Findings and Recommendations

Finding 1: Public safety agencies have made significant and costly investments to establish, enhance, and expand their land mobile radio communications systems. Narrowband voice communications will continue to be used into the foreseeable future as research continues into the viability of switching mission critical voice over to a broadband system. Please note the key findings are listed in order of their appearance in the Report and not in the order of their importance. Page numbers are included for readers to reference further detail on a subject of interest.

Recommendation #1

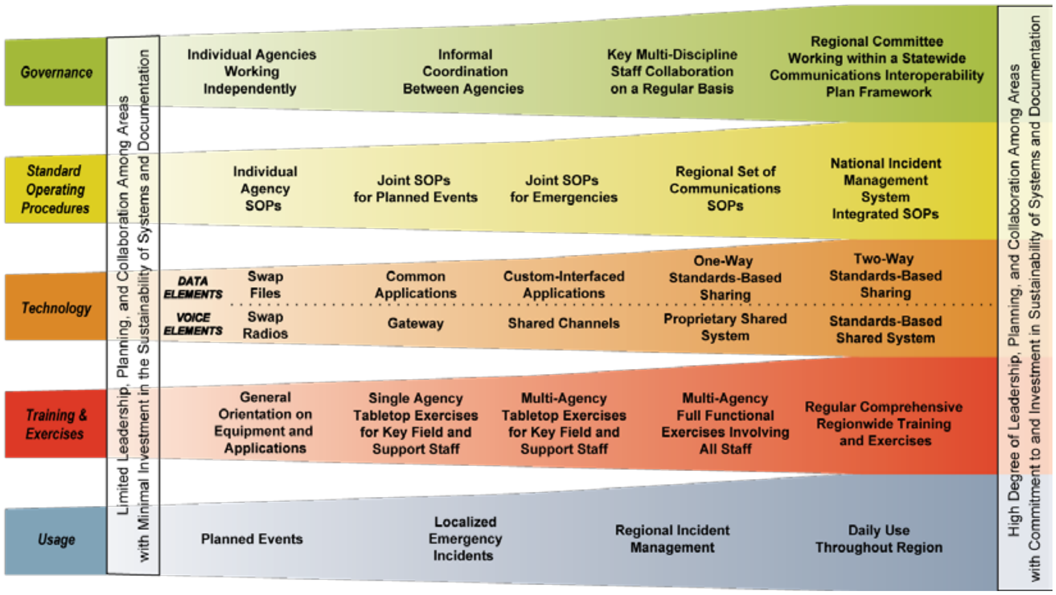
As demonstrated by the DHS SAFECOM Dual Path Graphic below, separate narrowband and broadband spectrum allocations should continue until broadband technologies and deployments can be proven to replace narrowband mission critical voice and data capabilities and until these technologies/deployments meet the needs of all public safety agencies using that particular spectrum.



Finding #2: Public safety agencies continue to experience problems achieving interoperability with neighboring jurisdictions and more distant mutual aid partner agencies. Lack of common channel naming schemes, failure to program subscriber equipment with available interoperability channels, conflicts over governance and policy direction, and financial limitations all contribute to less than optimal, or even satisfactory, inter-agency communications.

Recommendation #2

Public safety agencies are encouraged to implement all elements of the DHS SAFECOM Continuum towards the optimal levels to improve the interoperability issues identified in the NPSTC questionnaire to public safety.



Key Finding #3: Many public safety agencies are still using vendor proprietary radio systems which greatly limit interoperability with agencies that use disparate technology and systems. Many agencies reported a lack of sufficient interoperability talk paths for major incidents, noting the existing conventional channels in most bands were limited. This was especially true for agencies operating exclusively in the 800 MHz band.

Recommendation #3

While many jurisdictions continue to experience interoperability problems due to non-compatible LMR systems, the use of open standards systems and full implementation of the SAFECOM Continuum should provide sufficient talk path capabilities during multi-jurisdictional incidents.
[Caveat: See recommendations below regarding VHF spectrum.]

Key Finding #4: Agencies reported that they will be unable to migrate to open source radio platforms due to financial limitations that are currently preventing upgrades and needed enhancements to their existing proprietary systems. Larger systems experience huge cost implications when contemplating a migration to a new radio standard, including the need to likely replace all subscriber units.

Recommendation #4

NPSTC should develop a white paper on best practices for user agencies that need to achieve interoperability when working with disparate technologies and frequencies.

Key Finding #5: A majority of agencies surveyed indicated that while adequate RF technology and interoperability systems were in place, field user and dispatch center training were insufficient to leverage these assets effectively. A study of several After Action Reviews concluded that the key communications issues were caused by personnel not being sufficiently trained on how to access available interoperability resources. It was noted that subscriber and console radios are becoming increasingly complex and demand initial and recurring training.

Recommendation #5
Public safety agencies should provide initial and recurring training on operability and interoperability to their first responders.

Key Finding #6: Public safety managers report that newer model subscriber radios are being equipped with more and more features. Many of these are not designed for ease of use by the first responder. Examples included the need for an enhanced visual display to indicate if a radio is in a trunked/repeated or simplex mode of operation and use of buttons and switches when wearing gloves.

Recommendation #6
Future interoperability solutions and subscriber equipment should be designed for ease of use and minimum complexity.

Key Finding #7: A review of focus group session feedback, web questionnaire data, and interviews indicated incident commanders are increasingly aware of the complex set of interoperability options available to them. They also are aware that their expertise is in emergency operations and that a communications specialist is needed to help support the communications needs of the incident.

Recommendation #7
Public safety agencies are encouraged to use the expertise of a Communications Unit Leader (COML) to enhance incident interoperability.

Key Finding #8: Discussions with public safety field supervisors and focus group participants noted that first responders are frequently faced with multiple interoperability solutions which can distract them from their assigned operational mission. The need to switch to a conventional channel, to a designated interoperability channel or to operate in simplex mode, or to access a portable/vehicle repeater all require consideration of dozens of factors at the same time the first responder is confronting the emergency incident.

Recommendation #8
Next generation public safety broadband systems should be designed to automatically assess the available network options and automatically create the needed and approved communications paths.

Key Finding #9: In an emergency, public safety agencies must have immediate access to a network which will meet the unique mission requirements of first responders. Many agencies have reported ongoing problems with commercial data networks that do not provide sufficient coverage or which become overwhelmed during a major incident. The need for hardened facilities and reliable backup power are all essential components in a public safety grade network.

Recommendation #9
Public safety agencies should be able to access a nationwide broadband network that is designed for a public safety grade of service and is managed by public safety.

Key Finding #10: As research continues on the viability of providing mission critical voice communications on the broadband network, consideration should be given to how a nationwide network would interoperate with other agencies and jurisdictions. It was noted that roaming from one area to another may require that the public safety radio be reprogrammed by a technician for additional features, channels, and authorization. This proved to be a major impediment at the scene of several recent disaster events and hampered incident coordination and command.

Recommendation #10
Mission critical push-to-talk over broadband must include the ability for the first responder to automatically connect to other entities and remote jurisdictions on the public safety network (as authorized) without reprogramming or updating the subscriber device.

Key Finding #11: Existing public safety subscriber radios enjoy a broad mix of functions and features. Public safety data systems are typically accessed using proprietary applications and functionality. In some instances, first responders do not know if their mobile or portable device is connected to their data network.

Recommendation #11
The nationwide public safety broadband network should provide all public safety users with a common set of applications and features nationwide that can be supplemented as operational needs dictate. The public safety broadband devices should let the user know if the device is attached to the nationwide public safety system.

Key Finding #12: As work continues on the design for a nationwide public safety broadband network, it is critical that the first responder community provide input on the needed functions and features, including minimum quality of service standards, issues relating to priority access, and a host of other concerns.

Recommendation #12
NPSTC should continue supporting work to identify impediments and solutions for the provision of mission critical push-to-talk over LTE.

Key Finding #13: Today, many public safety agencies cannot share mobile and portable device information with other agency responders. Data from a Automatic Vehicle Location (AVL) or blue force tracking system may not be available to the incident commander managing an emergency in an adjoining community. Building preplan information, target hazard files, and other critical pieces of information typically do not flow to all responding units when that incident involves units from more than one jurisdiction.

Recommendation #13
Public safety agencies need broadband application standards which will allow multiple agencies to efficiently share information.

Key Finding #14: Public safety agencies are embracing the critical support that can be provided by video systems, while also enhancing the use of databases and Geographic Information Systems (GIS). There is an emerging concern that an agency's public safety data network may not be able to handle the required amount of traffic at the needed service level. Incident Commanders could lose critical video and GIS services in order to preserve sufficient bandwidth for transmission of AVL data and other files.

Recommendation #14
The nationwide public safety broadband network should be sufficiently robust to support the needed applications at the required quality of service and security.

Key Finding #15: There are tremendous opportunities for public safety agencies to leverage the use of a nationwide broadband network. It should be recognized that any migration to a new platform will take considerable time as agencies work through a variety of logistical issues including assessment of an existing system lifespan, financial implications, and user needs. It is also recognized that not all broadband services and functionality will be available simultaneously.

Recommendation #15
The NPSTC BBWG should identify short- and long-term opportunities for mission critical voice over broadband. Short-term benefits such as nationwide roaming, integrated applications, and others should not be held up by the longer term goal to replace LMR using broadband. The public safety community should create parallel paths to accomplish both long- and short-term objectives.

Key Finding #16: Public safety agency managers continue to be extremely worried that elected officials and some executive level officers will immediately embrace the concept of mission critical voice over broadband; and stop funding existing Land Mobile Radio (LMR) systems. There is much work to be done before a reliable timeline could even be established creating a roadmap for this possible transition.

Recommendation #16
Broadband networks and applications must affordably satisfy all of the requirements of public safety LMR systems before it can <u>replace</u> them.

Key Finding #17: The creation of a nationwide public safety broadband network requires considerable research and planning to meet the needs of the first responder community. Issues to be addressed include provision of data, voice, and video services; network security and authentication; local, regional, statewide, and national control elements; and quality of service levels and standards.

Recommendation #17
NPSTC should continue the work of the BBWG to develop broadband requirements and solutions.

Key Finding #18: Emergency events may occur anywhere without regard to the location of public safety communications infrastructure. Incidents which occur toward the edge of a communications node or cell frequently result in diminished bandwidth.

Recommendation #18
NPSTC should work with appropriate standards bodies to improve cell edge spectral efficiency to accommodate incidents occurring in non-ideal locations.

Key Finding #19: Data flowing to an emergency incident may originate from the central network or be passing from the incident scene up to the central network and back down to units. Efficient distribution of messages and data frequently relies on broadcast and multicast systems. Lack of multicast and broadcast capabilities in a broadband data network will result in dramatic increases in required spectrum.

Recommendation #19
Appropriate technical standards are needed to enhance the usability of broadcast and multicast capabilities in LTE.

Key Finding #20: A review of VHF spectrum allocations revealed that more spectrum is needed for narrowband communications in the band for general communications. Additional interoperability channels are also needed in the band.

Recommendation #20
Public safety agencies need additional VHF spectrum. The FCC should consider the following recommendations: Require Part 22 frequencies to be narrowbanded to create 12.5 kHz channels. Freeze non-public safety licensing in Part 22. Make certain lightly licensed Part 22 channels available for public safety use. Request that the FCC audit use of the VHF spectrum and recover any unused frequencies. Make those frequencies available for public safety licensing.

Key Finding #21: The reallocation of the T-Band in the Spectrum Act removes the primary band utilized in several major metropolitan areas. While funding for transitioning these current users is also unclear, the loss of this spectrum creates a potential major shortfall in urban capacity for narrowband applications.

Recommendation #21
Public safety needs to study the reallocation of the T-Band specified in the Spectrum Act. NPSTC should create a working group that identifies potential solutions to the loss of this spectrum to the extent viable solutions would be available.

Key Finding #22: Implementation of a public safety broadband network will require a system design to accommodate backhaul of data communications from the incident scene into the nationwide network. Agencies typically use microwave spectrum in addition to fiber optic connections to move large amounts of data from point to point. It is believed that public safety may need direct access to additional microwave spectrum, either through direct licensing of microwave bands or through partnerships or commercial leasing.

Recommendation #22

Public safety may need additional microwave spectrum. Recommended: Use broadband fiber in place of microwave, including partnerships with broadband facilities companies leveraging right of way assets. Use shorter microwave hops where possible to maximize frequency options. Encourage FCC to monitor issue and to be aware of concerns that current microwave (Part 101) spectrum allocations may be insufficient in areas where fiber is not available or not feasible to install. Increase use of the 4.9 GHz band for backhaul when no other option exists.

Key Finding #23: Public safety agencies need additional interoperability channels in all spectrum bands to support large-scale incidents. This is especially true in areas utilizing proprietary radio systems that rely on conventional channels for interoperability.

Recommendation #23

Public safety agencies need additional interoperability spectrum. The following recommendations should be considered: Some number of channels identified in Recommendation #20 should be allocated to public safety interoperability. NPSTC should ask the FCC to audit use of the UHF spectrum (450 to 512 MHz) after the narrowbanding effort is complete and determine if any recovered channels could be designated for interoperability on a regional basis.[15]

Key Finding #24: Public safety agencies are not able to access sufficient narrowband and wideband spectrum to enable operational control and video feed from bomb robots and other on-scene technical devices.

Recommendation #24

NPSTC should facilitate discussions between public safety users, wireless vendors, and robot manufacturers to find a solution to accommodate the narrowband and broadband applications needed using currently available spectrum allocations and wireless technologies

[15] Public safety currently operates in the 470 to 512 MHz T Band. Congress directed that band to be auctioned and the public safety operations moved elsewhere. At this time no suitable replacement spectrum is identified.

2 Operations Report

2.1 Introduction

Public safety communications will continue to evolve over the next 10 years. It is critically important that the first responder community help guide the development of new technologies and solutions to ensure they meet the operational needs of the agencies affected. A number of deficiencies have been identified in the current radio and data communications landscape and a number of future needs have been identified.

2.2 Public Safety Communications Overview

This chapter examines voice communications issues in current public safety LMR systems and provides a review of existing data applications and services in use by law enforcement, fire/rescue, EMS, and other first responders. The chapter also reviews the emerging broadband communications capability and notes some of the needs and requirements for public safety.

The Operations Report outlines a number of communications needs of the public safety community identified in 2010. The following represent those needs at a high level:

- Push-to-talk voice: Provides critical one-to-many communications services over wide areas and tactically at an incident scene where there is 100 percent availability of some type of voice communications through redundant mechanisms including network-based and direct communications options.
- Paging: Provides one-to-many notifications via voice or alphanumeric messages. Preferably provided over a low-power consumption and wearable device.
- Full duplex voice: Provides cell phone style (continuous bi-directional communication) voice.
- Data: Provides non-voice information such as computer aided dispatch (CAD) messages. In the future, data will include Next Generation 911 (NG911) forms of information such as text, images, and video.

2.3 PSWAC Findings and Recommendations

A number of statements, observations, and findings were listed in the Public Safety Wireless Advisory Committee (PSWAC) *Final Report* to the Federal Communications Commission in 1996. Those relating directly to Operations are listed below and continue to be valid more than 15 years later:

> *2.1.10 The currently allocated Public Safety spectrum is insufficient to meet current voice and data needs, will not permit deployment of needed advanced data and video systems, does not provide adequate interoperability channels, and will not meet future needs under projected population growth and demographic changes.*
>
> *2.1.14 New technologies generally produce two important, but counterbalancing effects for the Public Safety community. First, improvements in technology such as digital transmission and advanced modulation techniques permit users to increase the amount of traffic that can be transmitted over any given amount of spectrum. This phenomenon, considered alone, would minimize the*

requirements for new spectrum. However, the second corresponding effect of technology advances is the creation of a new range of functions and features. These additional capabilities such as high speed data and video transmission require additional spectrum to fully exploit.

2.1.15 Data communication needs are becoming as varied as voice needs, and are expected to grow rapidly in the next few years. New services and technologies (e.g., data systems enabling firefighters to obtain remote access to building plans and video systems for robotics-controlled bomb disposal) that are critical for Public Safety users to continue to fulfill their obligation to preserve life and property are now becoming available.

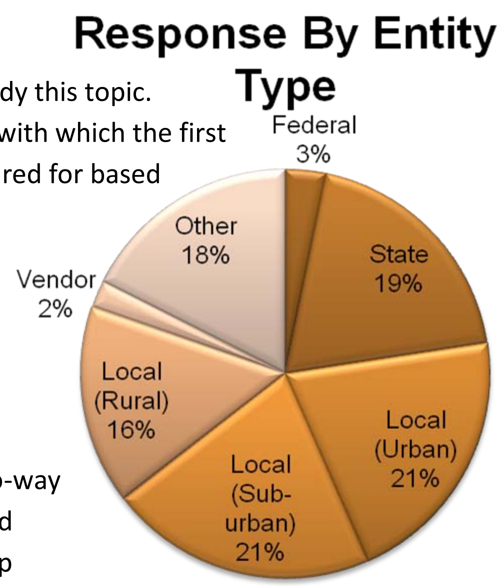
2.1.16 Wireless video needs are expected to expand in Public Safety applications.

2.1.17 Public Service providers require interoperable radio communications with Public Safety agencies.

2.1.19 Flexible mandates are needed in order to encourage the rapid deployment of new technologies.

2.4 Requirements Gathering Methods

In May of 2010, a web-based feedback tool was distributed to local, state, federal, and tribal public safety groups to provide feedback on a variety of questions relating to spectrum use and interoperability. When the feedback period ended on July 15, 2010, a total of 291 comments had been filed for consideration.



The AFST Working Group determined that a series of focus group sessions held around the country would create the best environment to further study this topic. Each session was designed to either discuss an actual emergency incident with which the first responders had significant knowledge or an incident which they had prepared for based on their domestic security threat assessments.

Finally, the Working Group provided an email address to collect any other requirements from the public safety community and conducted dozens of additional interviews and conference calls.

2.5 Communications Needs

Operational needs for public safety were identified through a series of two-way communications engagements with actual first responders. These included various interviews, a nationwide web questionnaire, a series of focus group discussions held with teams of first responders in cities across the U.S., and distribution of issues lists to the AFST Working Group and selected external participants to help validate the information received.

2.5.1 Voice and Data Communications

It should be noted that many agencies reported that the majority of their public safety communications needs were currently being met with existing technology and resources. Agencies who have sufficient funding and governance plans in place indicated that their daily operational needs are being met in most circumstances.

A review of the feedback from the public safety agencies also indicated several recurring themes regarding operations. Conventional interoperability channels are insufficient to meet the needs of any large-scale effort requiring involvement of personnel from multiple jurisdictions. There are a limited number of conventional interoperability channels in each radio spectrum band. At the scene of a large-scale emergency, EMS, fire/rescue, law enforcement, and other responders each need to segment their operations ("nets") into task force and work group configurations. Each "net" consists of a conventional radio channel (or a talkgroup on a trunked radio system); when a single net involves users operating in different bands and/or on disparate technologies, a single net may require multiple channel/talkgroup resources that are cross-connected through a gateway. It is possible that each public safety discipline may require four to five separate nets for coordination of their operations.

Most radio data features are lost when roaming from one system to another, when switching to a conventional channel or when using an IP based gateway system. Public safety agencies rely on a variety of data features included in the radio handset. These include Radio ID numbers which help identify the user of the radio and which are frequently translated via the radio console or the Computer Aided Dispatch system to display the actual name and/or Unit ID of the first responder. This is a critical safety issue that is often lost when units switch from a trunked environment to a conventional interoperability channel. Without special programming and installation of additional equipment, the Emergency Call Button (or "Trigger") is not functional when switching to a conventional channel. Field personnel are trained on the use of these buttons as a part of their safety and survival training. It is unfortunate that agencies must train their personnel to also understand that in certain circumstances these features may not work. Most encryption is lost when roaming to another system. Encryption is typically used for certain types of law enforcement activities in which there is an extreme level of danger and where a high level of message content confidentiality is needed. This includes barricaded suspects, high-risk warrant sweeps where dangerous fugitives are being tracked, and many drug and weapons violations. Response to many of these incidents involves more than one agency. However, the variety of encryption options and vendor proprietary features makes it very hard for these teams to communicate with message content confidentiality.

The majority of public safety agencies do not use equipment which will allow Incident Command to scan both trunked radio traffic and conventional radio traffic while trying to coordinate activity at a major incident. During many major incidents, mutual aid units may be operating on a conventional interoperability channel while other units are operating on a trunked radio system. This necessitates the purchase and use of multiple mobile or portable radios to coordinate responses or the purchase of expensive, new subscriber equipment.

It is difficult to ensure that all first responders receive sufficient training on the use of increasingly complex radio units and on the use of multiple interoperability solutions. Ironically as mentioned earlier, radios are the single most used piece of safety equipment used by responders (typically many times on every call) and one for which they receive the least amount of both initial and ongoing refresher training. This issue has been identified as a significant public safety communications impediment. Each public safety discipline typically has state-mandated training recertification requirements. As more and more mandated training is added to the list, agencies must scale back on non-required training programs. There are typically no state requirements for public safety radio training. Manufacturers, responding to feedback from the public safety community, continue to add more functions and features to the radio. This makes subscriber units increasingly complex to operate. The old "push to talk, release to listen" training is no longer acceptable in today's environment. Training is also expensive for agencies and frequently requires overtime payments to employees and/or the use of expensive backfill for employees being trained. Beyond training for the actual subscriber radio device, public safety personnel must have sufficient training to operate a myriad of complex interoperability solutions. These include awareness of gateways (including console patches), interoperability channels/talkgroups, Bi-Directional Amplifier (BDA) systems, vehicle repeaters, and other devices.

Lack of common channel and talkgroup names continues to cause confusion at the scene of an emergency incident. Many agencies have not reprogrammed their subscriber radios and consoles to display the currently adopted channel names for conventional interoperability frequencies. Other systems allow variations to channel and talkgroup names based on a request from the user agency. These disparate names prevent personnel from selecting an available and common interoperability channel.

Personnel who attempt to upgrade the programming of mutual aid units with compatible radios also encounter problems with differences in the naming of certain data fields in the programming software. These data field names vary widely by manufacturer and can slow down or stop the programming of the subscriber radio to connect to the radio system of the emergency incident.

Public safety needs an appropriate networking device solution that will automatically detect the appropriate technology solution and radio configuration needed at the scene of an emergency incident without analysis or intervention by the user.

- This would allow the radio to automatically switch itself from trunked or repeated operation to simplex if necessary to maintain a voice link with other team members in their work group on that specific net.
- This would allow the radio to alert both the public safety user as well as their incident supervisor when they have lost radio contact with the group.
- This would alleviate a significant amount of decision making and distraction as public safety personnel attempt to analyze the radio environment and make appropriate choices regarding their communications.

There is a loss of paging and alerting functions when agencies migrate from conventional to trunked systems and (often) to digital systems. Agencies generally must maintain separate infrastructure for fire station alerting and paging and/or implement other equivalent solutions. While other public safety disciplines may use paging, the fire/rescue service is especially dependent on voice and alphanumeric paging to alert personnel. A variety of National Fire Protection Association (NFPA) standards dictate how these systems must operate and usually preclude the use of commercial paging providers. A significant percentage of the fire agencies in the U.S. are still volunteer, with many of these departments operating in rural areas. Today, agencies migrating to trunked radio systems must either issue every firefighter an expensive trunked radio or continue to maintain separate infrastructure to support paging. Many agencies cannot get support from their elected officials to maintain these paging systems after an expensive transition to a trunked environment which was promised to fix all problems. Many agencies rely on inexpensive two-way or alphanumeric paging devices to alert volunteers. These devices cannot function in a trunked environment.

Tactical teams working in small groups need to be able to communicate among themselves while not losing contact with the Incident Command /operations channel or talkgroup net. For example, four firefighters who are working together need to be able to communicate with each other to coordinate hose line movement, rescue of injured persons, and entry and exit movements while wearing self contained breathing apparatus (SCBA). These conversations are only applicable to this particular work group. However, the firefighters must also be in communication with the supervisor who is directing their activities. The same type of communications is needed by law enforcement officers working to clear a building after a violent crime. In the absence of a robust standards-based solution, some agencies are experimenting with low power Bluetooth systems built into the SCBA air mask to solve this problem, but Bluetooth and other similar systems operate on unlicensed spectrum and are susceptible to radio frequency interference and spectrum congestion. Furthermore, such communications could interfere with the Incident Command communication structure.

There are also issues with frequency availability for specialized technical equipment at the scene of an emergency. The National Bomb Squad Commanders Advisory Board and NPSTC's Spectrum Management Committee continue to receive complaints on the difficulty of licensing suitable frequencies for the bomb robots. These complaints highlight the difficulty in finding interference-free narrowband VHF and UHF Frequencies required to control the robots. Broadband channels are also required for the robot to transmit video, often requiring an analog video channel. Current spectrum allocations and limitations in wireless technologies available from the robot manufacturers make it very difficult to license frequencies for these robots.

Given this environment, it is recommended that NPSTC facilitate discussions between public safety users, wireless vendors, and robot manufacturers to find a solution to these issues using currently available spectrum allocations and wireless technologies.

The cost of multi-band subscriber equipment is out of reach for most agencies. These new devices are too expensive for large agencies with large fleets of units and too expensive for smaller, rural agencies that have minimal budgets; however, NPSTC notes that as experience with the multiband technology advances, less expensive multi-band radios could become available.

Most agencies cannot support the cost to maintain, upgrade, and replace existing systems. The current financial situation, which is likely to continue for some time, precludes system expansion for additional capacity, migration to another band with more spectrum, or even the ability to join a regional radio system.

Public safety needs additional spectrum to support the voice and data demands of a large-scale incident.

- This includes the need to support tactical voice communications at the scene of a major incident, including a significant number of separate voice communications paths for various functional groups (for example, command functions, evacuation teams, fire operations teams, law enforcement tactical operations, medical transportation and treatment teams, perimeter security teams, etc.).

- This includes the need to support a range of data applications which would be supporting large numbers of public safety personnel on the scene of a major incident.
- This includes the need for the data to be moved from the scene to a centralized command system off site of the incident and the need to access or pull down data from a variety of remote databases and applications.

There is a concern about the coverage impact that narrowbanding will have on an agency's radio system. Changes may be required in tower site configuration and additional sites may be needed to meet agency needs. An agency that operates with three tower sites may require an expansion to four sites, which might require location site changes for the original three sites. This type of engineering and site work is very expensive and time consuming.

There is a perception by a number of the questionnaire respondents that narrowbanding will not free up sufficient new spectrum for expanded operations within the same frequency band and that existing system coverage will be compromised. [These issues will be discussed in greater detail in the Technology and Spectrum sections of this report.]

Funding continues to be a challenge including the cost to maintain interoperability across all bands. In many metro areas it is necessary to maintain interoperability systems in VHF, UHF, and 700/800 MHz to provide communications among the various responder agencies in the area and to support mutual aid assistance from neighboring areas.

Many agencies are concerned about the inability for their public safety units to "roam" beyond their primary service area without technician intervention. This may include new frequencies, new system keys, or system level authorization for access. Public safety needs a national vision of how to enable roaming to work more easily and efficiently and in a way that is mostly transparent to the first responder.

All agencies report needing access to video for situational/tactical awareness, planning, and mitigation. This includes situations where an Incident Command staff needs to see incident video to plan evacuation and tactical strategy.

2.5.1.1 Sample Communications Scenario

The issues and problems identified with today's public safety communications system can be further explained through the following routine scenarios which depict events happening across the U.S. today.

Major Traffic Crash: Multiple 911 calls are received reporting a major traffic crash on an interstate highway. The incident involves a gasoline tanker truck and several other vehicles. First responders from the local agencies are immediately dispatched to the scene. Law enforcement units arrive and immediately shut down interstate traffic flow and initiate a plan to reroute traffic. Fire/rescue units arrive and start treating injured patients while assessing the extent of a gasoline leak as well as other crash created hazards. Local EMS units arrive to take over treatment and to plan for transportation to local hospitals. The State Police have arrived on scene to assist but they operate in the HF or VHF radio band while local law enforcement operates on a trunked 800 MHz system. EMS units are operating on UHF while the local fire agency is on VHF.

The Incident Commander needs to communicate with those assigned to direct each Section to announce the "hot zone" area in which it is not safe to operate without advanced protective gear. Local law enforcement and State Police units need to coordinate the closing of interstate highway lanes and ramps. A firefighter paramedic needs to radio directly to one of the EMS ambulance paramedics that his patient is in critical condition and needs to be transported first. Another group of firefighters are working to cut the roof off a car to gain access to an injured person. They need to be able to communicate with their own work unit in a high-noise environment and decide to switch off of the main fire operations channel to a simplex channel. They are now not able to hear their supervisor who is calling them to confirm the need for a second ambulance.

As each unit arrives on scene they individually attempt to create an interoperability solution for their particular area of operation. A decision is made to move the local law enforcement units from their trunked system to a conventional 800 MHz channel that can be patched more effectively to a conventional HF or VHF channel to allow them to communicate with the State Police. This requires that all local police units switch over to the conventional channel and the dispatcher must then do a roll call to ensure that they all arrived on the correct frequency. A family member has seen a report of the crash on the local TV news and is trying to reach the scene. He encounters an officer at a closed interstate entrance ramp and a confrontation ensues. During the struggle, the officer presses his emergency button for help; however, because law enforcement operations were moved from the trunked radio system to a conventional simplex channel, the "emergency button" does not function.

Burglary In Progress: The local police department is on the scene of a burglary in progress at a retail store at 2:00 in the morning. A K9 Unit has been requested from the local Sheriff's Office to help search the building. An officer from a neighboring town has also arrived on scene to provide assistance. The local police department operates on an 800 MHz trunked radio system while the Sheriff's Office operates on a VHF radio system.

The police officer on the scene knows that an interoperability solution is needed to communicate directly with the deputy. While a multi-band radio would solve the problem, his agency cannot afford these units. Interoperability could be accomplished via a console patch between VHF and 800. The officer knows that sometimes the console patch cuts off the first few words of each person's transmission. Should the officer switch to one of the conventional 800 MHz interoperability channels? Some are repeated and some are not. Would the officer’s vehicle repeater provide any support? To further complicate the decision, the officer knows that the inside of the store is sometimes a radio dead spot. Should a simplex channel be used for in-building radio communication? There are many simplex channels in the officer’s radio; which one is the best one? The officer remembers being shown how to toggle the radio to “simplex” but does not remember what the radio front display should show when it is active. Switching to a simplex channel would move all communications beyond the range of the dispatcher who would not be able to hear any of the on-scene conversations and provide support. This switch also means that there will be no centralized voice recording of the radio transmissions for legal review or for use in training and after-action reports.

These two incidents demonstrate that public safety agencies need a comprehensive solution to interoperability that minimizes decision making by the end user, that is affordable, and that meets all of the operational requirements of the first responder community.

2.5.2 Broadband Data

Public safety agencies reported the following comments regarding broadband systems and applications which are needed to support daily emergency response as well as provide major incident coordination:

All agencies reported that data applications for terminal-to-terminal messaging, Computer Aided Dispatch (CAD), Automatic Vehicle Location (AVL), and Geographic Information Systems (GIS) were all "important" or "critical" and almost all agencies reported that video was "critical" or "important." Ninety-nine percent of all questionnaire responders felt that broadband in-building coverage was critical to support voice and data operations. There was increased awareness of the need for additional spectrum to support data. It was noted that video and data requirements keep expanding. Responders repeatedly expressed concern over the lack of data priority on commercial systems, as well as inconsistent coverage for public safety needs. Agencies noted that existing systems are easily overloaded on busy days and could not support a large-scale incident. There is uncertainty over evolving national standards for broadband. There is concern over how NG911 data coming from the general public will be integrated into systems and sent to first responders. Agencies see an urgency to develop capabilities to support data and video. Most agencies do not think mission critical voice can move from LMR before the year 2020, if ever. Agencies see a multitude of new applications on the horizon (tactical video, EMS video, fingerprint ID, location based in-building tracking, etc.).

During discussions with public safety communications representatives it became clear that many of the applications, features, and requirements for data deemed critical for response to a major incident are also needed during normal day-to-day emergency response. Access to GIS information would be needed to coordinate the search for a missing child in a neighborhood just as it would be needed during a major hazmat event requiring evacuation. Automatic Personnel Location systems are needed at the scene of a single family home house fire just as it would be needed during a large warehouse fire involving units from multiple agencies.

A series of focus groups were held across the United States to gather information on broadband applications and usage. These sessions brought together a multidisciplinary team to discuss tactics and strategies at the scene of a specific event. As each focus group discussed their response to the emergency event they also identified various data and video applications which would be needed to support their operations. Many of the applications identified by one focus group as essential were also identified as critical by subsequent focus groups, including access to GIS information and use of multiple video streams. The following information provides an overview of each data application that was discussed. It should be noted that some of these applications are used only on the incident scene while others require data from remote systems. In many cases the data would be monitored by dedicated individuals on the Incident Command team, and the reader should not assume that the actual Incident Commander or operations section chief is the person viewing this information. In some cases, critical data should be moved off site where it can be more efficiently monitored by others at a centralized location.

1. Geographic Information Systems (GIS)

A Geographic Information System (GIS) digitally creates and "manipulates" spatial areas that may be jurisdictional, purpose, or application oriented. It is an information system that analyses, displays, edits, integrates, shares, and/or stores geographic information for informing decision making. Incident commanders need to visualize street level detail and use stored information from various GIS layers. In addition to viewing streets and landmarks, GIS may also provide aerial photography snapshots of the incident area. This information on the proximity of other buildings and exposures is critical when creating an Incident Action Plan and when establishing a common operating picture. GIS data may also display various utility layers including sewer, water, electric and gas lines, and connections. This information is critical, for example, when determining what fire hydrants to connect because firefighters can't connect too many fire engines to a single underground water supply line. It is also critical when determining where toxic chemicals may have traveled once they entered the storm water system.

2. Automatic Location: Vehicles & Personnel

Command staff and many supervisors at an incident need to be able to visualize personnel and vehicle resources on scene, including units responding and units in staging to make appropriate tactical decisions during an emergency. This AVL information should include all resources on scene such as EMS, fire/rescue, law enforcement, and other public safety support units (i.e., mass care, public works, regional transit, etc.). For example, the decision to sustain the fire attack against a warehouse fire could be based on the number of fire trucks which are already in staging or are in close enough proximity to the incident scene to be effective. A decision on managing the safe evacuation of a nursing home would be impacted by knowledge of the exact location and proximity of transit vehicles to the scene. Tracking the location of personnel and vehicles is also a critical piece of an agency's accountability and safety program.

Command staff and many supervisors also need to also track individual public safety personnel, such as firefighters, who are on the scene of the incident. Automatic Personnel Location (APL) is especially critical for those employees who are conducting search and rescue operations inside the collapsed building and those who are working in the "hot zone" with the gas leak. Law enforcement supervisors also need to track the location of on-scene deputies and police officers who leave their patrol car and are operating on foot in a hazardous situation (e.g., conducting a building search for an armed suspect). This type of location technology must support X, Y, and Z coordinates, meaning that the Incident Commander must know if the injured public safety worker is in the basement or on the 17th floor. While this information may exist in multiple disparate systems, the Incident Command team needs to able to visualize the incident scene and the resources on a single display screen. This would require that AVL and APL data be collected from various agencies, consolidated, and then distributed to the Command Team and appropriate supervisors.

3. Incident Command White Board

Incident commanders need an application which will allow them to transmit "common operating picture" information, including an overview of the situation that might include a map or photograph with notes. This information is sent early in the incident via CAD messaging or a special application to give all units on the scene an overview of the event and the operational plan. As the Incident Command System is more fully implemented, a formal Incident Action Plan (IAP)[16] must also be distributed to all units on the scene. IAP documents are frequently converted to PDF files and transmitted via email communication or printed and distributed in hard copy. Public safety personnel identified several shortcomings with the IAP process as it exists today, including the difficulty in distributing updated information rapidly. The ability to transmit electronic updates and to transmit “white board” notes, documentation, and marked-up photographs was deemed very important by all participants.

4. Aerial Video

Video information was identified as critical by all public safety personnel in the various focus groups, including law enforcement, fire/rescue, and EMS as well as secondary responder agencies including public works. It was noted that airborne video could originate for a staffed unit, like a law enforcement helicopter, or from a non-staffed unit, such as a remote-controlled or radio-controlled aircraft.

Law enforcement command staff reported the need for access to real-time video to develop appropriate situational awareness of the incident scene, plan evacuation routes, monitor crowd behavior and movement, and to monitor the progression of the emergency. Fire/rescue command staff need separate real-time video to view the incident scene, progression of the emergency, identification of adjoining building fire exposures and other risk factors, and to observe movement of the fire or chemical cloud. An Infrared video feed is especially important to determine fire spread inside a large warehouse structure, to look for injured persons in the dark who may not be visible to first responders, and to see the liquid level of various storage tanks containing flammable materials. Rural areas also reported video is a critical tool in the management of large wild land fires to monitor fire spread, to determine the viability of fire breaks, to plan and monitor evacuation routes, and to identify homes and structures which may need immediate evacuation.

5. Vehicle-Mounted Video

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[16] The Incident Action Plan (IAP) is a formal National Incident Management System (NIMS) document that identifies incident goals (known as control objectives in NIMS), operational period objectives, and the response strategy defined by Incident Command during response planning. It contains general tactics to achieve goals and objectives within the overall strategy, while providing important information on event and response parameters. Equally important, the IAP facilitates dissemination of critical information about the status of response assets themselves. Because incident parameters evolve, IAPs must be revised on a regular basis (at least once per operational period) to maintain consistent, up-to-date guidance across the system. The following information is often included in an IAP: incident goals (where the response system wants to be at the end of response), Operational Period objectives (major areas that must be addressed in the specified operational period to achieve the goals or control objectives), response strategies (priorities and the general approach to accomplish the objectives), response tactics (methods developed by Operations to achieve the objectives), organization list/ICS chart showing primary roles and relationships, assignment list with specific tasks, critical situation updates and assessments, composite resource status updates, a health and safety plan (to prevent responder injury or illness), the communications plan (how functional areas can exchange information), the logistics plan (e.g., procedures to support Operations with equipment, supplies, etc.), a responder medical plan (providing direction for care to responders), and an incident map (map of incident scene).

Incident command staff and supervisors identified the need to access vehicle-mounted video cameras in fire/ rescue and law enforcement vehicles on an as-needed basis (versus a continual video feed). The video feed would allow command post and Emergency Operations Center[17] (EOC) personnel to visualize the incident scene in relation to damage and apparent needs when compared to other incident scenes. Vehicle-mounted video also enhances on-scene safety by allowing third parties to check on the incident scene, verify that personnel are accounted for, and monitor the success or failure of the incident mitigation plan. Vehicle-mounted video also allows the Incident Command team to “see” the incident and develop a better perspective of the operational requirements. In the absence of video, the command staff must rely on a radio transmission description of the scene from first arriving units.

6. Helmet Camera

Public safety personnel frequently need to report critical information to command or supervisory staff in need of detailed descriptions of the incident. This affects EMS, fire/rescue, and law enforcement units on a regular basis. Much of the Incident Command process and decision making revolves around “situational awareness” that is frequently reported as a voice message. The use of video greatly enhances situational awareness and allows for better decision making.

For example, appropriate command staff and supervisors need access to helmet-mounted cameras to obtain real-time video images from firefighters inside a burning building to better assess needed resources and tactics. Currently, a firefighter attempts to describe the interior conditions to the Incident Command via a voice transmission from inside their SCBA air mask. Video would also allow a subject matter expert to provide remote technical assistance. For example, a building engineer may provide advice to firefighters working inside a collapsed building on the status of a load-bearing wall that is in danger of collapse. A chemical plant engineer could look at helmet camera video of a damaged valve in a "hot zone" at the factory and provide advice on how to best shut the leak down without creating more problems or damage.

Trauma Center physicians and other critical care physicians have expressed the need to visualize the patient while the ambulance is en route to the hospital. Certain low volume, high risk procedures could also be performed more safely under the video guidance of a physician who was monitoring and guiding the patient care team remotely. Law enforcement personnel could use video feeds to monitor the progress of officers conducting a sweep of a building for a dangerous suspect, could allow personnel at the Command Post to confirm the identity of a subject discovered by the sweep team, and could provide expert support during an assessment of a bomb or explosive device. In a correctional facility, video feeds from officers provide an additional level of safety and security and accountability. These cameras would be capable of supporting high, medium, and low resolution "situational awareness" mode of video display. The resolution needed by the Incident Commander would depend on the type of incident and the issue being addressed.

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[17] An Emergency Operations Center (EOC) is typically located away from an incident at a pre-established facility (either at the local, county/parish, regional, and/or state level). Once staffed (often with significant response delay following an incident’s occurrence), the primary function of an EOC is usually resource management and prioritization, especially if multiple incidents are occurring or there is a wide-spread disaster such as an earthquake or hurricane. Direct incident response and mitigation activities are rarely managed from an EOC.

7. Third-Party Camera Resources

Command staff and supervisors need the ability to view third-party video feeds, including those from both public and private organizations. Security video has become extremely prevalent throughout the United States and many businesses, apartment complexes, and industries use video on a daily basis.

Appropriate command staff and supervisors should be able to view the security camera video on the 17th floor of an office building where the fire alarm is sounding. This situational awareness, including the presence or absence of smoke and fire, allows for appropriate decisions on the deployment of resources. For example, the ability to verify that no major emergency exists on the 17th floor could result in multiple fire engines being returned to service much more quickly than if they had to remain in staging until fire crews physically reached the 17th floor. Better management of available resources would allow one of the fire apparatus to respond to another emergency a few blocks away, instead of sending other, more distant, fire department resources to that scene. This translates into more lives saved and a reduction in property damage.

Law enforcement personnel should be able to view third-party security camera video while arriving on the scene of a robbery alarm, shooting, or other violent crime to determine appropriate tactical actions that are needed to protect human life. Video is also extremely helpful when dealing with large crowds and large-scale events. The ability to track a fleeing suspect in a crowded mall (where airborne video is unavailable) would be greatly enhanced via the ability to monitor security video from the various exit points in the area. The recent phenomena involving flash mobs may also be better managed via the availability of video resources. Access to existing traffic camera systems is also critical to assess traffic flow and congestion when determining suitable evacuation routes or checking on the status of a dedicated evacuation route. These cameras also allow wide area access to monitor smoke plumes and chemical cloud releases.

8. Mobile Data Computer Applications

Command staff indicated that each emergency vehicle on the scene should have access to remote messaging and data communications. For example, a regional transit bus being used to move evacuated persons to a shelter should be able to access information on street closures, best routes, and other information on their assignment. IAP documentation must be available as required, to personnel operating on the scene, including secondary responders and mutual aid personnel.

Certain vehicles and public safety personnel need access to specific remote databases and applications while working on the emergency scene. For example, rescue ambulances need to access a web-based application that shows hospital availability and also tracks ambulance/patient destinations. Law enforcement personnel must frequently query regional, state, and federal databases and be able to determine if a subject has a prior criminal history or an arrest warrant. Fire rescue units need the ability to retrieve building pre-plan information, photographs, and diagrams of hazardous materials storage, location of hydrants, and water valves.

9. File and Message Transfer

All vehicles and personnel on the scene need to be able to access and receive data files and messages. CAD terminal-to-terminal messaging is used substantially on the incident scene as well as methods for sending data messages directly to personnel who are outside of their vehicle. Fire rescue units need the ability to retrieve building preplan information, photographs and diagrams of hazardous materials storage, location of hydrants and water valves. EMS personnel also use data to review detailed drug information, poison control documentation, and advise on various emerging health threats.

10. Web Applications

Incident Commanders need to be able to access their agency intranet to pull down various documents and templates. Of specific interest are building pre-plan documents which contain draft version of the floor layouts, access points, control rooms, etc. An additional example would be instant access to critical information on the electrical system layout for hybrid cars. These vehicles use large batteries and have extremely dangerous electrical systems. Following a car crash, public safety personnel must know the location of various electrical cables and systems which are not standardized across various manufacturers. A special website exists with documentation, diagrams, and descriptions for all electric and hybrid vehicles.

In some cases, information is being uploaded from the scene to the network and in other cases large volumes of data, such as GIS files, are being downloaded from centralized servers.

11. Patient & Evacuee and Deceased Tracking

Command staff and supervisors need a mechanism that will track all persons on the scene and their eventual disposition. Paramedics currently attach a bar code or RFID bracelet on each patient and then use a grocery store scanner type device to enter in brief demographics before uploading a snapshot photograph and all information to “their network” for centralized tracking and distribution to the receiving hospital.

This same system would also track all evacuated persons, again using RFID or bar code scanner technology, allowing a snapshot photo of the citizen and demographics which are then uploaded to a server for distribution to the command post and Public Information Center. Some systems allow public safety personnel to swipe the individuals’ driver’s license to instantly collect identification information.

The location of all deceased persons, especially those who are not moved immediately because of the need for crime scene investigation or in the case of a multi-fatality event, needs to be tracked. GPS coordinates would also be collected with the photo snapshot and uploaded to the network. This approach was used during the Hurricane Katrina response and recovery operations.

12. Biotelemetry

There is a critical need to monitor biomedical telemetry, the monitoring, recording, and measuring of basic physiological functions, such as heart rate, muscle activity, and body temperature, of both public safety personnel and sick and injured patients. EMS and firefighters who are inside an Immediate Danger to Life and Health (IDLH)[18] atmosphere need constant monitoring. The telemetry system can track air supply, ambient temperature, vital signs, and other metrics and send them from the individual firefighter to an

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[18] “IDLH” refers to the Occupational Safety and Health Administration (OSHA) standard for "Immediate Danger to Life and Health" and typically involves "hot zone" areas with toxic gases and/or low-quality breathing air that will not sustain human life.

outside monitoring post and potentially move the data offsite to a central monitoring and recording station at their headquarters.

EMS paramedics need to be able to transmit a patient's heart rhythm, including a full 12-lead EKG, from scene to hospital for physician interpretation. Other types of biomedical telemetry monitoring and diagnostic applications require a high-speed and reliable network. For example, certain types of testing to detect the presence of poisoning require interpretation by a specialist. Additionally, monitoring would be needed for serial blood glucose readings, oxygen saturation levels, and carbon monoxide tracking.

13. Third-Party Sensors

Command staff and appropriate supervisors need to be able to "connect" to various automated building systems to view alarm codes and conditions. For example, the fire department may need to determine or change the status of the air conditioning and ventilation system during a toxic gas leak. Did the system turn itself off following the activation of the fire alarm or is it still circulating the toxic gas through the building? Law enforcement officials may need to access a specific building's security system to determine where a suspect may be based on a log of door activations. Likewise, there is a need to know the status of various hazardous sensors installed in many government buildings and large assembly areas, which are used to detect poisonous gasses, radioactive materials, biological, and other Weapons of Mass Destruction (WMD) profiles. During an emergency inside an industrial plant it would be critical to remotely monitor the status of various mechanical and automated systems.

14. Weather Tracking

Immediate access to real-time weather information is essential at many emergency scenes. This is particularly true with wild land fires where changes in wind and humidity can cause significant changes in fire behavior. Command staff and appropriate supervisors at the scene of a hazardous materials emergency also need to monitor wind speed and direction to determine evacuation areas and where "shelter in place" orders should be given. While a single weather data station may be adequate for some incidents, the capability should exist for a consolidated view of multiple onsite weather reporting units.

15. Vehicle Telemetry

A large number of vehicles are present at the scene of almost all major emergencies. It is not uncommon in the fire service for dozens of fire trucks to be stationary and providing pump support. In some cases, particularly wild land fires, these engines may be pumping water for days as the firefighter crews rotate on and off duty. Public safety needs a system where the vehicle's health data is transmitted back to the Incident Command post for evaluation by personnel assigned to Logistics. For example, attempting to determine which fire trucks need to be refueled can be a daunting task. The ability to react to a report of falling oil pressure could prevent a major mechanical failure.

16. Incident Command Video Conferencing

Public safety Incident Commanders need the ability to conduct a video conference call between the Incident Command post at the emergency scene and local officials in the agency's (or other) EOC or headquarters facility. Voice communications, without video, will also be needed to support telephone calls to request and coordinate various resources, supplies, and logistical issues. Many of these calls today are handled via wireless phones on a commercial system which frequently become unreliable during a major incident due to commercial network congestion.

17. Cell Phone/Voice over IP

The Incident Command team will need access to Voice over IP [Voice over Internet Protocol] phone connections to coordinate resources and supplies and to discuss incidents tactics with branch and group supervisors who are not physically located at the command post. In many cases, Incident Commanders prefer to not conduct these discussions over the public safety LMR system.

2.6 Broadband Focus Groups

In September of 2010, the AFST Working Group arranged focus group work sessions with public safety agencies in Southern California; Houston, Texas; Orlando, Florida; and Washington, DC. These tabletop exercises involved a broad cross-section of public safety agency representatives who were asked to provide operational feedback on a specific emergency event in their jurisdiction. The goals of the focus group process included these objectives:

- Study broadband communication needs at a major incident.
- Model realistic incidents easily understood by the agencies.
- Determine the operational objectives that drive application needs.
- Determine the incident demand timeline.
- Determine the geographic area of the incident.
- Determine the source and destination of each application.

The AFST Working Group collected a large amount of information in each session, including a discussion on specific operational needs at the scene of an emergency, as well as a list of data and video applications that are needed to support the responder community. The results of the focus groups were documented in a series of formal reports and were then shared with the AFST Operations Task Group to ensure the results from each agency were deemed credible and appropriate. In some cases, requests by the focus groups were scaled back and reduced based on a review of reasonableness, cost effectiveness, and efficiency. Specifically, the number of cameras and video resolution needed by public safety agencies was adjusted downward. The resulting list of applications was then analyzed to collect specific metrics including data rates, number of personnel using the application simultaneously, and where the data and video would likely be transported. This information was provided to the AFST Spectrum Task Group, which used the data as input into a broadband calculation model resulting in an estimation of the amount of spectrum needed by public safety agencies.

The list of applications identified as critical by the public safety agencies was surprisingly similar across the geography of the United States as well as being consistent across various emergency events including hurricanes, toxic gas leaks, wild land fires, and chemical plant explosions. All agencies reported that access to GIS files was critical as well as the need to access real-time video feeds from the incident scene back to the Incident Commander. Mission critical voice communications across all segments of the responder community were also discussed. All public safety agencies indicated that the majority of these applications were needed for day-to-day operations in addition to becoming critical at the scene of a major incident. The following list of data applications was identified as being essential to emergency response and management at the scene:

- Access to Third-party Video/Cameras (private and governmental)
- Automatic Location (both vehicle and personnel location systems)
- Biomedical Telemetry (patient and firefighter)
- Geographic Information Systems (GIS)
- Incident Command Post-Video Conferencing
- Incident Command White Board
- Message and File Transfer
- Mobile Data Computers Application Usage
- Patient/Evacuee/Deceased Tracking
- Sensor Technology
- Vehicle Telemetry
- Video (aerial video feed, vehicle mounted video and helmet camera video)
- Voice over IP Cell Phone Access
- Weather Tracking

The information received from the focus groups was particularly valuable because the public safety personnel present were all speaking from their personal knowledge of actual operations at the scene of a major incident. The discussion of how they would manage the incident, how they would manage the information, and what resources were needed were all compelling with regard to the need for more spectrum and more applications. All of the information gathered from the various focus groups was analyzed and validated by other public safety representatives on the AFST Working Group and was then used to complete the final report on operational needs.

2.6.1 Focus Group Results

The AFST Working Group ensured the focus group sessions were conducted in such a way as to gather meaningful and relevant information from a cross-section of agencies and incidents. Representatives from all public safety disciplines were present at the sessions, including EMS, fire/rescue, and law enforcement, public works, transportation, and other incident-specific groups. To provide appropriate geographical representation, focus group sessions were set up in various locations across the United States. The types of scenarios modeled in the sessions were also carefully selected to ensure they represented actual emergency incidents the agencies would likely encounter in their geographic area. The Working Group also chose to use incidents which were familiar to the local agencies to receive the best possible feedback. For example, the incident selected for Southern California was a review of an actual wild land fire that occurred in 2003. Many of the participants at this session were present during the 2003 disaster and were able to share specific details and events regarding the need for data services. Likewise, the incident selected for Orlando was a review of Hurricane Charley that struck central Florida in August of 2004. Again, almost all public safety first responders at the session were actively involved in the hurricane response and were able to provide keen insight into the need for data and video services.

In all sessions, the focus group team reviewed the definition of broadband and discussed sample applications to ensure all participants were aware of the scope for the session. The group facilitator used a timeline approach to guide each group through a discussion of on-scene operations and identification of necessary data and video applications. Detailed information was gathered during the sessions, including specific metrics about each data application to ensure that appropriate inputs were available for the broadband model.

Each focus group session was fully documented and the results shared with the entire AFST Working Group for feedback and validation. The purpose of the independent review was to ensure that the types and use of the applications were viewed as appropriate by a broad cross section of the public safety community and to guard against any single agency from over representing their needs.

2.6.1.1 Hurricane: Orlando, Florida

This focus group tabletop centered on Hurricane Charley, which hit the Central Florida area on August 13, 2004. To focus the conversation, the group was only asked to react to emergency conditions occurring in a 1-square mile area rather than discuss attempts to manage an incident that spanned the eastern half of Orange County, Florida. The group was given a scenario that involved the collapse of an apartment complex building with dozens of injured and trapped citizens. Another 500 residents in the area needed to be evacuated from damaged buildings; there were reports of a natural gas leak near the scene; and law enforcement agencies were notified of looters moving into the area as night fell.

EMS and fire/rescue agencies arrived at the scene, established an Incident Command system, and started an assessment of damage and injuries. Law enforcement units arrived and started to secure the area and move crowds of displaced citizens out of the danger zone to a common holding area. The Incident Command immediately assigned crews to start searching the collapsed apartment building and assigned additional crews to locate and secure the broken gas line and to begin treating injured persons. Emergency Medical Services personnel were organizing the treatment of multiple personnel via use of the area's Mass Casualty Incident (MCI) plan. As the scope of the incident was more fully identified, Incident Command requested additional units to respond to assist those already on scene. A secondary staging area was identified several blocks from the incident where incoming fire trucks and ambulances would park until they given a specific assignment and were called in to the scene.

Applications Identified as Essential for Emergency Response: Command personnel quickly identified the need for GIS information to assist them in painting a tactical picture of the surrounding area. Since the incident occurred at night, there was insufficient visibility to adequately determine the layout of streets and buildings in the immediate area. The damage from the storm had knocked down street signs and many landmarks used to determine locations. GIS information would provide a street layout and the location of utility lines including water, sewer, gas, and electric services.

Command personnel also identified the need to visualize the location of all public safety units on the scene or responding to the scene. The use of AVL allows command and supervisory personnel to see the exact GPS location of all vehicles around the scene. This information allows for efficient deployment of personnel and resources. In addition to tracking vehicles with AVL, command also needed to track individual personnel on scene through APL technology. This is particularly critical for EMS and fire/rescue personnel working in a "hot zone" or IDLH area. Firefighters working inside the collapsed building must have their location tracked for safety purposes, as do firefighters working to seal the broken gas line with toxic gases in the area. Law enforcement supervisors also reported the need to track their personnel who were deployed on foot around the incident scene. In many types of incidents, a deputy/officer's patrol car is parked and has no geographic relationship to their current physical location. Law enforcement personnel at this incident were working in the dark around severely damaged buildings while trying to apprehend looters. Being able to pinpoint their position in the event of an emergency was determined crucial.

In addition to tracking the exact location of EMS and fire/rescue personnel, it is necessary to track certain biomedical telemetry about these personnel to further monitor their health and safety. Data flowing from each firefighter should include their identification, heart rate, ambient air temperature, and amount of air in their SCBA.

EMS and fire/rescue managers also reported members of the Incident Command team would need to see various video feeds to organize and manage this event. Airborne video streams are needed to see the totality of the incident scene, to determine the best location to stage incoming resources, where to set up an evacuee assembly area, where to set up triage and treatment areas, and to determine the best access for fire trucks into the scene around the debris. Law enforcement personnel depend on airborne video streams to show the status of planned evacuation routes, the location of crowds that need to be contained or relocated, as well as the number and activity of looters in the area.

Helmet video was also identified as an essential tool for Incident Command allowing them to visualize the interior of the collapsed building as firefighters are describing the working conditions. Helmet video also allows support personnel at the Command Post (CP) to assist with critical decisions. For example, a building engineer at the CP can provide guidance to rescue crews on the impact of tearing down certain portions of the internal structure to reach victims. Removal of load-bearing support columns, which are not always apparent following a collapse, could cause a life-threatening situation for the rescue crew and trapped civilians.

Paramedics treating patients would be accessing a series of remote applications which indicate hospital status, availability, and critical care capability. Each patient would receive a bar code or RFID bracelet which would be used for identification and tracking. The paramedic would use a handheld scanner to record the patients ID and then key in additional demographic information (age, sex, race, injury status). A photo snapshot is also taken of the patient. At the time of transport, each patient's record is appended to include the destination hospital.

This information is uploaded in real time to the network where data about specific patients is sent to the appropriate hospital. A global view of patient status can be seen by Incident Command and personnel in the

Emergency Operations Center, as well as by personnel who staff an information center receiving calls from relatives trying to locate a missing loved one.

This same system is used to track evacuees being moved from the scene to a designated shelter. Demographic information must be collected to account for each person on the scene, while also providing an organized method of routing citizens to an appropriate shelter and providing tracking information to manage calls from concerned relatives.

Likewise, this tracking system would also be used to record the exact GPS location, photo, and demographics of deceased persons found at the scene. This information is of critical importance to the Medical Examiner who must work to reconstruct the events which led to the person's death.

Command personnel also need access to external databases allowing for the rapid retrieval of stored building pre-plans, blue prints, and other resource information.

All vehicles on the scene are also equipped with mobile data computers which are transmitting the unit's geographic location as well as processing requests coming from the agency's CAD system.

Law enforcement personnel need access to verify criminal justice information from various local, state, and national databases. They need to validate driver's license data and to determine an individual's criminal history or current "wanted" status. This is very important while processing large groups at the scene of an incident.

Command personnel also need an ability to transmit incident information and plans to appropriate personnel operating on the scene of the emergency. This IAP document has detailed information about the organizational structure of the incident needed by personnel.

2.6.1.2 Chemical Plant Explosion: Houston, Texas

This focus group discussed a chemical plant explosion occurring in the large industrial corridor between the City of Houston and the City of Pasadena, along the Houston Ship Channel. A large explosion and fire is reported along with the presence of a chemical gas cloud which is moving across an interstate highway. Dozens of workers at the chemical plant are reported to be injured or missing. The cause of the explosion is not known and it will later be revealed that an employee had been fired several days earlier and made threats during his departure. Similar types of non-terrorism incidents have occurred in the Houston area and public safety personnel were well versed in their response strategies.

Fire and EMS personnel reported they would arrive near the scene and set up an Incident Command post approximately 2 miles upwind from the incident. Additional units would be sent directly to the scene to meet with plant officials and to determine the extent of the incident. Law enforcement units are arriving at the command post, while other units are sealing off the area and starting to evacuate nearby businesses in the "safe zone." Law enforcement personnel are also working in conjunction with Department of Transportation staff to close the interstate in the area of the explosion.

Additional fire and EMS personnel are deployed directly to the scene in protective gear to locate and remove injured workers and to ensure a complete evacuation of the staff. Hazmat crews are on scene performing a detailed assessment of the damage that triggered the chemical cloud. Specialized sensors are used to test the level of toxicity of the fumes. A representative from the chemical plant is also sent to the Command Post to provide assistance in the decision making process.

Applications Identified as Essential for Emergency Response: Command personnel identified the need for GIS information to view the street layout of the immediate area as well as the need to view aerial cartography of the plant to paint a total picture of the incident area. Sewer and storm water run-off system information is also available which will help determine where contaminated water is flowing in order to direct future clean-up efforts.

Command personnel reported the need to know the location of every vehicle and firefighter on the scene for accountability and resource assignment purposes. In addition to AVL information, GIS coordinate information is needed for all personnel on scene, especially those working in the "hot zone." AVL data will show the Incident Commander which fire and rescue vehicles are arriving in the area first, allowing them to be immediately directed to the best position.

Command also identified a critical need for video of the scene. Airborne video is needed by fire and EMS commanders to visualize the extent of damage and to monitor the progress of on-scene units. Airborne video using an infrared camera will also display the heat signature throughout the building allowing for the rapid identification of "hot spots" or fire spread. This same infrared camera can also show the fluid level in the storage tanks and provide critical information from which tactics and strategy are developed. Law enforcement personnel need access to separate and simultaneous airborne video to plan evacuation routes, validate closure of roads and highways, and to assess crime scene information.

Helmet camera video is also needed in addition to the airborne view. The Incident Command team need to monitor and track their personnel who are working in the "hot zone," need to visualize the condition of the damaged infrastructure, and allow consultation from building officials or other experts brought to the scene. For example, input from the chemical plant supervisor on the best approach to repair a damaged valve will increase the likelihood of a successful operation.

Biometric feeds from firefighters engaged in IDLH activities are also helpful. The ability for command to know the amount of air in the firefighters' SCBA bottle, their heart rate, and ambient air temperature all assist command is making safe and appropriate decisions.

In order to make quick decisions in an emergency, command needs to establish a data link with the chemical plant safety and monitoring systems to view sensor data and other indications of the facilities' health. Being able to monitor a rise in pressure in a particular mechanical system following attempts to control a leak is critical. .

During the focus group incident, a plant supervisor advises law enforcement that an employee was terminated earlier in the week and the employee had made threats against the company. A picture is provided by the plant manager. Law enforcement supervisors need to scan and distribute this photograph to all units operating on or near the scene, as well as to personnel downtown at agency headquarters.

Law enforcement units also need access to local, state, and federal remote applications and databases to gather information on the suspect. Law enforcement agencies would also want to access video from controlled access highways in an attempt to locate the suspect. Video license plate reading systems in use by toll authorities to track violators also can be accessed to determine if the suspect's vehicle has left the area.

Persons being evacuated from the area need to be tracked as they are relocated from their neighborhoods to agency-designated shelters. Tracking applications are also used during the rescue and treatment of the injured plant workers, as well as biomedical telemetry feeds from the scene to various receiving hospitals. Other applications are used to ensure that all hospitals in the metro area received a Mass Casualty Alert and allowed them to confirm receipt of a special message that warned them of the possible transport of contaminated patients. This alert allows more time for the hospital Emergency Departments to take necessary steps to prepare for these patients.

2.6.1.3 Major Wild Land Fire: Southern California

This focus group session centered its discussion on a large wild land fire that occurred in 2003 called "The Old Fire." This fire caused $42 million in damage and burned an area of more than 35 square miles (approximately 91,281 acres) while destroying 993 homes and causing six fatalities. Fanned by high winds and fueled by abundant dried vegetation, this incident grew quickly and taxed the ability of local emergency officials to manage evacuations and road closures ahead of the fast moving fire storm. At the incident peak, more than 1,000 vehicles were on scene providing fire fighting, security, and support functions. Unlike the other focus groups incidents in which the peak activity period occurred in the first 90 minutes, this wild land fire incident experienced a peak activity period at around the 4-hour mark.

Fire and Rescue units would arrive in the area of the reported fire and immediately conduct an assessment to determine the size of the fire, how quickly it was spreading, how quickly it was growing in size and intensity, what exposures were immediately threatened, and what exposures were soon to be threatened. They would make rapid decisions regarding the need for additional resources and start to implement an attack strategy. Law enforcement units would arrive at the command post and would be briefed on which areas and neighborhoods were in immediate danger. Law enforcement representatives would start directing the closure of certain roadways and initiate evacuation of targeted neighborhoods.

Applications Identified as Essential for Emergency Response: Airborne video would be needed early in the incident to gain a full understanding of the fire behavior and to make appropriate plans. Helmet video from individual firefighters or vehicle video from selected fire engines, would also help command "see" the big picture with the incident.

GIS information would be needed to make appropriate evacuation plans and to select the best routes for emergency vehicles moving into the scene and for evacuees leaving the scene. As the incident grows in size and intensity, mutual aid units are arriving from outside the local area. These units do not understand local roads and need access to GIS and mapping information.

Command needs to visualize the location of all units operating in the area to make appropriate decisions regarding unit deployment. AVL data is needed when vehicles are operating in smoky conditions and in areas of low visibility. For example, school busses were brought to the Staging Area and then deployed up the mountain to help evacuate a nursing home. Incident Commanders needed to know the exact location of the bus at all times to provide appropriate tactical support. Decisions regarding movement of persons from shelters and the nursing home were dependant on the time the busses would arrive. Automatic Personnel Location was also discussed. In many instances firefighting and law enforcement personnel were away from their vehicles and their exact location was not known. In the event of a "Mayday" or other type of distress call, it would be critical to quickly pinpoint the employee's position.

Given the size of the Incident Command structure, a variety of applications were needed to manage information flow between the various agencies and units. An "Incident Command White Board" application was needed which would allow documents, pictures, and maps with appropriate notations to be rapidly distributed to all personnel. The IAP also needed to be distributed either via email or via some other "white board" application process. This information would be distributed to local agency units as well as mutual aid resources arriving from throughout the state.

Vehicle-mounted video was also deemed essential in allowing the Incident Command team to better develop their situational awareness of the incident. The ability to transmit vehicle health telemetry was also identified by this focus group, which would allow command staff to determine the vehicles' fuel level in real time and thus plan for appropriate refueling operations. Many of the fire trucks on the scene were in continuous use over a period of several days. Being able to remotely monitor oil pressure and other vehicle diagnostics would allow logistical support personnel to better manage the large fleet of fire engines on the scene.

The ability for command to provide updated information for traffic management signs was also critical. It was deemed desirable for public works personnel at the command post to have remote access to fixed and portable sign boards in order to change evacuation instructions and other information. A sudden shift in the wind direction would result in the immediate need to close certain roads and to redirect the evacuation route.

2.6.1.4 Toxic Gas Leak: Washington, DC

This focus group incident was patterned after a report of a toxic gas leak in a large public assembly building near the National Mall in Washington, DC. While this type of incident has not actually occurred in the DC metro area, it is in their domestic security threat profile and public safety response options have been practiced.

Reports to 911 indicate that dozens of citizens have collapsed inside the building while hundreds of others are fleeing out into the streets. Citizens in the area are flooding 911 with calls reporting some type of unknown emergency is occurring at the building. Additional calls are coming from inside the building reporting the location of downed persons. Responding units are receiving conflicting information on the type and extent of the emergency.

Public safety units from multiple jurisdictions would arrive on the scene almost simultaneously given the nature of compact and overlapping jurisdictions and the distributed way in which the emergency would be reported. The first wave of units has arrived before any clear operational picture has been established.

Fire, EMS, and law enforcement representatives would establish an Incident Command post a safe distance from the scene of the emergency. Fire personnel in protective gear would move directly to the scene to start removing injured civilians. Hazmat personnel would be conducting a rapid assessment of the situation while also using sensor sniffer technology to identify the type of chemical involved. Law enforcement personnel would be working to seal off the area, preventing additional access by citizens into the danger area. Law enforcement personnel would also be interviewing those who had fled the building in an attempt to determine what happened. EMS personnel would be setting up triage and treatment areas, requesting additional transport ambulances, and alerting area hospitals of the incident.

<u>Applications Identified as Essential for Emergency Response:</u> Incident Commanders identified the need for Automatic Vehicle and Automatic Personnel Location systems. Given the large number of law enforcement agencies likely to be at the scene, along with multiple fire, rescue, and EMS personnel, the Incident Command staff needs to be able to visualize the location of all resources. In addition to seeing the location of public safety vehicles, certain personnel working in "hot zone" areas need to be tracked individually. For example, personnel inside the building who are working in a toxic environment need to be tracked for their own safety.

Incident scene video was also identified as a critical component for command planning. Helmet video from a firefighter would be sent back to the command post showing a 360-degree "picture" of the conditions inside the building. Visual information can be more accurate than a voice message attempting to depict the scene. This is especially true if the firefighter is wearing an SCBA where the face mask muffles the radio transmissions. This video stream would also need to be sent to the Emergency Operations Center for further analysis. While several public safety representatives indicated that 10 percent of all camera resources might be viewed simultaneously, this number was reduced following a discussion with other practitioners based on the extremely high amount of bandwidth needed to accommodate the request coupled with operational challenges to scan that many cameras for useful information.

Hazmat personnel also identified the need to "connect" to existing building environmental systems, to include CBRNE [Chemical Biological Radiological Nuclear] sensors and status information on the HVAC [Heating Ventilation Air Conditioning] system. Law enforcement personnel also need to "connect" to building security systems to view access logs and security camera video in the moments leading up to the event.

Airborne video would assist command in understanding the "area of impact" around the building and the need to expand the "hot zone/evacuation" area. All agencies reported the need to access local, state, and national databases remotely, including the need to conduct some internet research. The ability to access GIS data and to "pull down" an electronic building blueprint was also identified as critical to the success of the mission. EMS personnel would use various web-based applications to determine hospital resources and closest available medical facilities. Telemetry feeds may be used, along with video, by paramedics as they consult with Medical Control and receiving hospitals. Patients being transported to area hospitals and any deceased individuals would also need to be accounted for using some type of RFID or bar code scanner database.

2.6.2 Focus Group Incident Summary

The table below depicts the variation in the focus group events and provides a review of the number of personnel and vehicles and the size of the impact area.

Table 7: Broadband Incident Scope (Personnel, Vehicles, Area)

Location	Type	Personnel	Vehicles	Area (mi^2)
Southern California	Wildfire	3,000	1,000	35
Houston	Chemical Explosion	200	50	5
Washington, DC	Toxic Gas	327	127	1
Orlando, Florida	Hurricane	220	60	3

All of the information from the focus group process was added to the information gathered from the nationwide web questionnaire to ensure that a complete set of operational needs for public safety were recorded and noted in the final report.

2.7 Future Trends

Future trends in public safety communications will likely continue to parallel the commercial market with growth in usage accompanied by growth in new applications and features. The majority of the commentary in this report is based on the ability of the public safety community to look forward into the future and predict what applications, resources, and technologies will be available to them. Given the rapid growth in the technology marketplace, it is reasonable to predict forward to the year 2015 but not to the year 2022. How many public safety officials, in 2001, would have predicted the current feature set which is available in most smart phones? As more technology becomes available, it quickly gets integrated into the emergency response force and eventually is integrated into daily operations. This full integration occurs as the technology becomes more affordable, and as agency executives become more aware and comfortable with its capabilities.[19]

[19] Results of San Francisco Bay Urban Area Security Initiative testing of the first public safety broadband network in the Bay Area. Tests were based on real-world incidents typical in both metro and suburban areas on a daily basis. Based on test results, the concluding report to the FCC strongly recommended that public safety be provided with at least 20 MHz of contiguous spectrum (10 MHz by 10 MHz) through allocation of the 700 MHz D Block to public safety. http://andrewseybold.com/2637-public-safety-broadband-real-world-testing-results

2.7.1 NG911

The public safety community is bracing for the full impact of Next Generation 911, or NG911, which should be fully implemented within the time period of study for this report. NG911 opens up an entirely new way for the public to access emergency services and frees them from having to use a voice communications device or phone to summon aid. NG911 technology will be heavily data dependent and will allow citizens to send text messages, pictures, and video to the telecommunicator in the Public Safety Answering Point (PSAP). Many PSAP managers are bracing for an avalanche of data to accompany emergency calls and must decide how much of that new information should be screened, and screened out, at the time of the 911 call, or how much of that unfiltered public information should be sent out to the emergency responders. For example, a PSAP may get several camera phone pictures of a traffic accident with reported entrapment. Should the 911 operator view the pictures and send a summary note to the responding firefighters, or will the agency's need for urgency require that all of the accident photos are passed on to the mobile data terminals in the fire rescue vehicles? The potential data demand for first responders will be heavily impacted by these decisions. Incident Commanders could easily be overwhelmed by the rapid delivery of non-filtered information. It should be noted that the spectrum calculations in this report do not include any of this additional data load from the dispatch center to the responding units.

2.7.2 Growth

It is logical to conclude that the public safety communications user community will continue to grow through the year 2022 as agencies add more personnel and vehicles and services to accommodate the growing number of citizens needing services. It is also logical to conclude that more units on the street will equal more demand for voice and data spectrum. As more technological advances are made, agencies will be eager to adopt those same technologies which will likely require more spectrum.

It should be noted that this report did not approach the issue of including mission critical voice communications over a broadband network. Public safety agencies have an immediate need for "push to talk" and/or wireless duplex voice communications at the command post to allow discussions between the Incident Commander, command staff, and supervisors. Those secondary conversations would likely be carried over a broadband system.

3 Technology Report

3.1 Introduction

Due to its unique operational requirements, public safety has multiple complex communications technology needs. These requirements involve communications solutions that are unique to public safety. The following sections detail the technology impacts of the public safety operational requirements outlined in the previous section.

Commercial wireless communication systems typically require one-to-one communications. However, public safety communications typically require one-to-many communications. A public safety incident can span from hundreds to thousands of first responders involved in an incident and may require coverage across a wide geographic area. Public safety systems have been optimized to deliver on this one-to-many communication with its LMR systems and will need to continue to operate with these same capabilities with broadband data.

Another unique requirement for public safety is high levels of coverage reliability, e.g., 95 percent. While commercial operations can focus wireless system coverage in heavily populated areas, public safety's role is nationwide, wherever an incident occurs. This includes mountainous forested areas, subways, under bridges, and in the depths of dense building structures. Public safety communications requires that every individual be in communication with at least one other individual. This creates a unique need that requires far greater coverage than commercial networks and additional coverage mechanisms (e.g., off-network unit-to-unit communications) that do not typically exist in traditional commercial wireless systems.

3.2 Public Safety Communication Systems Overview

The Operations Report documents a number of specialized public safety communications needs which exist today and will in the future. To support these fundamental needs public safety requires wireless and wired communications networks and systems, including:

- Narrowband trunked and conventional voice communication systems that address mission critical push-to-talk needs.
- Wireless broadband data networks to address non-voice high bandwidth applications.
- Narrowband data systems to address mission critical data messages where wireless broadband networks are unable to reach.
- Fiber optic, microwave, and copper landline systems to provide backbone links for voice and data applications connecting public safety facilities with data, dispatch, and emergency operations centers.
- Direct mode communications to support incident-based messages where coverage does not exist or where infrastructure is not otherwise available. Depending on the application, these needs may be met by narrowband or broadband systems. It may also require that data flow from one responder to another responder before being passed on to Incident Command.

This Technology Report highlights the public safety communications technology that will be needed to meet the operational requirements.

3.3 PSWAC Findings and Recommendations

The PSWAC *Final Report* of 1996 provided technology projections through the year 2010. The report had a profound impact on public safety communications. The key findings and recommendations the PSWAC *Final Report* in regards to technology includes:[20]

> *2.1.2: Public Safety radio systems must be highly reliable to withstand natural disasters, possess high capacity to ensure sufficient communications paths at peak usage in the event of major disasters, and provide high Delivered Audio Quality (DAQ), a factor that subsumes time delay, coverage, and other qualitative criteria.*
>
> *2.1.15: Data communication needs are becoming as varied as voice needs, and are expected to grow rapidly in the next few years. New services and technologies (e.g., data systems enabling firefighters to obtain remote access to building plans and video systems for robotics-controlled bomb disposal) that are critical for Public Safety users to continue to fulfill their obligation to preserve life and property are now becoming available.*
>
> *2.1.16: Wireless video needs are expected to expand in Public Safety applications.*
>
> *2.1.21 Funding for acquisition of new spectrum-efficient technologies and/or relocation to different frequency bands is likely to be a major impediment to improving Public Safety wireless systems.*
>
> *2.1.24 Commercial wireless systems, such as cellular, Personal Communications Services (PCS), mobile satellite, paging, data, and network applications, are evolving rapidly and may offer tangible and reasonable alternatives to the demand for additional spectrum to meet present and future Public Safety requirements.*
>
> *2.2.7 The Steering Committee recognizes that flexible mandates need to be established to promote orderly transition to new spectrum. However, the committee recognizes that these must be incentive-oriented based on the availability of funding*

The PSWAC Final Report also projected a number of expected advances in communication system technology including:[21]

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[20] See PSWAC *Final Report*, pages 18-24
[21] See PSWAC *Final Report,* pages 33-34

- *Digital Integrated Circuits will have a ten-fold improvement every five years to deliver more processing, more storage, improved compression, and enhanced modulation.*
- *Batteries will become lighter, will have improved efficiency.*
- *Oscillators will improve in stability and smart antennas will reduce interference.*
- *Coding of voice and images will enable compression significantly.*
- *Spectral efficiency will increase.*
- *No new multiple access techniques beyond FDMA, TDMA, and CDMA.*
- *Error correcting coding use will be widespread in land mobile communications.*

The Technology Sub-Committee (TESC) also acknowledged that "*[i]n the year 2010, a great many of our requirements will be served by some technology which has not yet even emerged from the research labs.*"[22] TESC also identified a number of broadband applications that are commonly in use today over commercial wireless or private systems such as building plan transmission, patient image transmission, fingerprint transmission, video surveillance, and others. The report projected that MPEG-4 would be implemented by 2010 and that linear modulation would deliver approximately 5 bits per second per Hertz (bps/Hz) by 2020. The technical parameters used for forecasting spectrum demand assumed spectral efficiency for voice and facsimile based systems at 1.5 bps/Hz while snapshots, data transfers, and video achieved 3.5 bps/Hz. The source coding for video and facsimile were assumed to be 6 kilobits per second (kbps) versus 384 kbps for the remaining data applications.

The report was on the mark with few exceptions. Most notably, the commercial wireless marketplace introduced an access method called Orthogonal Frequency Division Multiple Access (OFDM or OFDMA) upon which the Third Generation Partnership Project (3GPP) technology LTE is based. OFDM-based technologies provide enhanced spectral efficiencies over alternative access methods. Additionally, the spectral efficiency predictions of 2010 did not come to fruition. Instead, these efficiencies represent the values expected more in the 2022 time frame.

3.4 Commercial Services

The PSWAC *Final Report* articulated the criticality of reliability in public safety communications. Simply stated, public safety personnel can never be without some form of communications. This inherent need creates a divergence between commercial systems that are focused on profitability and public safety systems focused on near 100 percent communications availability. As underscored by multiple catastrophic events since September 1996, these commercial wireless services are often not available when needed most. Either through network outages, congestion, or lack of coverage, the commercial networks today do not fully meet the objectives of the public safety community. Since 1996, first responders have been faced with multiple events from terrorism, earthquakes, and hurricanes that have rendered commercial services unavailable. But even on a day-to-day basis public safety experiences commercial shortfalls. For example, the news media and the public inundate commercial networks when a local disaster occurs – leaving limited resources for public safety personnel. Lack of reliable broadband was among the most mentioned operational

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[22] See PSWAC *Final Report,* page 34.

deficiency expressed by questionnaire responders in 2010 and should be a high priority through 2022. The magnitude 5.8 earthquake (minimal to moderate for earthquakes in the U.S.) that struck the Virginia/Washington DC area on August 23, 2011, provides a good example of commercial shortfalls with both wire-based and wireless communications (including voice and text messaging) disrupted across hundreds of miles for many hours.

It should be noted, however, that the technologies developed for commercial purposes have evolved to new levels of performance. As predicted by the PSWAC *Final Report,* the commercial wireless marketplace has made substantial gains in technology since 1996. In 1996, cutting edge commercial cellular technologies delivered typical raw data speeds of 19.2 kbps. Today, the operators deliver user throughputs in excess of 20 megabits per second (Mbps), a 1,000-fold improvement in data speeds. Public safety has been able to benefit substantially from these commercial innovations. As application and throughput needs eclipsed the capabilities of narrowband data, public safety adopted broadband to address its needs for high-resolution image delivery, streaming video, and graphics-rich websites. Importantly, it is not commercial technologies themselves that cause the lack of availability of commercial networks. Instead, such shortfalls are caused by the congestion on these networks and the way they are constructed; however, the commercial cellular technologies are applicable, and public safety has embraced the fourth generation (4G) technology Long Term Evolution (LTE) as the nationwide standard for broadband data.

Public safety's broadband traffic is expected to vary widely. During major incidents such as those identified in the Operations Task Group focus groups the usage of broadband is extremely high. However, on a day-to-day basis, the use is lower. There is thus a potential for commercial networks to accommodate the overflow traffic of the public safety community for these major incidents; however, such a possibility is predicated on two important factors. First, the public safety device operating on a public safety network must be able to seamlessly move to the commercial network when the public safety network is congested. Second, the commercial network must be available and those commercial carriers must dedicate spectrum to public safety with appropriate programming and priority access. Even if public safety were to develop a technology that recognized congestion on the public safety network, there is no publication of congestion on the commercial network. A public safety subscriber using a single modem device would then be taking a "leap of faith" that bandwidth was available on the commercial network. This is an unlikely scenario for most major incidents where the public and the media have substantial communications needs. Therefore, public safety cannot assume commercial networks can handle the excess capacity of major events.

Channel aggregation or bonding solutions are available whereby multiple modems leverage multiple networks at the same time. In this case, the throughput of these multiple networks can be aggregated to deliver higher rates of speed and without risk of leaving the public safety network because connections to public safety and commercial networks would be maintained. However, such a solution presents additional challenges. First, as discussed previously, the availability of commercial networks and their capacity would be brought into question during large public safety events. Second, the cost of equipping all public safety devices and the resulting subscription costs would be prohibitive. And third, multiple modem or chipset solutions will draw more power and will present challenges in handheld device scenarios. As a result, channel aggregation solutions can be deployed as necessary, but it is not a solution for all applications. For example, a Mobile Communications Unit could be equipped with such a solution to ensure it always has access to all available bandwidth.

The commercial carriers can play a role in the future of public safety communications. The Spectrum Act provides a path whereby public safety can leverage commercial cellular infrastructure and expertise to help fulfill the public safety mission. Public safety will need to carefully articulate its requirements for certain technology, spectrum, and deployment needs; however, experience has shown that not all of public safety's unique requirements are likely to be met by commercial systems.

Public safety is a major user of other services available from commercial communications providers and will continue such uses through 2022. In 2012, public safety uses satellite services for disaster recovery or to otherwise provide services where none exist. Public safety may also embrace satellite services that operate directly to handheld devices if such services are affordable. Since 1996, public safety has also continued its substantial use of commercial wire line communication services. With the growth of broadband applications such as streaming video and high-resolution image sharing, such trends will dictate increased commercial fiber optic transport. Such needs may also be addressed through public-private partnerships that provide public safety agencies with fiber optic strands. Public safety will continue using commercial wire line networks especially when they can provide a public safety grade of service with dedicated capacity.

Since 1996, the wireless communications marketplace has changed dramatically. The Specialized Mobile Radio (SMR) and Enhanced Specialized Mobile Radio (ESMR) services have been overtaken by commercial cellular and broadband services. Commercial paging services that were prevalent in the mid 1990s have also been largely overtaken by commercial cellular services. Public safety will likely continue using paging services through 2022. Paging is used by many volunteer fire and EMS departments as well as various regional specialty teams who need rapid alerting over a wide geographic area.

Finally, some of the required services are not available from commercial providers at all or in limited capacity or service areas. For example, push-to-talk voice communication is available from national commercial providers, but the services do not provide the features (e.g., emergency alert) of the public safety community. Voice paging services are available from a number of commercial providers, however, they are not available nationwide and they do not typically meet the National Fire Protection Association (NFPA) Section 1221 requirements for redundancy and reliability.

3.5 Narrowband vs. Broadband Technologies

Public safety operations are in the field, where incidents involving protection of life and property occur. In addition, public safety personnel are highly mobile and their communications solutions need to move with them. As a result, public safety's greatest needs are in wireless communications and radio spectrum is the lifeblood of wireless communications. In 2012, public safety uses spectrum allocations ranging from 25 MHz to 4900 MHz. Most bands are channelized in narrowband (25 kHz or less) while half of the 700 MHz band and the 4.9 GHz band are channelized in broadband (1 to 10 MHz) channel sizes. Each of these spectrum allocations plays an integral role in meeting the public safety communications needs identified in the Operations Section of this report.

The Technology Task Group identified the need for both narrowband and broadband technologies. Each allocation fulfills important requirements identified in the Operations Section. The following table identifies the critical and unique requirements of each spectrum allocation.

Table 8: Critical and Unique Requirements of Spectrum Allocations

Unique Narrowband Requirements	Unique Broadband Requirements
• Direct Mode Communications: Peer-to-peer communication without infrastructure. While direct mode technologies exist for broadband communications, the public safety spectrum allocations do not meet the coverage requirements associated with direct mode communications. • Nationwide push-to-talk standards: The P25 standards suite will currently and uniquely meet the push-to-talk requirements. No public safety broadband push-to-talk standards yet exist. • Coverage: Narrowband systems possess better link budgets (i.e., they can incur more losses through buildings or over-the-air than broadband systems) and can uniquely meet the coverage needs of public safety. Additionally, narrowband can cover mountainous areas with high sites, whereas broadband cannot effectively use those sites. • Devices: There are currently no subscriber devices that meet the comprehensive requirements of public safety for push-to-talk communications over broadband. • Redundancy: Due to multiple individual channels in the narrowband bands, narrowband spectrum can support redundant coverage across the same area with no single points of failure.	• High throughput: Only broadband spectrum allocations can meet individual (user) and aggregate data throughput requirements of the public safety community for many data-related applications. Additionally, only broadband technologies can provide the backhaul capacity (connectivity to infrastructure) needed for broadband applications such as video surveillance. • Leverages commercial technologies: The broadband spectral allocations are sufficiently wide that they can accommodate commercial broadband technologies such as LTE and 802.11. Furthermore, the proximity of public safety spectrum allocations to similar use commercial allocations are such that leveraging commercial off-the-shelf solutions, and therefore, commercial economies of scale, are feasible. • Spectral Efficiency: Broadband technologies are highly spectrally efficient and are poised to make substantial improvements in spectral efficiency by 2022.

As the table above shows, there are several critical public safety requirements that currently (and probably for many years) can only be met with narrowband technologies. Therefore, public safety must continue to determine the capacity requirements of narrowband and broadband applications separately until broadband can also meet all of the narrowband requirements. As a result of these determinations, the Spectrum section of this report separately calculates the push-to-talk voice, paging, and critical message and status updates for narrowband systems.

3.6 Spectral Efficiency

To satisfy communications capacity requirements, public safety must accommodate the simultaneous communications paths needed at each location. The factors driving these calculations are described fully in the Spectrum section of this report. This section is dedicated to the translation between the desired communication quantities (e.g., voice channels or bits per second) to the amount of spectrum required to carry that information. Technological advances have improved the ability to communicate more with less spectrum. Over time, technologies have been able to reduce the amount of spectrum needed to carry the same piece of information. Therefore, this section will discuss the expected state of deployed spectral efficiency through the year 2022.

3.6.1 Narrowband Voice Spectral Efficiency Overview

Narrowband spectrum allocations predominately support mission critical, push-to-talk, voice communications. Therefore, the amount of radio spectrum required to support a single voice channel is a critical component in the determination of the amount of spectrum required by the public safety community. Narrowband spectrum allocations are divided into channels that create hundreds or thousands of voice communications channels in each band. The technology in use by a system or pair of radios determines the spectral efficiency. The technologies expected to be in use between 2012 and 2022 include:

Table 9: Technologies Expected To Be In Use Between 2010 and 2022

Technology	Channel Size	Access and Modulation Type	Equivalent Spectral Efficiency	First Availability of Technology[23]
Analog	25 kHz	FM	25 kHz	1960s[24]
Analog	12.5 kHz	FM	12.5 kHz	1990s[25]
P25 – Phase 1	12.5 kHz	FDMA – C4FM	12.5 kHz	1995
P25 – Phase 2	12.5 kHz	TDMA – CQPSK (2 slot)[26]	6.25 kHz	2011

It is important to note that there are multiple tradeoffs with these technologies. For example, the TDMA technology improves the spectral efficiency two fold over the P25 FDMA technology; however, it does so with a reduction in link budget. In other words, the range of a P25 FDMA system at the same audio quality levels, all else being equal, is greater than the range of a P25 TDMA system. To combat this, some TDMA

[23] The approximate time reliable communications was first demonstrated in a public forum.
[24] 25 kHz analog became available in the 1960s, but the exact date is not known to the authors of this Report. There are still 25 kHz channels in the 100 MHz band and in low VHF, 30-50 MHz.
[25] 12.5 kHz analog became available in the 1990s but the exact date is not known to the authors of this Report.
[26] Project 25 Phase 2 standards are currently only being developed for the trunking environment. 6.25 kHz technologies have been identified for the FDMA conventional use, but no detailed standards have been developed at the time of the development of this Report.

systems are being constructed using additional technologies (at an additional expense) to try to match coverage levels. Additionally, life cycles of public safety infrastructure range from 10 to 20 years. Therefore, while an agency may desire to upgrade to a new technology and leverage the various benefits of that system, it typically needs to fully amortize an existing system before making an investment in that new technology. The Commission, however, requires increases in spectral efficiency to address increased spectrum demand in the public safety bands. Therefore, the ultimate assumption of which technologies are employed at any one time is a combination of factors.

During the period addressed by this report, two important FCC spectral efficiency milestones will come in to effect per their current regulations. The following table outlines the FCC's required spectral efficiency:

Table 10: FCC's Required Spectral Efficiency

Band	2010 Spectral Efficiency (kHz/channel)	Transition Date	2020 Spectral Efficiency (kHz/channel)	Notes
VHF LOW	25	N/A	25	
VHF (High), UHF (450-470 MHz[27])	25	1/1/2013	12.5	Specified in the 3rd Memorandum Opinion and Order of December 2004. Exempts paging frequencies.
700 MHz (Narrowband)	12.5	1/1/2017	6.25	Specified in the 5th Report and Order of January 2005. Applies to general use and state channels.
800 MHz[28]	25	N/A	25	Per the commission's Tech Talk "[T]he rebanding currently underway in the 800 MHz band should provide public safety users with adequate spectrum."

The transitions referenced in the above table are mandatory. Therefore, those bands must have spectral efficiencies of the FCC-mandated levels. However, the bulk of public safety systems in urban areas, where capacity issues are greatest, currently use the 800 MHz band. Many of these 800 MHz systems are transitioning to Project 25, and therefore, will secure a 12.5 kHz spectral efficiency. However, the Project 25 Phase 2 common air interface that supports 6.25 kHz equivalent efficiency in the 700 MHz band is not fully standardized. Per NPSTC's letter to the FCC on September 11, 2011, "[t]he full standards suite for TDMA trunking won't be completed until well into 2012 … it will still be some time before ANSI-compliant

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[27] The FCC waived the narrowbanding requirement for the T-Band spectrum. See *Order*, WT Docket No. 99-87 and RM-9332, released April 26, 2012.

[28] 800 MHz band NPSPAC channel centers are spaced every 12.5 kHz but the rules allow 25 kHz wide channels with tighter emission limits and geographic spacing between adjacent channels.

equipment that can meet the 6.25 kHz equivalent requirement is operational."[29] In that letter, NPSTC recommended a delay to the year 2024 to allow for a graceful migration to 6.25 equivalent technologies and full amortization of recent public safety investments. Also, while some urban systems may migrate to TDMA capability, and 6.25 kHz spectral efficiency, they may choose to continue to operate at 12.5 kHz in 800 MHz. In addition, many Project 25 systems were deployed prior to TDMA standardization and equipment availability. Some may today be in the process of deployment, however, and may not be able to transition to TDMA without a "forklift" change out; those are therefore likely to remain at 12.5 kHz. Others operating at 800 MHz may continue to operate at 25 kHz due to financial or operational requirements.

By 2022 it is anticipated that there will be some combination of systems operating at 25, 12.5, and 6.25 kHz. In VHF allocations, it is anticipated that there is mandated 12.5 kHz spectral efficiency. In the UHF, 700, and 800 MHz bands, it is assumed there will be an average and aggregate 12.5 kHz. While most urban areas will have transitioned to at least 12.5 kHz in all bands by 2022, some public safety users are not comfortable in the aggressive assumption they will be 6.25 kHz compliant. In the PSWAC *Final Report*, public safety assumed a migration to 12.5 kHz spectral efficiency by 2010 that did not materialize. Therefore, the assumed spectral efficiency for all bands shall be 12.5 kHz in 2022. Importantly, as noted in the table above, Project 25 Phase 2 standards for 6.25 kHz equivalent efficiency are only being developed for trunked radio systems. Agencies, particularly those with smaller systems, require conventional FDMA channels, as does direct-mode (unit-to-unit) communications for all public safety radio systems. TIA has yet to address the development of 6.25 kHz FDMA standards beyond identifying the modulation to be used and, based on experience over the past several years, development of such standards would take a number of years.

3.6.2 700 MHz Broadband

The presumed technology from 2012 through 2022 for the 700 MHz broadband spectrum is Long Term Evolution (LTE) from the Third Generation Partnership Project (3GPP). LTE was recommended by all key public safety associations to be the standard for public safety interoperability in the 700 MHz broadband allocation. In 2011, the FCC backed these positions and established LTE as the required standard for entities operating under waivers in the 700 MHz band. Therefore, the spectral efficiency of the 700 MHz broadband spectrum will be that of LTE systems.

Unlike the narrowband allocations, LTE is expected to have continual improvements in spectral efficiency over time and largely *using the same infrastructure*. LTE Advanced is the technology that was approved as an official 4G technology by the International Telecommunication Union (ITU) in early 2011. Standardization of LTE Advanced was included in 3GPP Release 10 in March 2011. This technology is expected to be commercialized initially in the 2013 to 2014 timeframe with the bulk of the capacity-enhancing features

[29] Letter to David Furth from John S. Powell, dated September 11, 2011 is available at the following link http://npstc.org/download.jsp?tableId=37&column=217&id=1930&file=20110911 - FCC 700 MHz Issues Summary.pdf

deployed by 2015. The following table provides the target LTE spectral efficiency as established by the 3GPP for various configurations:[30]

Table 11: Target LTE Spectral Efficiency

Radio Envelope Antenna Configuration		Case 1 Average Spectral Efficiency [bps/Hz/cell]	Case 1 Cell Edge Spectral Efficiency [bps/Hz/cell/user]
UL	1x2	1.2	0.04
	2x4	2.0	0.07
DL	2x2	2.4	0.07
	4x2	2.6	0.09
	4x4	3.7	0.12

The table represents the target spectral efficiencies for LTE for all users on average and for a single user at cell edge. The data is based on simulations using a uniform distribution of traffic over the service area using ten users per cell. The targets identify lower spectral efficiencies for uplink (UL) than downlink (DL) paths. Higher order Multiple Input Multiple Output (MIMO) antenna configurations produce greater spectral efficiency. They also shed light on the decreases in spectral efficiency at the cell edge. With ten users per cell, cell edge efficiency is only 30 percent of the average cell efficiency for a uniform distribution. The ten users in the formula represent the data needs of a full complement of public safety personnel at the incident scene.

A public safety incident can occur anywhere. Unlike commercial traffic where known thoroughfares and occupied structures cause high densities of user traffic in a fairly common pattern, a public safety incident could bring hundreds of responders to a location where traffic loading simply cannot be planned. Degradation in throughput and spectral efficiency at cell edge then becomes critical to public safety spectrum needs. If, for example, a terrorism incident described in the Operations Report occurs at the intersection of two cells, interference between those two cells and the low signal-to-noise ratios impact available throughput at the incident. While the typical and average throughput of an LTE system will be substantially higher, it simply cannot be assumed the incident traffic will always occur at those locations.

In some situations, such as the wildfire incident outlined in the Operations Report, the traffic is spread more uniformly over a wide area. In those situations, it is reasonable to assume that LTE spectral efficiency will reflect the average or typical throughput levels. But the location of Incident Command, where substantial traffic will be generated and received, could occur at cell edge, thereby resulting in spectral efficiency levels that resemble cell edge spectral efficiency. Additionally, these latter kinds of incidents almost always happen

[30] Source: 3GPP; Technical Specification Group Radio Access Network; Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) 3GPP TR 36.913 V9.0.0 (2009-12), page 10. Case 1, first column is based on efficiency of the **cell** sector while Case 1 second column is based on cell edge performance of the **user**.

in rural areas where the density of cell sites (if any exist at all) will be significantly less than in metropolitan areas leading to both capacity and coverage constraints.

The spectral efficiency figures from the 3GPP above represent targets, and not actual delivered spectral efficiency; the real-world values must be considered. For example, the Commission, in its capacity white paper, assumed an average of 7.5 Mbps downlink and 3.5 Mbps uplink with a 10 MHz (5 MHz downlink and 5 MHz uplink in a paired configuration) allocation.[31] The target spectral efficiency above from the 3GPP results in 12 megabits per second (Mbps) downlink and 6 Mbps uplink for 2x2 and 1x2 MIMO configurations respectively, a roughly 40 percent reduction compared to the targets.[32] NPSTC bases the spectral efficiency on the FCC figures to provide a more realistic estimate.

Finally, public safety must consider the non-uniform traffic distribution. As discussed above, there is roughly 30 percent reduction in the spectral efficiency of a cell edge user in a uniform distribution compared to the average spectral efficiency from the target spectral efficiencies determined by the 3GPP. However, in a non-uniform distribution with all users grouped at the cell edge, the path loss is extremely high and requires high-power levels to achieve required signal-to-noise ratios. And, if the incident occurs at the border of multiple cells, the signal and noise levels from adjacent sectors will be roughly the same, offsetting any gains that would occur by distributing the traffic among multiple cells. Unfortunately, at this time, publicly available simulations that would shed light on spectral efficiency for incidents occurring at cell edge are not available to NPSTC. However, NPSTC predicts there would be further reductions in spectral efficiency due to the extremely low signal-to-noise ratios and the resulting high-power conditions needed to communicate with mobiles on scene at cell edge. As an approximation for the cell edge spectral efficiency of a public safety incident, the engineers adjusted the average FCC spectral efficiency figures by the 3GPP cell edge reduction to determine cell edge efficiency. The following table represents the initial spectral efficiency figures used to determine the required spectrum needs in the following section:

Table 12: Initial Spectral Efficiency Figures To Determine Required Spectrum in Focus Groups

Location	Type	Serving Sectors	Traffic Distribution	DL Spectral Efficiency (b/s/Hz)	UL Spectral Efficiency (b/s/Hz)
Southern CA	Wildfire	1	Uniform	1.57	0.73
Houston, TX	Chemical Explosion	2	High Concentration	0.47	0.22
Washington, DC	Toxic Gas	2	High Concentration	0.47	0.22
Orlando, FL	Hurricane	2	High Concentration	0.47	0.22

[31] The Public Safety Nationwide Interoperable Broadband Network: A New Model for Capacity, Performance, and Cost, June 2010, Page 18
[32] Note that the Commission did not indicate the MIMO antenna configuration in its white paper.

Public safety recognizes there will be additional improvements over time due to other technologies such as Multi-user MIMO (MU-MIMO) and beamforming. These technologies may deliver substantial improvements to spectral efficiency, depending on the type of environment, network configuration, and implemented technologies. Additionally, vendors may develop scheduling algorithms that intelligently organize traffic to minimize congestion and interference. Public safety users expect these technologies to improve LTE spectral efficiency over time. For example, 4G Americas reports show a number of technologies such as Co-operative Multipoint, and other technologies in future 3GPP releases providing improvements in cell edge and average spectral efficiency over time.[33]

The 3GPP expects dramatic improvements in spectral efficiency derived from various techniques. Combining the technologies is likely to further improve spectral efficiency. For example, multi-user MIMO (MU-MIMO) is effective at improving average spectral efficiency, but does little to improve cell edge spectral efficiency while co-operative multipoint (CoMP) does improve cell edge efficiency. Together they may help to improve both scenarios; however, these projections may not come to reality or, for other reasons, may not be physically feasible or deployed by infrastructure vendors. For example, a portable device may lack the battery power to support multiple transmitters and the size to achieve the required de-correlation between antennas and the resulting improvements in the table above.

To deal with these factors, NPSTC has adopted the spectral efficiency improvements assumed by the ITU values used in assessing commercial spectrum needs between 2010 and 2022. In 2006, the ITU Radio Communication Sector (ITU-R) published its spectrum requirements. The following table provides the spectral efficiency values assumed by ITU-R in those calculations: [34]

Table 13: Spectral Efficiency Values Assumed by ITU-R

	2010		2015		2020	
	Macrocell - Unicast	Macrocell - Multicast	Macrocell - Unicast	Macrocell - Multicast	Macrocell - Unicast	Macrocell - Multicast
Spectral Efficiency bps/Hz/cell	2	1	4.25	2.125	4.5	2.25

The ITU-R included both unicast and multicast values, indicating that multicast traffic has roughly half the spectral efficiency of unicast. NPSTC expects a substantial amount of the traffic at public safety incidents will use multicast technology. While the ITU did not explain the difference between the two modes, the

[33]See, for example, 4G Mobile Broadband Evolution: 3GPP Release 10 and Beyond, 4G Americas, February 2011 based on 3GPP Self-evaluation Methodology and Results, "Self-evaluation Results," Tetsushi Abe, December 2009. http://www.4gamericas.org/documents/4G%20Americas_3GPP_Rel-10_Beyond_2.1.11%20.pdf
[34] Source: ITU-R M.2078. Figures represent Radio Access Technology (RAT) Group 2, IMT-Advanced, dense urban scenarios for macro cell radio environments. Set 1: Non-Shannon approach.

Technology Task Group suspects it to be based on lower modulation and higher error correction rates for multicasting as is the case for cell edge scenarios. Therefore, the Task Group assumes that the use of cell edge spectral efficiency accommodates the multicast inefficiencies referenced above.

Nonetheless, the progressive improvements in spectral efficiency are equal over time. From 2010 to 2015 the table depicts a 112.5 percent improvement in spectral efficiency and from 2010 to 2020, the improvement is 125 percent. NPSTC applies these improvements to the FCC-based efficiency figures to apply to each incident in 2010, 2015 and 2020. These values will be used in the spectrum calculations in the Spectrum Report.

The table below depicts the scenarios for spectrum modeling for each of the four incident scenarios. The number of serving sectors in the third column establishes how the traffic is distributed across multiple resources. The California wildfire scenario can be accommodated in the service area of a single sector. Because the incident's resources are spread over this large area, the single serving sector represents the worst-case scenario. For the remaining scenarios, a two sector cell edge scenario represents the worst case. In each case, the Spectrum Task Group selected the expected user distribution and the resulting spectral efficiency, measured in bits per second per Hertz. This measure identifies the raw physical channel rate in bits per second per unit of spectrum in Hertz. Spectral efficiency is provided for the downlink (DL) and uplink (UL) for each incident for 2010, 2015, and 2020 as described earlier in this section.

Table 14: Broadband Spectrum Modeling Inputs

				2010		2015		2020	
Location	**Incident Type**	**# Serv. Sect.**	**Traffic Distribution**	**DL Sp. Eff. (b/s/Hz)**	**UL Spectral Eff. (b/s/Hz)**	**DL Spectral Eff. (b/s/Hz)**	**UL Spectral Eff. (b/s/Hz)**	**DL Spectral Eff. (b/s/Hz)**	**UL Spectral Eff. (b/s/Hz)**
Southern CA	Wildfire	1	Uniform	1.57	0.73	3.34	1.55	3.53	1.64
Houston TX	Chemical Explosion	2	High Concentration	0.47	0.22	1.00	0.47	1.06	0.50
Washington DC	Toxic Gas	2	High Concentration	0.47	0.22	1.00	0.47	1.06	0.50
Orlando FL	Hurricane	2	High Concentration	0.47	0.22	1.00	0.47	1.06	0.50

3.6.3 4.9 GHz Band

The diversity of uses for the 4.9 GHz band prevents the ability to determine specific spectrum needs for this band. The applications can range from point-to-point broadband links with very high spectral efficiency of 4 bits per second per Hertz to lower levels associated with 802.11 type deployments at around 1 bit per second per Hertz. The net spectral efficiency will then depend on the individual mix of applications. In addition, frequency reuse may also be highly variable. For example, if a region uses the 4.9 GHz band for airborne operations on multiple assets, nearly the entire band can be exhausted with 4.9 GHz because of the difficulty in reusing frequencies. Therefore, this report does not specifically address spectrum calculations for the 4.9 GHz band, but the above sections provide ample individual justification for the 50 MHz of spectrum allocated to public safety. Importantly, the role and authority of the Regional Planning Coordinators (RPCs) should be strengthened to allow for enhanced coordination and efficiency in this band. It should also be remembered that this spectrum is not practical for wide area mobile use and does not penetrate buildings.

3.6.4 Satellite

The Spectrum Report highlights important roles for satellite communications in public safety operations. As with other wireless technologies, the spectral efficiency of satellite communications depends on the link budget – antenna size, path loss, and other factors. The spectral efficiency for satellite-based communications is estimated at between 1.9 and 4.9 bits per second per Hertz.[35] Assuming the average spectral efficiency falls between this range, the average is 3.75 bits per second per Hertz. These frequencies can be reused in non-adjacent coverage areas, however, each region (each spot beam covering a region of the country) has its own individual demand that may require that the total capacity be applied to that region.

3.6.5 Backhaul

As outlined in the Spectrum Report, a broadband public safety network will cause substantial needs for additional backhaul of data traffic. The Report identifies how fiber and microwave will play an important role in meeting the operational needs. Therefore, the Technology Task Group evaluated fixed microwave service spectral efficiency to address this need. The spectral efficiency of an individual microwave backhaul link is 4 bits per second per Hertz. For example, a 20 MHz channel achieves 80 Mbps. The channels are paired for bi-directional communication, and therefore, a total of 40 MHz is needed to achieve 80 Mbps of bi-directional communication.

3.7 Broadband Application Throughput

The calculations for required spectrum for broadband applications require a conversion of application use into throughput requirement. Broadband applications can have dramatically different speed requirements that place varying levels of demand on broadband network capacity. Therefore, spectrum calculations must account for the load on the network for each of these applications. This section provides details on the values used in the spectrum calculations.

The data rate values listed in this document are derived from a variety of sources, including previously published reports, information from focus group meetings with public safety users and technical support staff, and from vendors. Given the dynamic nature of agency applications and network throughput controls, these numbers may not always match those listed in other publications. These figures are intended to represent typical data rates necessary to sustain sufficient quality of service. A modest "return path" data speed is also included to accommodate acknowledgement or other traffic associated with two way communications where appropriate.

It is the aggregate of all of the applications operating over a public safety broadband network that establishes the required capacity of a public safety broadband network. As with any shared access network, the nationwide public safety broadband network will be constrained by the simultaneous usage for a single

[35] Telecommunication Transmission Handbook, Roger L. Freeman, page 262.

shared resource. At the base level for an LTE broadband network is the sector. Typical LTE systems use three sectors per cell site. The next level of aggregation is then the combination of traffic for the three sectors plus overhead traffic that must be backhauled from the cell site location to the core network. From there, additional aggregation points will combine traffic from other cell sites or groups of cell sites to carry the traffic to the LTE core.

The degree to which each of these individual demands occur simultaneously then defines the needed capacity of each resource. Therefore, public safety must consider not only the throughput required for each application, but also the duration (and therefore the simultaneity) of each application. An application that sends a burst of information one time will send that information and pause. Web browsing is a good example of this. Typically, when the user clicks on a link, the browser sends a request to the web server and the server responds back with the web page associated with the link in a matter of seconds. Then the system waits until the next click on a link allowing other users to use those resources. On the other hand, streaming applications send data continuously until the session is over. For example, a real-time streaming video session continues to transmit video data for the duration of the session. A 2-minute video session ties up significant resources for the full 2 minutes.

3.7.1 Video

According to a 2011 published report, "real-time entertainment" that includes video and music streaming, accounted for 49 percent of downstream traffic. The same report indicated that the Netflix video streaming service represents "the single largest source of peak downstream Internet traffic in the U.S." at 29.7 percent.[36] In the same Sandvine report, mobile video represented 41 percent of peak traffic in September of 2010, up from 27 percent in January of 2010.[37] It is no surprise then that video is expected to be the largest source of traffic on the public safety broadband network. Therefore, in establishing the spectrum needs for broadband communications, it is critical that the video usage be accurately projected.

The broadband focus groups conducted by NPSTC for this report revealed a number of video applications for public safety including: Aerial video, helmet cameras, vehicle-mounted video, and third-party camera resources, each using different types of cameras with different qualities and capabilities. This study presumes that there can be two uses of each camera's content: Stored video for evidentiary, training, or other purposes, and real-time video streaming and sharing. This study further presumes that the two different uses can have different quality attributes. For example, the stored video content can be very high resolution and quality whereas the streamed video content might be lower resolution and vary as needed. While the technology to accommodate this does not necessarily exist in all cameras, this analysis assumes that such technology will exist by the time video use at incidents becomes prevalent.

Video throughput is highly dependent on a variety of factors. In recent years, the coding engines that convert the raw video information into a highly compressed data stream have dramatically improved. This

[36] "Netflix Now The Largest Single Source of Internet Traffic in North America," Tech Crunch, May 17, 2011. See http://techcrunch.com/2011/05/17/netflix-largest-internet-traffic/ for more information.
[37] Source: Ten Questions Internet Execs Should Ask & Answer, Morgan Stanley, Web 2.0 Summit, November 16, 2010

trend will likely continue through 2022. The state-of-the art commercial video coders in 2012 are capable of sustaining very high quality video with a relatively low bit rate and requiring relatively low computing resources. The resolution of the image as well as the frame rate (number of images per second) also have dramatic impacts on needed throughput.

The Office for Interoperability and Compatibility (OIC) within the DHS Science and Technology Directorate, partnered with the Public Safety Communications Research (PSCR) program, has studied public safety's video requirements extensively in its Video Quality in Public Safety (VQiPS) Working Group. The work has identified a number of factors that impact the video quality including target size, motion, lighting level, usage timeframe, and discrimination level. These factors impact the amount of broadband network capacity to transmit video that meets the user's requirements. The conversion of real-world scenarios for video use to throughput models is then highly complex. This study simplifies the video use into three general categories:

- High Quality: 1 megabit per second throughput requirement, provides high resolution (NTSC), and high frame rate communications. High quality is capable of high motion in a highly dynamic range of light, with small target size, and discrimination capable of facial recognition.
- Medium Quality: 512 kilobits per second throughput requirement, medium resolution, and high frame rate communications. Medium quality is capable of high motion in high dynamic range of light, with small target sizes, and discrimination capable of license plate recognition (similar to OCR). It provides an overview of an incident scene and enables visualization of broad elements of action.
- Low Quality: 256 kilobits per second throughput requirement, low resolution, and high frame rate communications. Low quality is capable of low motion, with large target size, high dynamic light range, and object identification. Low speed is capable of providing situational awareness with some level of perspective of each video source. It provides a large area tactical view but little specific details.

These throughput numbers are experienced in both the uplink (end user to the fixed network) and downlink (fixed network to end user) directions depending on the source and destination of each video stream. For example, a low-speed situational awareness stream may be transmitted from the incident location on the uplink, and then back down to Incident Command on the downlink. Therefore, these rates are applied to the uplink and downlink separately.

Furthermore, the model assumes the ideal scenario of broadcasting all applicable video streams to all necessary users. In other words, if five individuals need to receive the same helicopter video stream, the model assumes that this stream is sent once, instead of five times and requiring five times the LTE capacity. The model assumes that airborne video arrives to the fixed network first via a 4.9 GHz uplink and is then distributed to the field using 700 MHz LTE for the downlink.

3.7.2 Web Apps

The bandwidth required to interact with websites is dependent on the type of content on that site. For example, Google's home page has limited graphics. The Bing search engine with an additional image adds some 100 kilobytes (depending on the image) to the download. Other sites contain embedded video content (real-time or stored) and substantial additional graphics. Therefore, the "cost" to a network for a user to interact with a web application depends on the type of content on the page.

Web-based applications can be inherently inefficient. For example, a map that refreshes every 15 seconds for Automatic Vehicle Location could require a new image every 15 seconds. NPSTC expects that many of the applications that would be used at the incident during the busy hour would be delivered using a web-based interface. However, the model assumes the most efficient delivery of data; ancillary web page data that would normally be associated with a page view is not considered. This then represents a conservative estimate of web-based traffic.

Examples of applications that would be utilized in a web application format include:

- Accessing hospital status information
- Accessing EMS transport destination data
- Accessing national HAZMAT databases
- Accessing local databases for criminal justice inquiries
- Accessing incident history, prior responses, master name files, etc.

3.7.3 Automatic Location

The Operations Report highlighted the importance of monitoring the location of public safety resources. Traditionally this resulted in tracking vehicles, but by the year 2022, public safety expects to be able to track personnel as well. The device location does not require a substantial amount of data. Narrowband data systems, however, are constrained and often have much longer unit reporting/polling intervals. With a broadband system, unit reporting intervals can be 15 seconds or shorter,[38] providing near-real time awareness of resource locations. The impact of the automatic location is then a function of the size of the message and the frequency of location messages. Importantly, tracking of personnel requires the ability to locate inside buildings and includes not only latitude and longitude but also altitude. To address this need, the model assumes each resource (person or vehicle) sends 10 bytes of data every 15 seconds and that each message must be received within 2 seconds of transmission. This results in 40 bits per second on the uplink from the units.[39]

Conversely, Incident Command must be able to visualize the location of these users. This transmission occurs on the downlink and is at least equivalent to the net uplink demand expressed by the resources above. Therefore, the model includes a bi-directional demand at the incident scene for all Automatic Location traffic. For example, location data would flow from the firefighter's device to the public safety network where it would be available to the dispatch center mapping application and then would have to flow from the network out to the Incident Commander's application in the field.

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[38] Personnel polling will likely occur at 15 second intervals, but vehicle polling today occurs at 5 second intervals.

[39] Uplink bps = (10 bytes / 2 seconds) * (8 bits/byte) = 40 bits per second

3.7.4 Geographic Information Systems (GIS)

GIS systems will play an important role in the incident management of the future. As expressed in the operations reports, a variety of geo-spatial based data will be required by Incident Commanders and other personnel at the incident. GIS data sources are becoming extremely robust including high-resolution aerial images and other data layers. The raw databases for a metropolitan area may contain more than 1 gigabyte (GB) information; however, the personnel on the scene need only a portion of the metropolitan area for the incident and may not need all data layers. These databases are updated frequently. Therefore, the ideal model is one where GIS-based data is retrieved as needed for the incident. The size of the area under study, the quantities of layers of data, and the type of data will play a significant role in the required to be downloaded. NPSTC assumes the downloaded data for each GIS view is 350 kilobytes and that data must be transmitted over five seconds for reasonable quality of service. As a result, the network must deliver 560 kilobits per second on the downlink.[40]

3.7.5 Incident Command Applications

Incident Command requires a variety of applications to fulfill its mission. It is both a consumer and producer of substantial amounts of information. Other sections of this chapter, such as Video, contain some video use for Incident Command; however, this section details its specific requirements. The incidents reflected in the Operations Report fully elapse over several hours, however, this study focuses on the busy hour – specifically within the first 2 hours of units arriving on scene, depending on the scenario. Furthermore, this spectrum study isolates the impact of the incident itself on peak capacity for a cluster of sectors. Therefore, the Incident Command applications and usage included in this section reflect applications that are used while personnel are physically located at Incident Command and while the incident is at its peak communications activity. For example, while en route to the incident, Incident Command will download or otherwise receive (e.g., push from a CAD application) an incident schematic. These files are expected to be 500 kB in size and are required within 5 minutes, implying a throughput of 13.3 kbps.[41] This traffic would be generated on cell sites approaching the incident, and not on the cell site(s) serving the incident. Therefore, this traffic is excluded from the calculation.

On the other end of the event timeline, Incident Command will disseminate an Incident Action Plan (IAP) to all teams engaged in the incident. These plans may comprise images, electrical plans, HAZMAT information, building drawings, ingress/egress points, and other content that can require several megabytes and be distributed to dozens of personnel. The plans are generally disseminated in multipage files of approximately 1 megabyte (MB) and must be disseminated within 15 minutes of their creation. This then requires both upload from the incident scene and download to each incident team within that period of time. However, the uplink occurs only once, while the quantity of downlink users is a function of the size of the incident. The IAP is distributed long after the busy hour occurs (typically 4 to 12 hours), and therefore, would not impact the <u>initial</u> busy hour for the incident.

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[40] Downlink kbps = (350 kilobytes / 5 seconds) * (8 bits/byte) = 560 kbps.

[41] Downlink kbps = 500 kilobytes / (5 minutes * 60 seconds/minute) * (8 bits / byte) = 13.3 kbps

3.7.6 Patient, Evacuee, and Deceased Tracking

The tracking of civilians is a critical component to incident management. The patient, evacuee, and deceased tracking application enable Incident Commanders to provide this function. Public safety personnel collect a 100 kB data set that includes patient demographic information, images, and medical information. The data is not extremely time sensitive and can be transmitted over 1 minute. One person can process one patient per minute; therefore, the impact to the system is 13.3 kbps[42] per user on the uplink.

3.7.7 Biotelemetry

Incident Commanders and hospital officials need biomedical telemetry from public safety personnel and for patients involved in the incident. Patient biotelemetry transmitted during the busy hour is sent one time per patient, while first responder biotelemetry is send throughout the incident to monitor the health of incident personnel and their surroundings.

Patient biotelemetry includes substantially more data including 12-lead EKG transmission to the hospital, initial vital signs, and other patient information. This data is estimated to be approximately 100 kB in size per patient and must be transmitted from the scene within 5 minutes. The models assume 50 patients on average per incident. While the number of patients varies across the four incidents, the total impact to the network is very low, and therefore, does not have substantial impacts on the net required throughput. This results in an uplink demand of 9 kbps.[43]

First responder biotelemetry data consists of less data per transmissions, but transmissions from the incident scene occur every 30 seconds. These samples must be received within 5 seconds. They include air level, heart rate, body temperature, external temperature, and other information at a package size of 84 bytes. The resulting bit rate is 17 bits per seconds and translates to 0.134 kpbs on the uplink. The model assumes a 10 percent acknowledgement rate (i.e., 0.013 kbps) on the downlink and that the uplinked data will also be downlinked.

3.7.8 Third-Party Sensors

The focus group sessions identified the need for Incident Commanders to receive building system information and view alarm codes and conditions. The information includes HVAC system status, security system alerts, building logs, and potentially gas sensors. The data transmitted to commanders is small in nature and contains status codes or simple integer numbers. The model estimates 84 bytes of data in each message and a message is sent twice per hour and is downlinked to Incident Command and others.

3.7.9 Public Switched Telephone Network (PSTN) Voice (Cell Phone)

The Operations Report reflects a need for personnel at the incident scenes to have real-time cell phone style communications. This allows these personnel to contact individuals on the Public Switched Telephone Network (PSTN). This application requires streaming audio packets in both directions for the duration of a call. The Technology Task Group suspects that public safety would take advantage of the 3GPP standard Adaptive Multi-Rate Wideband (AMR-WB) as the voice coder for future PSTN voice calls over a broadband

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[42] Downlink kbps = 100 kilobytes / (1 minute * 60 seconds/minute) * (8 bits / byte) = 13.3 kbps
[43] Uplink kbps = 100 kilobytes / (5 minutes * 60 seconds / minute) * (8 bits/byte) = 9 kbps

LTE network. The codec uses variable bit rates based on radio conditions, background noise, and other factors. The codec ranges in bit rate from 6.6 kbps to 23.85 kbps. The higher bit rates (between 14 and 24 kbps) are needed in situations with high background noise. Many of the scenarios identified in the incident scenarios are high-noise environments. As a result, the Technology Task Group used 10 kbps as an average between low- and high-noise environments.

3.7.10 File and Message Transfer

Fire rescue units at the incident scene need to receive building preplan information, photographs, and diagrams of hazardous materials storage, location of hydrants, and water valves. This information is received at the early stage of the incident. Building plans and photographs are the biggest contributors to the file size transferred. The model assumes that the file is 1 MB in size, is transferred once, and has to be received in less than 5 minutes. Therefore the load created by this transfer on the network is 9 kbps on the downlink.

Additionally, during the incident all vehicles and personnel on the scene need to be able to access and receive data files and messages. This includes CAD terminal-to-terminal messaging and transmission of data messages directly to personnel who are outside of their vehicle. These messages are small in size (2 kilobytes) and need to be received in less than 1 second, which translates to 0.016 kbps. The model assumes that each user sends and receives a message once every 15 minutes. The busy hour traffic load this generates is equivalent to sending and receiving an 8 kilobytes file once, at 0.064 kbps per second.

Overall, the impact of File and Messaging Transfer application on the system is 9.064 kbps in the downlink and 0.064 kbps in the uplink; however, because this information is deemed to be transmitted outside of the busy hour, it is not included.

3.7.11 Weather Tracking

Wireless Weather Data feeds provide immediate access of weather information to Incident Commanders. The weather data may be transmitted from a remote system up to Headquarters and sent back to Incident Command. The information contains temperature, humidity, rain forecasts, wind speed and direction, and should be received every 5 minutes. The model assumes it is 100 kilobytes in size and needs to be received within 60 seconds, adding a traffic load of 13.3 kbps on the network.

3.7.12 Other Applications

It must be acknowledged that this report cannot capture all of the various specialized applications which are used by public safety agencies across the United States. The information presented in this report was designed to demonstrate likely or expected usage by most first responder organizations through the year 2022.

3.7.13 Summary

The following table summarizes the application throughput and usage parameters used in the spectrum modeling for each application:

Table 15: Application Throughput and Usage Parameters in Spectrum Modeling for Each Application

Application	Peak Throughput (kbps)		Session Duration (sec.)	Sessions Per Hour
	Downlink	Uplink		
Incident Video – High Quality (DL) (aircraft)*	1024	16	3600	1
Incident Video – Medium Quality (DL) Traffic Camera	512	16	3600	1
Incident Video – Low Quality (DL) - Situational	256	16	3600	1
Incident Video – Low Quality (UL) - Situational	16	256	3600	1
Incident Video – High Quality (DL) helmet/vehicle	1024	16	3600	1
Incident Video – High Quality (UL) helmet/vehicle	16	1024	3600	1
Incident Video – Medium Quality (DL) helmet/vehicle	512	16	3600	1
Incident Video – Medium Quality (UL) helmet/vehicle	16	512	3600	1
Incident Video – Medium Quality (UL) Video conference	16	512	3600	1
Incident Video – Medium Quality (DL) Video Conference	512	16	3600	1
Automatic Location (UL+DL) Vehicles	0.04	0.04	1	240
Automatic Location (UL+DL) Personnel	0.04	0.04	1	240
Geographic Information Systems (GIS) - Street View	160	16	1	5
GIS Detailed View	683	68	1	60
File and Message Transfer UL	0.0016	0.016	1	4
File and Message Transfer DL	0.016	0.0016	1	4
Patient and Evacuee and Deceased Tracking	5	13	60	60
Biotelemetry – First Responder (UL+DL)	0.13	0.13	30	120
Biotelemetry - Patient	0.027	2.7	300	50
Vehicle Telemetry	0.027	2.7	300	4
Third Party Sensors	0.025	0.0025	30	2
Weather Tracking	13.3	13.3	60	12
PSTN Voice (Cell Phone)	10	10	3600	1

Please note the table represents the usage impact of a single user of each application. In some cases the uplink and downlink traffic is shown because the data is transmitted up from the incident and back down (generally) to Incident Command. In other cases, such as video, the need must be determined separately because some video is transferred from the fixed network down to the incident (e.g., traffic cameras), while other video is both uplinked and downlinked at the incident (e.g., helmet cameras).

3.8 Technology Needs

The public safety community clearly has operational requirements that have not been met and technology improvements are needed. The list of needed improvements was derived from the web-based questionnaires, the broadband focus groups, and other gaps identified between technology performance and the public safety need. This document does not intend to specify the standards to be employed or to fully detail the requirements of new technologies. Instead, this document should serve as public safety's roadmap for technology improvements that are needed by the year 2022.

As expressed earlier, the technologies available to public safety today do address the vast majority of public safety's requirements. Project 25 (P25) and other narrowband solutions meet almost all of the requirements for push-to-talk voice communications. In terms of broadband data, LTE meets a substantial number of public safety's functional requirements. **A recurring comment from the Operations Task Group's questionnaire was the issue of insufficient funding.** In other words, for the most part, the technologies exist to meet the need, however, financial resources to acquire the technology is inadequate. This document does not attempt to uncover technology solutions that reduce costs. Instead, the focus of this section is on the unmet operational needs of the public safety users. The Working Group determined great value in all of the initiatives of the Broadband Working Group (BBWG) and recommends these efforts continue. The importance of the BBWG activities is strongly supported by the findings of the AFST Working Group.

The ability for public safety to access mission critical push-to-talk style communications over an LTE network has been discussed extensively in recent years. Policymakers seek a new paradigm in public safety communications that enables the United States to deliver more capabilities and applications with smaller investments. The anticipation is that public safety could abandon LMR networks in lieu of broadband networks running a push-to-talk application. Earlier sections this report identified reasons why public safety must retain its spectrum allocations in narrowband for the foreseeable future because broadband lacks multiple key capabilities to replicate LMR systems. NPSTC's BBWG has developed requirements for mission critical voice that must be addressed by broadband networks and applications.[44] In addition to these functional requirements, broadband has several other disadvantages that must be overcome. Before they replace LMR systems, broadband networks and applications must affordably satisfy all of the requirements of LMR systems.

Broadband networks and applications must affordably satisfy all of the requirements of public safety LMR systems before it can replace them.

A key step in delivering on this capability is a national push-to-talk standard over IP networks. The standard must provide a generic capability to provide connectivity over any broadband network because public safety could leverage 4.9 GHz, LTE, Wi-Fi, or other communications networks to exchange data. The standard must provide public safety with the same breadth of capabilities in today's P25 radio. In other words, it must satisfy all P25 functional requirements. But many of those functional requirements in the P25 Statement of Requirements are embedded in the specialized air interface, and therefore, public safety must separate network from application functional requirements when developing the requirements for a mission critical voice application.

It must be stressed that one of the major obstacles to abandoning LMR systems and technology is that Voice Over LTE currently is a network technology that requires access to a network. It does not provide for direct mode or talk around communication when either the broadband network does not exist or is not reachable by the public safety user. This can mean the difference between life and death for a first responder.

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[44] See Mission Critical Voice, http://npstc.org/download.jsp?tableId=37&column=217&id=1911&file=Functional Description MCV 083011 FINAL.pdf for that document.

The use of narrowband channels presents other benefits. For example, narrowband systems can utilize very high sites that maximize coverage per site without serious ramifications. Broadband networks, on the other hand, require high frequency reuse too often to use these high sites. This creates a substantial benefit for narrowband systems to cover mountainous or less populated areas of the country and to require fewer sites. Unlike broadband, narrowband systems also use a small percentage of the total spectrum at each site or in each system. It is technically feasible to "reserve" LTE Resource Blocks[45] to fix the problem of high elevation coverage. A handful of high sites may each have a reserved Resource Block that is not used through most of the remainder of the system, and therefore, these high sites would not interfere with low lying sites. However, if five Resource Blocks are reserved, the other impacted cell sites will see a 20 percent reduction in capacity, and furthermore, a single Resource Block at these high sites will have very limited capacity at the cell edge of the high sites and does not allow broadband speeds capable of multiple radio over IP voice channels. One potential solution to the problem is additional spectrum to deal with these inefficiencies; however, as will be demonstrated in the Spectrum Report, that spectrum is needed in urban areas for capacity purposes. It may then be a potential solution in areas where capacity is not of concern. Preferably, however, the problem should be addressed by the LTE equipment makers, standards bodies, or both in order to ensure that LTE-based systems can provide the ubiquity of coverage in all types of terrain.

Next, the LTE standard specification currently defines the output power of broadband subscriber devices as 200 milliwatts, compared with 3-5 watts (for handsets) and 25-100 watts (for mobiles) for a public safety LMR subscriber radio. This factor also translates into substantially better coverage per site for an LMR system, and therefore, many more broadband sites would be required to match the coverage of a typical LMR system. Additionally, this report has addressed the importance of VHF spectrum in public safety communications due to its enhanced propagation characteristics. The Spectrum Report showed it would take substantially more sites in the 700 MHz band to cover the equivalent area in the VHF band. Public safety may be able to leverage commercial towers that typically operate at 800 MHz in urban, suburban, and some rural areas; however, due to lack of demand, these assets do not exist in many rural areas throughout the country. Therefore, a significant number of additional towers would be required to match the coverage of VHF, UHF, and 700/800 MHz narrowband land mobile radio systems.

The NPSTC mission critical voice requirements document underscores other important elements that must also be resolved before LTE-based systems can replace narrowband-based systems. For example, the requirements include *"Direct or Talk Around: This mode of communications provides public safety with the ability to communicate unit-to-unit when out of range of a wireless network OR when working in a confined area where direct unit-to-unit communications is required."* No such voice capability exists with an LTE-based broadband system. Therefore, public safety must determine how it will accommodate this requirement before it can satisfy LMR-based requirements.

Importantly, there are items in the area of unit-to-unit communications and in interoperability situations that public safety finds insufficient even in current land mobile radio technologies. These technology needs are addressed in the following sections. Instead of merely replicating the current LMR experience, public safety

[45] A Resource Block is the smallest spectrum allocation in a LTE system. It is fixed at 180 kHz.

should seek to solve all of these issues. However, there are important immediate needs that could be resolved by push-to-talk over LTE that should be addressed in parallel with the longer term vision of replicating LMR functionality over broadband. At the same time, the public safety community and policymakers should not assume that the longer term vision will become reality and must continue to plan LMR and LTE networks in parallel. Public safety needs a national standard for push-to-talk over LTE in the short term, and to resolve these incident and mutual aid needs in the longer term.

3.8.1 Enhanced Incident Communications

The Operations Report highlighted scenarios where there is difficulty in bridging tactical and wide-area communications. Proper configuration and training can largely resolve these impediments with voice communications. However, technology can improve upon today's solutions. As mentioned in the Operations Report, some fire departments are solving team communication with Bluetooth systems that are not integrated with tactical radio communications and therefore represent a safety risk. The objective should be a framework whereby the communications systems automatically configure themselves along with the subscriber devices to maximize their reach and connectivity on a continual basis. [46] The solution should allow intra tactical team communication, team to Incident Command (Incident Area Network), and Incident Command to wide-area communication and dispatch (Jurisdictional Area Network) all at the same time and allow the most critical communication to take priority. A common problem as articulated in the Operations Report is the complexity of training public safety personnel to deal with various scenarios. The final solution should be as transparent as possible, reliable, and allow any public safety user to communicate with all others as required.

Next generation public safety broadband systems should be designed to automatically assess the available network options and automatically create the needed and approved communications paths.

Additionally, by 2022 the public safety user should know his communication status. The user should know whether or not they are connected to other users and to the wide area network on a continual basis. Such is the case for trunking networks, but for conventional and talk-around applications, users don't know if others can hear them unless a response is heard. By 2022, public safety users should have this knowledge without doing radio checks. Radio checks may still be required, but only to address non-communications issues.

The nationwide public safety broadband network should provide all public safety users with a common set of applications and features. The public safety broadband devices should let the user know if the device is attached to the nationwide public safety system.

The Operations Task Group questionnaire response was mixed on the need for peer-to-peer connectivity for broadband applications with 60 percent of the respondents indicating direct mode for broadband applications was **not** required. However, the Working Group suspected this may be the result of a lack of understanding about how broadband applications could play a role in tactical operations of the future. Furthermore, 40 percent of the respondents did indicate that direct mode for broadband applications was a requirement. This broadband direct mode need may become a component in how the desired solution is

[46] We note that the 3GPP SA1 WG is tasked with exploring a "direct mode" and this work is starting at the time of writing this report.

resolved and public safety should solve this problem for both voice and data applications. It should be noted that the questionnaire did not ask the respondent to differentiate between broadband data applications and potential broadband voice services.

There are many ways to solve this problem with a variety of tradeoffs. NPSTC does not intend to solve this problem in this document; instead, this report establishes the technological need to address this problem and to do so by 2022. This need may impact the net spectrum required by public safety. For example, additional spectrum may in fact be required to provide for broadband peer-to-peer connectivity.

Finally, the solution to incident-based broadband data needs should incorporate or consider indoor geo-location needs. GPS signals are generally not available in buildings, preventing geo-location of personnel indoors. Networking technologies used for incident communications can assist with locating personnel in three dimensions using time difference of arrival (TDOA) techniques. Such techniques may augment other technologies such as inertial sensors. Therefore, the ultimate peer-to-peer technology should be developed such that it enhances the ability to geo-locate personnel at the incident scene in three dimensions.

3.8.2 Comprehensive Interoperability Solution

The Operations Report indicated that today's interoperability capacity is inadequate in certain circumstances, particularly with users constrained to certain radio frequency bands, most of which have few FCC-designated interoperability channels. Many of the potential scenarios are resolved by regional systems and proper system configuration and operating procedures. However, in the case of very large incidents requiring mutual aid, first responders arrive from outside the region and are generally not configured to operate on the local systems. Following September 11, 2001, many regions purchased radio caches to address these mutual aid needs. Such caches may not be sustainable in the future. By 2022, public safety needs a solution to deliver a nationwide schema that provides clear and common access to voice radio communication with sufficient capacity to address day-to-day and major incidents. The Technology Task Group feels this problem should be resolved via the nationwide broadband infrastructure. In this case, public safety will need to provide a roaming framework not only for network data and full duplex voice, but for the push-to-talk application. It should be noted, however, that the remaining mission critical voice requirements still apply. While this feature would be delivered via a broadband framework, the remaining requirements such as peer-to-peer communications may require traditional narrowband communications unless a viable broadband solution is developed.

3.8.3 Application Interoperability Standards

The nationwide public safety broadband network will provide network level interoperability. This will allow users to exchange Internet Protocol (IP) packets, but it doesn't provide public safety with useable and useful information. NPSTC addressed the need for a push-to-talk standard earlier in the document; however, there were a number of other applications identified in the focus groups that will require interoperable communications. As a result, public safety requires application standards for these applications prior to mass deployments. The following applications were identified as requiring interoperable standards:

- Incident Command White Board systems
- Video (ad hoc)

- Text, Multimedia
- Auto-Location
- GIS
- Building drawings (CAD)
- Building Interfaces (motion, door, HVAC, security access logs)
- Telemetry (biometric, radiological)
- Hospital availability/resources and patient tracking
- Records management
- Mug shots, BOLO, finger print scans
- Traffic Control

The Spectrum Report demonstrates that even with the 20 MHz of 700 MHz broadband spectrum currently allocated, there will be congestion on the network at certain times and particularly during major incidents. The LTE technology will provide substantial improvements to Quality of Service; however, if the network lacks information on the importance of any individual transaction, it cannot ensure it gets through. At any one point in time, a police chief or field officer may have the most important content or a high-resolution image may have priority over a video stream. The network can easily prioritize on the user and the application, but it can't determine the priority of the importance of a particular video stream, image, text message, or other application. Therefore, public safety requires an overarching framework which is consistently applied to deal with this particular issue.

Users must have methods to indicate which pieces of data are critical in the new framework. There may also be some additional mechanisms to automatically prioritize certain user or application data depending on known situations. For example, if the system has the ability to "know" which individuals are actively involved in an incident, it can prioritize that traffic above others in the area. But in the scenarios identified in our focus groups, all traffic would be associated with the incident. This means Incident Commanders and general staff will require tools to help make sure the most critical information gets through. This implication highlights the need for a COML or similarly trained technical professional to be involved in the public safety communications incident planning process.

The application standards must also economize bandwidth use. Focus group participants identified video uses of incident-based content at Incident Command, Emergency Operations Centers, and other locations. It would be grossly inefficient to use three uplink streams for the content of one camera. Application standards need to efficiently use the capacity of the system. The participants also identified the need to adjust video quality on-the-fly depending on circumstances. For example, in some instances, the video content would provide some level of situational awareness, and then later, the same camera's view would become a focal point and require high-quality video. Therefore, the video application must accommodate variable and controllable video quality. Some of the parameters may be defined as a function of the available bandwidth, but it is important to place as much control over quality with public safety personnel.

Finally, the application standards must account for the network architecture. Today, most public safety applications require a server at a static address. Future applications could be running over mesh networks that will be detached from the wide-area network and applications may need to operate in peer-to-peer mode to share information at the incident.

3.8.4 Improved Broadband Cell-Edge Spectral Efficiency

The cell edge represents the worst case spectral efficiency. Public safety needs a broadband solution that can accommodate demand anywhere. Some of the broadband focus group incidents can be supported by the average spectral efficiency of a 10 or 20 MHz allocation; however, none of the incidents can be accommodated with 10 MHz at the cell edge. LTE capacity is insufficient for major incidents that occur at cell edge with traditional architectures and there is a need for ongoing improvements to cell-edge spectral efficiency. The standards themselves introduce features such as Cooperative Multipoint (CoMP) to improve the performance at the cell edge, but these improvements are already factored into the spectral efficiency improvements over time.

This problem may require affordable deployable systems to improve spectral efficiency. For example, an agency could deploy Cell on Wheels (COW) to boost coverage and capacity; however, such a device requires significant backhaul (e.g., 4.9 GHz or broadband satellite) which may not be available at the incident. A COW solution is only of value when the incident is pre-arranged or is expected to be of long duration because of the time it takes to request, deploy, and set up the system. Most incidents are short term and bandwidth is needed quickly.

Alternatively, the agency could deploy an LTE relay but that device shares the host site capacity which could effectively cut its capacity in half. Public safety agencies could also boost incident capacity using Distributed Antenna Systems (DAS).[47] These systems improve the coverage inside buildings and other areas and improve throughput. While these systems are extremely expensive to deploy throughout an entire city, public safety could leverage deployments by the cellular carriers and third parties by adding public safety frequencies. This solution could also help to resolve the in-building communication needs of public safety, but it is important to recognize that with loss of power in the building (during an emergency) the DAS could cease to function. Finally, the nationwide public safety broadband network could be built using heterogeneous networks that combine both macrocell (using tower and rooftop sites) and small cells (using pole mounted sites) to augment capacity. However, the ability for public safety and its partners to build and operate such an architecture can be impacted by asset, backhaul, and financial restrictions.

[47] A Distributed Antenna System is a network of spatially separated antenna nodes connected to a common source via a transport medium that provides wireless service within a geographic area or structure. Typically the transmitted power is split among several antenna elements separated in space so as to provide coverage over the same area as a single antenna but with reduced total power and improved reliability. The idea works because less power is wasted in overcoming penetration and shadowing losses, and because a line-of-sight channel is present more frequently, leading to reduced fade depths and reduced delay spread. The transport medium is often fiber optic based, operating at the frequency(ies) to be broadcast. A fiber medium is inherently very wide bandwidth and can thus be shared among many different communications systems. Source: Wikipedia

3.8.5 Broadband Multicast Standards

Public safety's one-to-many communications method will continue with data. The focus groups identified multiple content sources that would be distributed to many individuals on the incident scene or in the field. The calculations included in the Spectrum Report assume all traffic that is transmitted to more than one user is automatically and dynamically multicast or broadcast using a single stream. Delivering on this capability requires a system that can fluidly move traffic in and out of multi-cast streams and subscribers that dynamically subscribe to the appropriate stream. Furthermore, it assumes the applications that require multicasting can send their traffic to the appropriate LTE systems. Lack of integrated solutions that leverage multicast/broadcast will result in increased congestion or increased spectrum needs.

The broadcasting capabilities of LTE will also likely be critical for public safety operations. Broadcast push-to-talk audio for critical talkgroups will provide more efficient transmission over a multi cell site area. It will also provide enhanced coverage in the same way that LMR simulcast systems do.

4 Spectrum Report

4.1 Introduction

From the time the PSWAC *Final Report* was issued until this updated report, public safety has received significant spectrum allocations. Yet the nature of public safety operations and the growing need to better manage day-to-day operations and response to large complex incidents still leave public safety short of spectrum in key areas. Also, at the end of the period covered by this document, a significant portion of public safety's narrowband spectrum in major markets is slated for reallocation under the provisions of the Spectrum Act.

The 700 MHz nationwide narrowband allocation along with specific UHF TV sharing allocations in large urban areas has met public safety mission critical voice needs in most regions. Some areas will be forced to make large investments in new 700 MHz voice systems.[48] Other rural areas reported through the NPSTC questionnaire that they experience a shortage of VHF spectrum for growth. The VHF band is ideally suited for rural areas and is cost effective to implement for smaller cost-constrained agencies.

This section will provide an overview on the status of narrowband voice channels, wideband data allocations and needs, discuss the ITU Broadband Model, and provide public safety situational assessments and metrics.

4.2 Review of PSWAC Spectrum Findings

This section lists excerpts from the PSWAC *Final Report* and is intended to allow comparison of the key material of the PSWAC *Final Report* to this current report. The recommendations regarding spectrum issues from the PSWAC *Final Report* are compared to actual outcomes from that report.

4.2.1 1996 Public Safety Allocations from PSWAC

Public Safety Land Mobile Spectrum – 1996 allocations[49]

Frequency Band (MHz	Number of channels	MHz (Approximate)
25-50	315	6.3
150-174	242	3.6
220-222	10	.1
450-470	74	3.7
806-821/851-866	70	3.5
821-824/866-869	230	6
Total*	941	23.2

**Various amounts of spectrum have also been allocated in the 470-512 MHz band in 11 markets: Boston, Chicago, Dallas, Houston, Los Angeles, Miami, New York, Philadelphia, Pittsburgh, San Francisco, and Washington, D.C.; ranging from 6 to 18 MHz. (In Los Angeles, 6.5 MHz is allocated).[50] This table and the asterisk note reflected the spectrum available for public safety use in 1996.*

[48] At the time of this report we are aware of large 700 MHz systems being built out in Houston, Texas; the State of Maryland; and the County of Riverside, California.

[49] From PSWAC *Final Report*, Page 640. Note the number of channels is based on pre-narrowbanding channel widths

4.2.2 Findings of the PSWAC Spectrum Requirements Subcommittee[51]

The material in the table below is excerpted from the PSWAC *Final Report* Appendix D. These findings differ somewhat from the PSWAC main report findings and recommendations but it is useful to review here to set a baseline for what was recommended and what actually has happened from 1996 to 2012.

Table 16: Comparison of PSWAC Recommendations and Outcomes

Report Recommendation	Actual Outcome
Immediate further sharing of the 470 to 512 MHz (TV band) in all areas	Only partial sharing on a waiver basis in two areas – Los Angles and New York
Reallocate all or part of the 746 to 806 MHz (TV channels 60 to 69) for public safety use	24 MHz reallocated TV channels 63-64 and 68-69
Immediate allocation of the channels in other services created in the FCC's refarming proceeding at both VHF and UHF (including TV sharing bands.)	This was not implemented by the FCC
Eventual reallocation of all TV sharing 470 to 512 MHz channels to public safety	This was not implemented by the FCC
Immediate new sharing of the VHF TV band (174-216 MHz) (primarily outside of urban areas and for statewide systems).	This was not implemented by the FCC
Reallocation of the 380 to 399.9 MHz band to public safety	This was not implemented due to Department of Defense (DoD) opposition
Sharing of the 380 to 399.9 MHz band with DOD on a mutually agreeable basis to minimize interference to public safety to nuisance levels.	This was not implemented due to DoD opposition
Hold a portion of the 174 to 216 MHz (TV band) in reserve to meet future public safety needs or needs not met by this effort	This was not implemented by the FCC
For wide band data and video systems: *Make allocations from the 1710 to 1755 MHz band*	Partially Implemented with the 4.9 GHz allocation (short Range only)
For short range video systems: *Make allocations from the 4635 to 4685 MHz band*	Implemented with the 4.9 GHz allocation
For fixed microwave systems: *1. Make allocations in the 4635 to 4685 MHz band.* *2. Make allocations in the 1990 to 2110 MHz band*	This was partially implemented by the 4.9 GHz allocation. The FCC has also made several changes to the Part 101 microwave rules that increased access to spectrum but availability for new hops is still limited
For Intelligent Transportation System: *Make allocations in the 5850 to 5925 MHz band*	The FCC implemented this allocation

The recommendation to reallocate the 380 to 399.9 MHz band to public safety use received great opposition from the Department of Defense. The findings in the PSWAC *Final Report* changed that recommendation to

[50] The reference to 6-18 MHz of spectrum available appears to be an error as only parts of at most two TV channels were available in given market.

[51] PSWAC *Final Report,* pages 660-663. These findings differ from the findings in the main report.

allocate 24 MHz from the TV channels 60 to 69 in the planning stages to be freed up by the conversion to digital TV technology.[52]

The PSWAC *Final Report* also made the following conclusions and recommendations:

Conclusions [PSWAC *Final Report Conclusions and Recommendations Continued]*

State and local public safety agencies require additional spectrum to satisfy voice, data, video, and fixed service requirements, especially in major metropolitan areas. An additional 25 MHz of spectrum is needed immediately to satisfy existing voice and data requirements. A total amount of 95 MHz is required by the year 2010. The additional spectrum is required for additional voice and data use, plus use of new technologies such as wide band data and video. An additional 161 MHz of spectrum is required to meet fixed service needs.

The existing Federal Government spectrum allocations will satisfy Federal public safety/public service requirements through the year 2010 provided: a) no additional spectrum is transferred to the FCC for commercial use; b) the assumed spectrum efficient technologies become available; and c) funds are provided through appropriations to implement the new spectrum-efficient technologies.

Public safety agencies will continue to use commercial services to decrease the demands on private systems. It is estimated that commercial services will satisfy 10% of the spectrum need by 2010.

Additional spectrum is required for Federal, state, and local interoperability communications. The implementation of Shared Federal, state, and local public safety systems will provide both fiscal and spectrum efficiencies, plus enhance interoperability requirements.

Recommendations

It is recommended an additional 25 MHz of spectrum be immediately authorized to meet existing voice, data, and video requirements. Another 35 MHz should be reallocated by 2005 and the remaining 35 MHz prior to 2010. It is recommended the following frequency bands be analyzed to determine the feasibility of authorizing public safety use.

4.2.3 Comparison of Findings

The recommendation for allocation of 25 MHz of immediate spectrum was met by the 24 MHz allocation at 700 MHz; however this spectrum was not usable in almost all urban areas until June 2009. An additional 50 MHz was later allocated at 4.9 GHz and was immediately available after the FCC Rulemaking authorizing the allocation. No specific allocation was made for video systems. An additional 10 MHz of spectrum in the D Block was authorized for public safety use in early 2012. The 700 MHz band is configured for 4G LTE and narrowband voice. The 4G LTE portion is just starting to be built out and is envisioned to be a nationwide interoperable network with multi-agency access for public safety mission critical needs. Only limited expansion of TV sharing has occurred in New York and Los Angeles and those channels must be given back to the FCC for auction based on the Spectrum Act. No additional VHF spectrum was allocated to public safety.

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[52] PSWAC *Final Report*, page 3

4.3 Current Spectrum Use

Table 17 represents the current spectrum allocations to public safety. It excludes spectrum allocations from microwave licenses, leased services from satellite services, and other spectrum not directly allocated to public safety:[53]

Table 17: Current Public Safety Spectrum Allocations

Frequency Band (MHz)	MHz[Approximate]	Useage
25-50	6.3	Narrowband Voice
150-174	3.6	Narrowband Voice
220-222	.1	Narrowband Voice
450-470[54]	3.7	Narrowband Voice
809-815/854-860[55]	3.5	Narrowband Voice
806-809/851-854[56]	6	Narrowband Voice
758-763/788-793[57]	10	Wide Area Broadband
763-768/793-798[58]	10	Wide Area Broadband
768-769/798-799[59]	2	Guard
769-775/799-805	12	Narrowband Voice[60]
4940-4990	50	Short range Broadband
Total	107.2	

This table doesn't include the TV-sharing spectrum allocated to public safety in 11 markets.[61] Subsequent to the PSWAC *Final Report,* TV channels 15 and 16 were allocated to the Los Angeles market and TV channel 16 to the New York market. Markets other than Los Angeles and New York have less than 6 MHz allocated for public safety use. The exact amount depends on the licensing of the General Access Pool for each market, (*see footnote #51*). Table 17 also does not include the 50 MHz of spectrum allocated at 4.9 GHz which is not

[53] As of 1/1/2012. With the addition of broadband spectrum and the various bandwidths of the voice spectrum channels, the number of channels is not included in this table.
[54] Also available in 11 market areas are TV-sharing frequencies in parts or all of TV channels 14 to 20. See the Spectrum Section 4.3.1.4 for more details. Also note that these T Band frequencies must be vacated as a part of the Congressional action authorizing the D Block.
[55] This allocation was altered by the ongoing 800 MHz reconfiguration. Some additional channels are being made available to public safety as the reconfiguration completes and the total number varies per geographical region. These additional channels are not included in the table count. See FCC 90.615.
[56] The National Public Safety Planning Advisory Committee (NPSPAC) band moved to the low end of the band with no change in the size of the allocation due to the 800 MHz band reconfiguration. See FCC 90.677.
[57] 10 MHz of additional spectrum in the D Block was allocated by Congress in 2012.
[58] This does not include the 1 MHz internal guard band.
[59] This is a 2 MHz guard band between the broadband and narrowband allocations.
[60] The Spectrum Act provides the FCC with the flexibility to permit broadband operations in this band, but any move to do so would first need to consider the potential for interference between broadband and narrowband systems.
[61] The markets are Boston, MA; Chicago, IL; Cleveland, OH; Dallas/Fort Worth, TX; Detroit, MI; Houston, TX; Los Angeles, CA; Miami FL; New York, NY/NE NJ; Philadelphia, PA; Pittsburgh, PA; San Francisco/Oakland, CA; and Washington DC/MD/VA. See FCC Part 90.303 for details.

practical for wide area or mobile data networks and is used commonly for local area networks and point-to-point back haul.

4.3.1 Narrowband Allocations

Public safety spectrum allocations in the 25-50, 150-174, 220-222, 450-470, 769-775/799-805, and 806-860 MHz bands are narrowband in nature, i.e., they are channelized such that the maximum channel size is limited to 25 kHz or less. These bands play an important role in meeting the totality of the public safety requirements and are all required for the foreseeable future to meet the operational requirements of public safety.

4.3.1.1 25-50 MHz

This band is primarily used by states for statewide voice systems for law enforcement use and some state highway maintenance radio systems. The band also supports a few smaller agencies that need a cost-effective wide coverage footprint with relatively few total units and little use for portable units. This band is poorly suited for portable use because the portable antennas are very inefficient in this frequency range. There is also poor reuse of frequencies in this band because of the wide coverage footprints and due to "skip" interference. While the band comprises almost 18 percent of narrowband voice allocations, this band does not support nearly that percentage of voice use for public safety. It is also very difficult to purchase radio equipment or equipment parts for this band and many of the systems in use in this spectrum are aging and in need of replacement.

4.3.1.2 150-174 MHz

This band is heavily used throughout the nation. It is a popular band for rural areas and also supports mutual aid almost exclusively for wild land firefighting. The federal agencies involved with wild land firefighting use this band and there are coordinated frequency plans between local, state, and federal agencies. This band was identified in user surveys as being overcrowded in rural areas.

4.3.1.3 220–222 MHz

This band has a few narrowband channels allocated for public safety use. Because there are few channels and they are limited in bandwidth, there are only a few public safety systems using this band. This band also has very limited interoperability with the other public safety bands.

4.3.1.4 450- 470 MHz, Also TV Sharing to 512 MHz

This band is heavily used in urban areas, particularly the TV-sharing allocations above 470 MHz. This band is well suited for urban systems with good propagation characteristics and building penetration in urban settings. Also available in 11 market areas is TV-sharing spectrum. The spectrum available varies considerably based on market. The Los Angeles and New York markets received the most spectrum, over two full TV channels (over 12 MHz) for Los Angeles and over 1 full TV channel (over 6 MHz) for New York.

4.3.1.5 809-815/854-860 MHz and 806-809/851-854 MHz

There was great growth in the 800 MHz band over the last 10 years. In some areas of the nation with high population density this band is saturated. In those areas, agencies are looking to the 700 MHz for growth.[62] This band saw the greatest growth in use nationwide over the last 10 years primarily because the National Public Safety Planning Advisory Committee (NPSPAC) band was fully built out over this time period. The 800 MHz band is used in both urban and rural areas with the greater use in urban areas.

4.3.1.6 769-775/799-805 MHz

This is the narrowband portion of the 700 MHz band. The band is currently supporting mission critical voice and narrowband mission critical low-speed mobile data systems. Recent Congressional action also allows for flexible broadband use in this spectrum. The band is becoming popular for vehicular repeater systems (VRS). With the reconfiguration of the 800 MHz band, it is more difficult to get the required spacing in the 800 MHz band for VRS use. This band was only fully cleared of TV stations in June 2009 so many systems are in the planning stages or beginning implementation at this time.

4.3.1.7 Narrowband Coverage

Each of these bands plays a vital role in creating affordable public safety communications solutions. This section describes the fundamental coverage differences of the various bands. Path loss varies by frequency band, and for free space, loss is lowest for the lower frequency bands used by public safety. Coverage prediction for a given band is a complex task to model with many different factors impacting the coverage in a given area for each frequency band.[63] Other factors such as building penetration or foliage losses make the different bands more or less desirable for urban, suburban, and rural use. The table below depicts the relative coverage of VHF (150 MHz) to other public safety bands:

Table 18: Coverage of VHF Relative to Other Public Safety Bands

Frequency (MHz)	Relative Service Radius	Relative Service Area	Site Multiplier
162	1	1	1
475	34%	12%	9
770	21%	4%	23
820	20%	4%	26

The table shows that a T-Band system (475 MHz) would require nearly 10 times the number of VHF sites (162 MHz) to cover the same area based only on free space path loss. Systems operating in the 700/800 MHz band require more than 25 times the sites of a VHF system covering the same area based only on free space loss; however, such stark differences would not apply to areas where path loss is limited to only free space

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[62] Examples of this are the County of Riverside, California, which is migrating entirely to the 700 MHz band from 800 MHz with a new voice and narrowband mobile data system; the State of Maryland which is implementing a new 700 MHz system; and the City of Houston, Texas, is also implementing a new citywide 700 MHz system.

[63] See *Handbook of Land Mobile Radio System Coverage* by Garry C. Hess for a more complete treatment of Land Mobile coverage engineering.

path loss. In urban areas, coverage is more constrained by in-building losses which tend to be higher for the lower frequencies somewhat negating the coverage benefits of lower frequencies. As a result, the in-building coverage between 475 MHz and 700/800 MHz in urban areas is roughly the same. In rural areas where building losses are less of a constraint, VHF coverage is generally far better and fewer sites are required for coverage.

The greater number of sites required at higher frequencies results in proportionally higher capital and operating costs. Over a wide area, such as a regional or statewide system, costs of a higher frequency system can be substantial. On the other hand, the limited number of channels in VHF prevents operations in many urban areas where the demand for more capacity is high. As a result, VHF systems are largely reserved for state and rural systems where VHF spectrum can meet the lower density demand and provides for better coverage at lower cost. Therefore, the AFST spectrum modeling splits the public safety narrowband needs between VHF and the remaining bands (UHF, 700 MHz, and 800 MHz). The spectrum modeling of this assessment then focuses on two distinct areas: First a rural area to determine spectrum needs in VHF spectrum, and second, an urban area to determine the spectrum needs in UHF, 700 MHz, and 800 MHz bands collectively.

4.3.2 Broadband Allocations

As of June 1, 2012, public safety's broadband allocations include 20 MHz of spectrum in the 700 MHz band, and 50 MHz of spectrum in the 4.9 GHz band. There is no regulated channel size in the 700 MHz band. It is expected that the 20 MHz of spectrum allocated will result in a single 10 + 10 MHz broadband LTE channel. The 3GPP provides channel size options of 1.4, 3, 5, and 10 MHz at 700 MHz.[64] In the 4.9 GHz band, channel sizes can range from 1 to 10 MHz. Like public safety's narrowband allocations, the broadband allocation's propagation characteristics are substantially different. To further complicate matters, building penetration, the ability for radio signals to penetrate walls, glass, and other building materials, is substantially different between the two bands. These fundamental differences impact the uses of each band significantly.

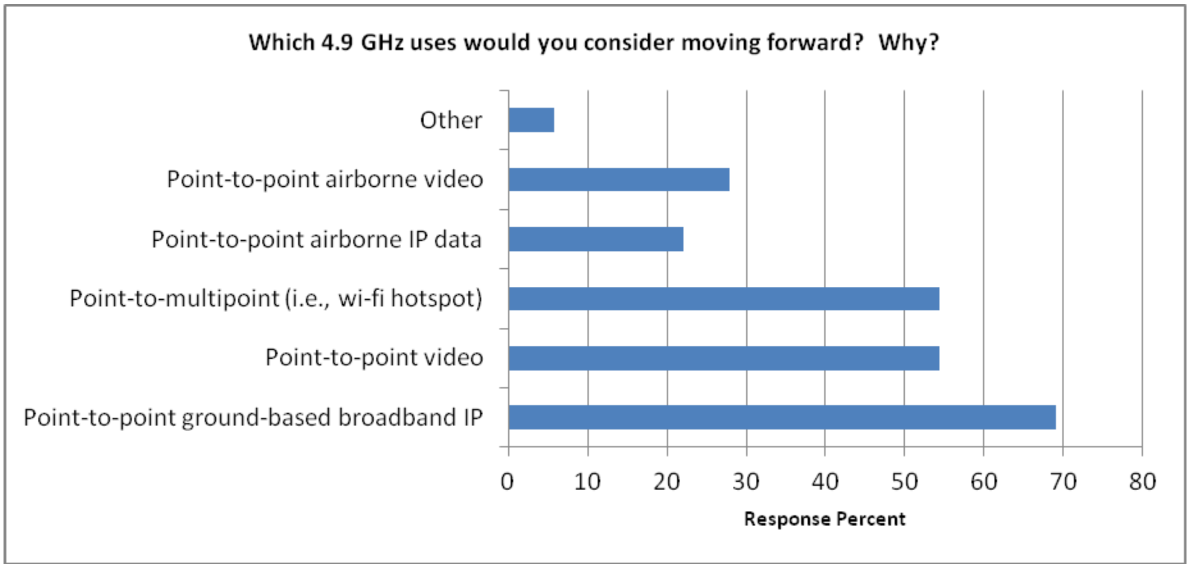
4.3.2.1 4.9 GHz

The uses of 4.9 GHz vary, including point-to-point backhaul, support for video surveillance, and hotspot uses. NPSTC issued a questionnaire to better understand this band. The results are available as a supplement to this report. Using the free space path loss comparison above, all things being equal, 42 sites at 4.9 GHz would be required for every single 700 MHz site. In this case, all things are not equal. Output power limitations at 4.9 GHz further exacerbate the coverage differential. Building penetration data published by NIST show that 4.9 GHz mean losses are as much as 20 dB more than those at 900 MHz with mean building penetration losses of nearly 60 dB.[65] The end result is one where the 4.9 GHz spectrum systems often rely heavily on line of sight (LOS) conditions to achieve reliable communications. Given the stark differences between 700 MHz and 4.9 GHz propagation, 4.9 GHz is simply not a viable solution for large geographical areas or for most mission critical voice applications. However, the 4.9 GHz spectrum allocation does fill very important gaps in

[64] These are the allowable channels sizes for Band Class 14 in the 3GPP standard.
[65] NIST Technical Note 1545, August 2008, page 31

public safety's operational needs. This is especially true in cases where systems can be pre-planned to ensure reliable service.

NPSTC conducted a web-based questionnaire in January 2011 asking about public safety's future uses of the 4.9 GHz band. The following table provides the results of that query.



The results of the questionnaire show there are a variety of viable uses for the 4.9 GHz spectrum allocation. For example, in the case of airborne communications (which require a waiver from the FCC), an LTE device operating 1,000 feet above ground level could interfere with hundreds of LTE cell sites, drastically reducing the net system throughput. Each of the above referenced applications requires substantial spectrum, and importantly, because each use has limited interference tolerance, frequency reuse must also be considered in each area of operation. For example: An airborne video application will require 5 MHz of spectrum for each high-definition video stream. With large urban areas potentially having a dozen helicopters in use at one time, the 50 MHz of spectrum available in the 4.9 GHz band would quickly become saturated. Three helicopters in use at the same incident would be unable to use the same frequency due to interference, and therefore, those three helicopters alone would occupy at least 15 MHz of spectrum.

Likewise, an LTE cell site (eNodeB) with a 20 MHz spectrum allocation (10 MHz paired) generates typical capacities of approximately 50 Mbps.[66] At present, point-to-point solutions in the 4.9 GHz band require 10 MHz of spectrum to satisfy this capacity; however, it is unlikely that such a link would provide access directly to the LTE Evolved Packet Core. Currently, ring architectures are often used to accommodate public safety reliability requirements. These additional hops and additional sites will require more capacity. The amount of capacity depends on the simultaneous load for all sites in the ring. For example, in a medium-sized public

[66] Using the FCC's average throughput per sector of 7.5 Mbps, times three sectors delivers 22.25 Mbps with a 5 MHz channel. Adding overhead for signaling results and doubling to accommodate a 10 MHz channel (20 MHz in total paired spectrum) in roughly 50 Mbps per eNodeB.

safety system under half of the typical site capacity[67], six links and seven sites in a microwave ring, which is connected to a wired aggregation point, requires up to 175 Mbps (seven sites at 25Mbps each). A 4.9 GHz link with an 80 Mbps capacity utilizes 20 MHz of spectrum and 175 Mbps would require 40 MHz of spectrum utilizing a substantial portion of the 50 MHz. Furthermore, there would be no additional spectrum available for frequency reuse and public safety would have to rely solely on dual polarization to mitigate interference. As a result, the 50 MHz of spectrum in the 4.9 GHz band will only be able to satisfy a portion of the net backhaul/interconnect needs of public safety LTE networks and other licensed spectrum allocations will be required to meet the need.

Point-to-point video communications was also noted by questionnaire respondents as an important application for 4.9 GHz. A high-resolution point-to-point video link requires 4 Mbps and 5 MHz of spectrum. Many cities have dozens of law enforcement surveillance video cameras. Assuming an aggressive frequency reuse whereby half of the spectrum is available for each path (including dual polarization use), surveillance video would require 10 MHz of spectrum allocation.

The 4.9 GHz band is also generally thought of as a licensed Wi-Fi band for public safety providing point-to-multipoint hotspot communications. The access points available in the 4.9 GHz band are available in 10 and 20 MHz channel configurations. While Wi-Fi technology has Carrier Sense Multiple Access (CSMA) techniques to minimize interference that could theoretically allow very tight frequency reuse, such techniques severely limit the throughput of the access point (through pauses in transmissions for a shared frequency, retransmissions, hidden nodes, or a combination of these issues). Therefore, frequency reuse is a necessity for hotspot style communications. This then creates the need to use smaller 10 MHz channel sizes and limit the available capacity when hotspots are deployed.

Different regions will use the 4.9 GHz spectrum in different ways. Some may choose to focus on point-to-point video while others may choose to focus on vehicle to portable user hotspots or bomb robots. The ideal configuration will continue to take shape over the coming years. Altogether, the above 4.9 GHz uses require more than the 50 MHz of available spectrum and there are other uses that will further exacerbate the problem. Regional Planning Committees will need to carefully manage their 4.9 GHz spectrum allocations to ensure that their most critical applications are satisfied.[68] Ultimately, public safety will have to turn to other spectrum allocations to fully address the backhaul and interconnect needs of a future nationwide public safety network. These frequency bands themselves are becoming increasingly saturated. Because of the variability of the uses and the uncertainty of the level of backhaul assets of the private partners, these applications have been removed from spectrum planning and are not included in spectrum calculations in the following section.

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[67] This would represent a 50 percent average load on the cell sites assuming typical cell capacity (50% of 50 Mbps or 25 Mbps).

[68] As of September 2012, Regional Planning Committees do not have jurisdiction over the administration of 4.9 GHz spectrum. NPSTC has recommended that they do to improve use of the spectrum and minimize intra-public safety interference. See http://www.npstc.org/download.jsp?tableId=37&column=217&id=162&file=4_9GHz_Comments_090714.pdf for the NPSTC FCC filing on the 4.9 GHz proceeding.

4.3.2.2 700 MHz Broadband

Through the Spectrum Act, a portion of the 700 MHz public safety band is now designated for a nationwide public safety broadband network using LTE technology. The available spectrum in this band has doubled as a result of the Spectrum Act which added the D Block spectrum to 10 MHz already allocated for public safety use. The 700 MHz band is ideally suited for public safety broadband operations. Unlike the 4.9 GHz band, the cell sizes can cover larger areas and penetrate buildings with less loss than 4.9 GHz. The cell sizes can also be made larger (with a decrease in data throughput) to cover the more rural areas. This is not possible with the 4.9 GHz band.

It should be noted there are ongoing discussions in the public safety community over allowable uses of the 700 MHz guardband (768/769-798/799 MHz). It is the desire of public safety to leverage this portion of the spectrum for some public safety benefit. Possible uses being discussed include a nationwide set of vehicular repeater channel pairs and possible localized on-scene voice links.

In addition, the Spectrum Act states, "The Commission may allow the narrowband spectrum to be used in a flexible manner, including usage for public safety broadband communications, subject to such technical and interference protection measures."[69] However, given extensive use of the 700 MHz narrowband spectrum for narrowband applications nationwide, its availability may be severely restricted for broadband communications.

4.3.2.3 Satellites

Communications satellites regularly deliver space-based bandwidth to terrestrial communications network providers to expand or restore backhaul links from cell towers to their network. In times of emergency, satellites are a key part of the infrastructure that can provide additional connectivity for surge use by cell networks, first responders, and other key personnel as demand rises to manage post-disaster activities. In the event the terrestrial communications infrastructure is physically damaged, whether an undersea fiber optic cable is cut or due to network damage from an incident, satellites often deliver network restoration capabilities. Operators of terrestrial wired and wireless networks contract for satellite capacity for such ongoing network restoration capabilities.

The degree to which satellite can provide such capabilities in response to a given incident depends upon its geographic coverage, spectrum compatibility, and commercial availability. Requirements for satellite capacity for surge, backhaul, or network restoration purposes will be specific to a geographic location and the radio spectrum frequencies compatible with the ground equipment of the network operator. The amount of spare capacity available to a particular geographic area is fixed by the number of satellites in orbit with coverage of that area, the number of antenna beams, and by commercial availability on those beams. Communications satellites typically are designed with coverage of specific geographic regions including trans-oceanic, continental, national, or more defined areas and they operate in specific frequencies. Fixed Satellite Services (FSS) satellites operate in the C-, Ku-, Ka- and commercial X-bands, and Mobile Satellite Services (MSS)

[69] Section 6102 of the Middle Class Tax Relief and Job Creation Act of 2012.

satellites operate in the L- and S- bands. Both FSS and MSS networks each have corresponding fixed, portable, or mobile ground stations or terminals.

Satellite operators do have some flexibility to react to urgent requirements. While satellite operators do not typically reserve capacity for surge requirements, they may re-position movable beams, if already built in as a design feature of a spacecraft, or re-load certain customers to maximize availability in a geographic area in reaction to an incident. For longer-term requirements, satellite operators may re-locate a spacecraft in orbit to increase capacity for a given region. The ideal solution for public safety communications would be reserved nationwide capacity so that some level of connectivity is always available. Importantly, configuration of the satellite terminals is far simpler with pre-configured channels. Especially in the case of satellite communications where many in state and local governments lack day-to-day exposure to configuring satellite terminals, pre-configured access to nationwide capacity could save precious minutes in establishing communications to remote locations.

Satellite connectivity should accommodate the net throughput required at a major incident in both the uplink and downlink directions. The worst case incident identified in the Operations Report, the Southern California wildfire incident, required more than 23 Mbps of throughput at its peak as modeled in the Spectrum Report with roughly 12.9 Mbps on the downlink and 10.4 Mbps on the uplink. Therefore, the satellite link must be sized to accommodate the entire bandwidth.

The current vision of the public safety community is that satellite should eventually be integrated into a nationwide public safety broadband network and that most user devices will eventually have dual terrestrial/satellite capability so that when the terrestrial system is not in service or there is no terrestrial coverage the public safety user will have service.

4.3.3 Backhaul

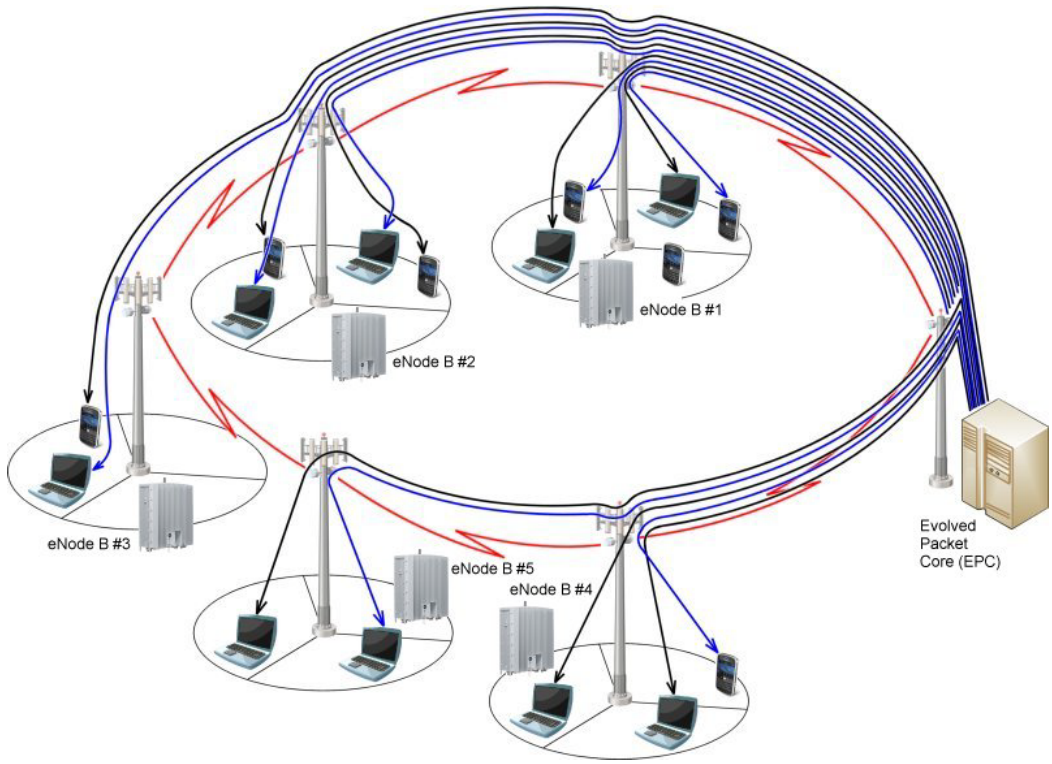
An important component in public safety's communication networks is the connectivity between remote sites and the central switching and routing,[70] otherwise known as backhaul. Some government agencies have built extensive fiber networks, but this is not the norm. Many agencies lease circuits from telecommunications providers; however, many of these links are single points of failure for remote site survival. Public safety communication plans must account for its communication needs associated with the net future demand at these remote sites. The connectivity, as highlighted in the 4.9 GHz section above, includes backhaul of LTE-based traffic, point-to-point IP links, point-to-point video, and backhaul of LMR voice and data traffic. Public safety plans must accommodate transporting this traffic from the remote sites to the Evolved Packet Core (EPC).

In each backhaul category, technology changes are expected between 2012 and 2022. Video resolution needs are expected to increase along with spectral efficiency of backhaul systems. In some cases, traffic optimization will lead to less traffic that must be backhauled. For example, LTE features such as Local IP Access (LIPA), Selected IP Traffic Offload (SIPTO), and IP Flow Mobility and Seamless Offload (IFOM) have

[70] The central switching and routing functions in LTE are provided by the Evolved Packet Core (EPC).

been specified through Release 10. The ability for these technologies to minimize backhaul requirements will depend on femtocell and Wi-Fi deployments as well as the type and destination of traffic.

The sheer volume of traffic from the future nationwide broadband network is a concern. With a 20 MHz allocation at 700 MHz for LTE, each cell site is expected to have a capacity of 40 to 50 Mbps.[71] The public safety requirement of redundancy requires dual paths (no single point of failure) between these remote locations and the core network. This often leads to a ring architecture whereby the individual links connecting the remote sites must carry the traffic of more than one site. Consequently, the individual backhaul links making up these rings must be sized to carry the net traffic of the sites on the ring. Furthermore, because any one link could fail, the system must be designed to continue to support the full capacity of the system during that failure. This means that in a seven-site ring, the traffic may require six sites worth of traffic to reach the seventh site and support the aggregate and simultaneous demand of those six sites. In that case, with fully loaded cell sites, the LTE network would require the final link in the ring to accommodate 240 to 300 Mbps. Furthermore, this substantial amount of traffic must traverse back to the EPC from the ring.[72] A major 300-site regional network may require total aggregated traffic of more than 10 gigabits per second (Gbps).



While there are multiple wireless solutions that could address the individual site rings, the aggregation rings could exceed the capacity of current microwave links (300 Mbps) or free space optics (1.25 Gbps). It will require fiber optic communications instead.

Importantly, public safety will need to develop these fiber optic aggregation links over the coming decade as public safety broadband use increases. The traffic generated by public safety will be unlike that of

[71] This is based on the FCC specified 7.5 Mbps per sector for three sectors or 22.5 Mbps using 5 MHz channels. Adding in overhead and signaling on the various LTE interfaces and doubling based on 10 MHz channels associated with a 20 MHz allocation would result in a net backhaul requirement of up to 50 Mbps.

[72] Unless, as discussed above, IP traffic offloading technologies are used.

commercial markets. Public safety broadband traffic will typically be limited on a routine basis, but it is during major incidents that the peak simultaneous demand exists. Therefore, in normal circumstances, all sites will not generate 50 Mbps each. Instead, the average simultaneous load from each site will be somewhat less. At this point in time, it is unclear what the reduction will be, and therefore, it is difficult to assess how that may reduce the net backhaul requirements for LTE systems. In fact, the potential inclusion of consumer traffic on the network further complicates matters.

It is important to quantify and plan for public safety's ongoing net spectrum needs and recognize the financial realities of the alternatives. Fiber deployment in urban areas costs between $25,000 and $500,000 per mile in typical scenarios depending on aerial versus buried cable and if boring is required. Some municipalities can secure wide-reaching dark fiber access through cable franchise agreements to establish the kind of network extent required to reach LTE cell sites every 3 to 5 square miles. But, where this is not the case, it is unwise to assume governments can afford dual-path fiber to every LTE site. Instead, in the absence of a private partner with backhaul assets, the expected model in those scenarios is one where microwave rings transport traffic to fiber aggregation rings. Therefore, the spectrum requirements associated to this scenario is limited to those rings. The size of the rings will be limited by system reliability. Microwave rings will tend to include six to ten links.

There are a number of commercial microwave bands public safety can leverage for point-to-point backhaul. The primary spectrum bands to meet the net aggregate demand for public safety include:

Table 19: Primary Microwave Backhaul Bands

Band	Commercial Spectrum Available (MHz)	Uses / Notes
6 GHz	850	Lower 6 GHz band (5925-6425 GHz) congested because shared with satellite
11 GHz	1130	
18 GHz	2000	
23 GHz	2400	Band shared with federal government (lengthy review process)
26 GHz	1000	
38 GHz	1400	

Many different types of organizations are utilizing these fixed microwave service bands and many bands have become very congested, especially in urban areas and especially at lower frequencies. The higher the frequency of the microwave link, the shorter the maximum range due to the effects of signal propagation at the higher frequencies. As a result, despite substantial amounts of spectrum at the higher frequencies, they may not provide sufficient reliability to support public safety broadband service. In order to "hop" from cell to cell in order to create connections from all sites to the core via microwave depends on a variety of factors including the distance between sites and the availability of microwave frequencies. The cell radius of an LTE site will vary depending on the level of coverage (in building versus outdoor) and the environment (open versus significant natural or manmade clutter). If LTE sites can be sufficiently close together, public safety network designers can choose from a variety of spectrum bands increasing the likelihood of successfully implementing a system.

4.3.4 Spectrum Use Summary

The following table provides the spectrum bands currently available to public safety, the amount of spectrum available, and the applications for each band:

Table 20: Public Safety Spectrum Amount Available, and Applications

Band		Frequency Range MHz	Spectrum Available MHz	Channelization	Notes / Spectrum Uses
HF NB	Low Band	25-30	6.3	Narrowband: 20 kHz	• State and rural wide area coverage
VHF NB				Narrowband: 25 kHz pre 2013, 12.5 kHz post 2013	• State and rural wide area coverage • Paging • Push-to-talk voice communication (analog, digital, simplex, repeated) • Mission critical data (low speed data including status update and computer aided dispatch messaging)
	High Band	150-174	3.6		
	SMR Band	220-222	0.1		
UHF NB	Low Band	450-470	3.7	Narrowband: 25 kHz pre 2013, 12.5 post	• Metropolitan/urban wide area coverage • Push-to-talk voice communication (analog, digital, simplex, repeated) • Mission critical data (low speed data including status update and computer aided dispatch messaging)
	TV Sharing	470-512	6 – 24		
	700 MHz	769-775 799-805	12	12.5 kHz[73]	
	NPSPAC	806-809 851-854	6	25 kHz[74]	
	Interleave	809-815 854-860	?	25 kHz	
700 MHz GB			2	N/A	• Undefined at this time
700 MHz BB	PSBL	758-768 788-798	20	Broadband (1.4, 3, 5, and 10 MHz options in 3GPP)	• Broadband data applications such as real-time streaming video, high-resolution image transmission, building plans, and others available at the desktop today • Eventually satisfying some or all of the push-to-talk voice requirements
4.9 GHz		4900-4950 MHz	50 MHz	Broadband: 1 – 10 MHz channels	• Local area wireless hotspots • Video surveillance connectivity • Airborne broadband operations • Stopgap backhaul for 700 MHz broadband cell sites
Satellite		C-, Ku-, Ka-, L, S and X-bands	N/A. No public safety allocations		• Disaster recovery • Rural/underserved area coverage
Backhaul		6 GHz 11 GHz 18 GHz 23 GHz 26 GHz 38 GHz FSO	No block grants, individual licensing varies		• Connectivity for Land Mobile Radio, LTE, and fixed IP/video to network cores • Connectivity to fiber aggregation points for LTE systems

[73] Pending Rulemaking from the FCC which could expand this band to allow for broadband channelization.

[74] 800 MHz band NPSPAC channel centers are spaced every 12.5 kHz but the rules allow 25 kHz wide channels with tighter emission limits and geographic spacing between adjacent channels.

4.4 ITU Spectrum Model

The Spectrum Task Group surveyed for a model that would be suitable for public safety needs. The Task Group identified an ITU model based on an ITU cellular model but which was updated to include narrowband voice in the spreadsheet implementation. The model is flexible and can accommodate both public safety and broadband spectrum modeling. The model leverages four fundamental variables to determine the amount of spectrum required: Demand for a given area, number of sites/cells covering the area, spectral efficiency of the technology providing the service, and the amount the technology is able to reuse frequencies. The model provides a spectrum calculation for each type of service. For example, in the case of narrowband spectrum, the model can include voice calls and messaging. The basic equation employed in the model for each service and path is as follows:

$$Spectrum\ (MHz) = \frac{Traffic\ Per\ Cell\ (Mbps)}{Net\ System\ Capability\ \left({}^{bits}/{}_{second}/{}_{Hz}\right)}$$

This fundamental equation was applied for the various service categories in both the uplink and downlink paths. In calculating the total demand per cell, the model factors in the total seconds of usage per user, the average users per cell, and the bit rate for the application in question. The net system capability is determined by calculating the available channels in a given cell and the net capacity in a cell to determine the spectral efficiency of a single cell. The details of the model can be found in the ITU White Paper *REPORT OF THE INTERIM MEETING OF WORKING GROUP 8A3.*[75]

Spectrum models are not precise tools. They are sensitive to the inputs and assumptions. For example, the ITU model assumes traffic is spread equally over the entire service area while there may be some "hot spot" locations that may have substantially higher demand. The inputs for public safety population used in the voice modeling below are based on U.S. Census, Federal Emergency Management Agency (for the fire population), and Bureau of Labor statistics. In each case, the number of public safety personnel per 100,000 in population was used to estimate the number of EMS, fire, and police for each scenario. The Spectrum Task Group used 2010 Census figures with no projected growth over the next 10 years. Public safety voice systems support more than just EMS, fire,

Public safety voice systems often support more than just EMS, fire, and police. Public works, transportation, animal control, and other general government functions are supported on these systems; however, with no supportable penetration data, the modeling does not include the spectrum impact of the other governmental functions (non EMS, fire, and police) and users. ***<u>As a result the calculations will tend to represent conservative estimates of spectrum.</u>***

[75] See http://www.npstc.org/download.jsp?tableId=37&column=217&id=2344&file=ITU_Report_WorkingGroup_8A3.pdf

and police. Public works, transportation, animal control, and other general government functions are supported on these systems; however, with no supportable penetration data, the modeling does not include the spectrum impact of the other governmental functions (non-EMS, fire, and police) and users. As a result the calculations will tend to represent conservative estimates of spectrum. Other assumptions used are explained below in the modeling sections.

The results of the modeling are intended to show trends and not absolute quantities of spectrum required. For example, the broadband modeling for each focus group incident resulted in a different predicted amount of spectrum needed. This is to be expected as each incident required different numbers of personnel and differing application usage. What is important is the relationship of the predicted spectrum as a whole to the available spectrum.

4.5 Spectrum for Voice

4.5.1 VHF Spectrum

Results of the Operations Task Group survey and input from the Spectrum Task Group members indicated the VHF band was congested in less populated and rural areas. Normally if spectrum needs can be met in the most dense urban areas like Los Angeles or New York, then other areas spectrum needs will also be met; however, in rural areas some bands are better suited for use than others. The primary band for rural areas is the VHF band. It has very good propagation over long distances and requires fewer sites than would be needed on at higher frequencies. The infrastructure and subscriber equipment is less expensive compared to higher bands especially compared to 700 MHz and 800 MHz trunked systems. Most agencies in rural areas are small in size but are responsible for large geographical areas. Frequently the availability of suitable radio sites for infrastructure is limited due to a number of factors such as environmental constraints, power availability, and site access issues. There are few trunked systems in this band and there normally is a considerable amount of direct unit-to-unit communications also. These constraints along with cost drive the need to cover the largest area with the fewest sites. This in turn reduces the frequencies' reuse. The VHF band also is not a paired band so when channels are needed for repeater operations essentially random frequencies are paired together. This reduces spectrum efficiency in that band and is not easily modeled.

To determine the validity and extent of the rural congestion, the northern counties of Arizona were selected for modeling. These counties have the characteristics described above. They are large with small populations and varied terrain. The counties are Mohave, Yavapai, Coconino, Navajo, and Apache. The number of users was determined from public source documents.[76]

The model assumes a trunked system and the efficiencies trunking provides. Rural areas seldom use trunked technology due to the cost and their small population size; therefore, assuming trunked operation results in a

[76] This data was derived from Census data for the counties studied to determine the number of police, EMS, and local government workers. This assumed 2.2 police officers per 1 k of total population, 2.21 EMS units per 1 k of total population. Fire population was determined from http://apps.usfa.fema.gov/census/.

conservative spectrum requirement. The 30 km site coverage radius, while large for an urban area, is also conservative for rural areas.[77] The table below shows the primary inputs used for the VHF spectrum model:

Table 21: Arizona (VHF) Area Spectrum Modeling Parameters

Parameter	Value	Notes
Total Police Personnel	1344	Based on Census data
Total Fire Personnel	2881	Based on FEMA data
Total EMS Personnel	1350	Based on Census data
Total Study Area Size	51255 km^2	Represents the five county area
Cell Radius	30 km	Results in 18.1 sites to cover the study area
Total Width of Frequency Band	3.6 MHz	The VHF spectrum
Guard band and reserved channels	5%	Results in 7.2 channels
Average Call Duration – Voice Uplink	7.5 seconds	
Average Call Duration – Voice Downlink	26.5 seconds	

Total spectrum requirement from the model is **7.07 MHz** to support the above number of users. The study assumed a 30 km site radius, 12.5 kHz bandwidth per voice channel, and Omni cell pattern resulting in 18 sites to cover the area. The model includes spectrum for low-speed data service and status messaging at a 20 percent penetration rate. The voice-only spectrum need is 6.83 MHz. Furthermore, this figure represents the sum of uplink and downlink spectrum needs, and does not assume paired spectrum. The following table represents the summary of the VHF spectrum modeling results for Northern Arizona:

Table 22: Arizona (VHF) Spectrum Results

Service	Uplink (MHz)	Downlink (MHz)	Total (MHz)
Narrowband Voice	.93	5.9	6.83
Narrowband Data	.08	.15	.23

This conservative result validates the operations questionnaire as only 3.6 MHz of VHF spectrum is available for public safety use. Unfortunately, the 6.3 MHz allocated to public safety between 25 and 50 MHz cannot be leveraged towards this need for multiple reasons. First, portable subscriber devices in the HF band work very poorly and portables are essential to modern public safety communications. Many of the rural public safety operations require portable radios. Second, the HF band itself is congested with statewide law enforcement and state transportation operations. This latter factor is due to propagation characteristics that result in very poor frequency reuse. As a result, this leaves only 3.6 MHz of spectrum while the model represents more than 7 MHz of demand. The rural need identified by this study must be addressed by additional spectrum allocations for public safety in the VHF band.

[77] FCC Part 90 rules allow up to 40 km radius without special showings.

4.5. 2 UHF Narrowband Voice Spectrum

To judge the need for narrowband voice spectrum in a mixed urban/suburban/rural area, the Task Group modeled the spectrum needs for the Seattle, Washington area. The model included King, Pierce, and Snohomish Counties. These counties, while not having the large population density as the New York or Los Angeles areas, do have a combined population of 3.4 million. The geographical area is 6203 km. The Puget Sound area is a dense urban area, with suburban and rural communities to the east. Spectrum availability is reduced because of the need to share with Canada.

The modeling assumed 7.7 km site radius and a frequency reuse pattern of 21. Most systems in the three counties are implemented on the 800 MHz band with some new transit systems using the 700 MHz band (112 channels licensed). From a review of licensing data, nearly all 800 MHz channels in the three counties are licensed. This area also makes heavy use of simulcast systems to improve coverage and maximize efficiency of the available channels, since simulcast systems reuse the same frequencies at each site in the system. The license data showing the number of sites and knowing that simulcast technology is used, lead the Task Group to the selection of a 7.7 km site radius. The selection of 21 for reuse duplicated the lack of channel reuse, except for re-use within the simulcast system. The ITU model paper suggested which Erlang values to use from the PSWAC *Final Report*. A review of that document showed the traffic to include most communications in the direct mode not using infrastructure.

While this was appropriate for the VHF modeling, it is not correct for this area. The use of trunked and simulcast systems allows users to keep nearly all traffic on the infrastructure system. This implies a balanced load between uplink and downlink traffic. The model inputs were modified to reflect the uplink and downlink balance. Also the Erlang "per user value" used was an average of the values shown in the PSWAC *Final Report* for police, fire, and EMS. All input values were selected to reflect the nature of this geographic area, reflecting the mixed urban, suburban, and rural nature of the area. The parameters and results are shown below:

Table 23: Seattle Area (UHF) Spectrum Modeling Parameters

Parameter	Value	Notes
Total Police Personnel	5847	Based on Census data
Total Fire Personnel	5114	Based on FEMA data
Total EMS Personnel	2371	Based on Census data
Total Study Area Size	6203 km^2	Represents the three county area
Cell Radius	7.7 km	Results in 33.3 sites to cover the study area
Total Width of Frequency Band	5%	Represents 70.2 channels (most of these are in the 700 MHz band
Guard band and reserved channels	5%	Results in 7.2 channels
Busy Hour Call Attempts – Voice (Uplink and Downlink)	13	Per the PSWAC voice model
Average Call Duration – Voice (Uplink and Downlink)	13.9 seconds	This average call duration delivers the average busy hour Erlang result from the PSWAC model (0.0502 Erlangs per user)

Table 24: Seattle (UHF) Spectrum Results

Service	Uplink (MHz)	Downlink (MHz)	Total (MHz)
Narrowband Voice	8.33	8.33	16.66
Narrowband Data	.1	.189	.29
Narrowband Status	.005	.007	.012
Total (Unpaired)			16.96

Total spectrum required is 16.96 MHz of unpaired spectrum from the model. The total available spectrum includes high band 30 to 50 MHz, VHF, and UHF 450 to 470 MHz plus the 700 and 800 MHz bands. In general, the narrowband spectrum available is 35.1 MHz but due to sharing agreements with Canada not all is available to use in the greater Seattle area.

For the reason cited in the VHF modeling, the 30 to 50 MHz band is not practical to use in this area. The VHF band is also a poor choice because the frequencies are not paired and are not licensed on an exclusive basis making it very difficult to implement compatible trunked systems. The 450 to 470 MHz band could be used if exclusive channels are available in the band, but that option is unlikely based on a review of license data. Also the cost for dual band operation would be high. Therefore the useable spectrum is the combination of the 700 and 800 MHz narrowband voice spectrum or 21.5 MHz minus what is not available due to sharing with Canada. For the 800 MHz band, all 6 MHz of the NPSPAC band is available but only about half of the 800 MHz spectrum above 854 MHz for an approximate 1.75 MHz and total available of 7.75 MHz for 800 MHz. In the 700 MHz band for most of the area only 50 percent (6 MHz) of the spectrum is available, but for southern Pierce County, where all 12 MHz is available. The net result is between 13.75 and 18.75 MHz of spectrum in the 700/800 MHz bands with the more congested City of Seattle falling on the lower end of the range. Any further growth of voice systems in this three-county area will need to use the 700 MHz spectrum. As can be seen by comparing the model predictions to available spectrum, availability of voice narrowband spectrum is tight. The 700 MHz narrowband spectrum is needed now and will be more heavily used until voice PTT can be substantially transitioned onto the nationwide public safety broadband network system.

4.5.2 Additional Narrowband Spectrum Options

The analyses show there is a continuing need for the current narrowband spectrum allocations as well as a shortfall of needed narrowband spectrum. In the VHF band, the model showed nearly a doubling of spectrum is needed. There are few options for additional spectrum allocations in the UHF band. One option to gain additional channels would be sharing of channels from the Part 90 Subpart C Industrial/Business Pool VHF channels. There are issues to address that can make this option viable. A study would be necessary to determine the extent of licensing of the VHF channels in rural areas, along with an audit of current use of the Industrial/Business pool channels. The FCC would also need to amend the rules to provide for exclusive use of the channels by public safety where the sharing is possible. Another option is for the FCC to allow public safety access to the Part 22 radio telephone VHF frequencies. [78] These channels appear to be lightly used

[78] FCC Part 22.725 channels

now because cellular has replaced the main use of these channels. A search of the FCC ULS database for Arizona shows the following use:

Table 25: Part 22 License Count for Arizona

Base Frequency(MHz)	Number of Active Licenses
152.030	0
152.060	1
152.090	2
152.150	2
152.180	0
152.210	1
152.510	0
152.540	1
152.570	0
152.600	0
152.630	0
152.660	0
152.690	0
152.720	0
152.750	0
152.780	0
152.810	1

It is apparent from the search results that these frequencies are lightly used in Arizona. A quick random search of California and Nevada on a few of these frequencies showed a similar pattern. These frequencies have advantages: They are paired allowing easy repeater or trunked configurations, they are assigned on a non-interference basis and, with a 30 kHz bandwidth, they can be split into two 12.5 kHz wide channels for public safety use. This could also enhance interoperability if one of the two 12.5 kHz narrowband channels was designated for interoperability use.

For other bands, few options are available. There will be varying amounts of 800 MHz spectrum available as areas are rebanded. Areas similar to the Seattle area will need to use the 700 MHz band to expand voice systems in the future. This is being seen in many parts of the nation now. One option to gain some voice spectrum is for the FCC to audit usage of all narrowband voice spectrum and reclaim unused spectrum. This reclaimed spectrum could then be made available for public safety use.

4.6 Spectrum for Broadband Data

Following recent passage of the Middle Class Tax Relief and Job Creation Act of 2012, public safety is now allocated 20 MHz of broadband spectrum in the 700 MHz band. The majority of public safety representatives believe this spectrum allocation is needed to provide sufficient capacity to meet data needs both day-to-day and to manage large incidents. This spectrum block is compatible with LTE equipment and comprises band class 14.

Using data from the Operations focus groups and technical data from the Technical Task Group, the amount of spectrum needed was modeled using the ITU model for each scenario. This modeling did not include the routine day-to-day traffic load, but only the incident load. The complete spreadsheet model is available on the NPSTC website.[79] The following table represents the general assumptions that apply to all four incidents:

Table 26: Broadband Spectrum Modeling General Parameters

Parameter	Value	Notes
Cell Type	Sector	Based on the typical public safety architecture
Frequency Reuse Group Size	1	Assumes reuse of same frequency in each sector as is customary with LTE systems
Application Penetration Rate	100%	The specific number of users for each application was identified for each scenario; therefore, the penetration per application is 100%.
Activity Factor	1	Based on dispatch voice ITU White Paper
Grade of Service Traffic Multiplier	1.5	Per the ITU White Paper for public safety systems.[80]
Overhead and Signaling Factor	1.15	Represents overhead from Layer 1 to Layer 3 and other signaling traffic in LTE.
Weighting Factor	1	Environments are assumed to have coincident busy hours
Adjustment Factor	1	Assumes one system in a given area (not per agency or per municipality)

The following sections provide the input values and justifications for the remaining inputs to the broadband spectrum models.

4.6.1 Incident Area and Spectral Efficiency

The four public safety incidents outlined in the Operations Report and their scopes are outlined in the following table:

[79] Spectrum spreadsheets are online at http://npstc.org/pswac.jsp

[80] See REPORT OF THE INTERIM MEETING OF WORKING GROUP 8A3, April 2001, Page 28. The multiplier is due to the intolerance of public safety systems to blocking. Due to the extensive expected use of video, which is highly sensitive to available bandwidth with modern codecs, video sessions are expected to be "blocked" to avoid degradation of other services or video sessions. Because low quantities of such video sessions can be supported on a single sector, the "Erlang B factor" identified in the ITU report for narrowband voice environments is applicable to public safety's broadband environment.

Table 27: Public Safety Incidents Used in Focus Groups

Location	Type	Area Type	Personnel	Vehicles	Area (mi2)
So. Cal.	Wildfire	Rural	3,000	1,000	35
Houston	Chemical Explosion	Suburban	200	50	5
Washington, DC	Toxic Gas	Urban	327	127	1
Orlando	Hurricane	Suburban	220	60	1

The table highlights how the various types of public safety incidents can impact LTE system capacity. Depending on the density of cell sites, each of these incidents could have one or more serving sectors (cells). For example, the District of Columbia deployed 12 broadband sites to serve its 68 square miles, or 1.34 square miles per sector. The urban incident of the table above could then be contained within a single sector with this cell density. If Incident Command or the incident itself occurred at the cell edge, the bulk of the traffic could have low spectral efficiency. The incident could also be spread across two or three intersecting sectors. In that case, the spectral efficiency would be very low due to the poor signal-to-noise ratio at the incident, but the traffic could be load balanced among the sectors to handle the additional traffic.

A dense, in-building coverage site radius of 1 mile would result in a 1-mile square sector service area. A rural or suburban site might have a cell radius ranging from 2.5 to 5.0 miles or 19 to 78 square miles per sector. The cellular carriers have much higher build densities approaching 0.25 mile radius due to their need for higher capacity levels; however, such a deployment would require 16 times the quantity of sites in the urban areas. Public safety cannot assume it will have the funds to build to that level, and therefore, the Task Group assumed the build density is based on coverage, not capacity.

Due to the size of the incidents and the likely sector service area, the impacts to the LTE system will vary. In order to ensure public safety has the broadband capacity it needs throughout its entire service area, NPSTC considered the worst case scenarios. The following table outlines the assumptions regarding the type of LTE system serving each of the above scenarios (the table is a repeat of Table 14 above):

Table 28: Broadband Incident Spectral Efficiency Inputs

Location	Incident Type	# Serv. Sect.	Traffic Distribution	DL Sp. Eff. (bps / Hz)	UL Sp. Eff. (bps / Hz)	DL Sp. Eff. (bps / Hz)	UL Sp. Eff. (bps / Hz)	DL Sp. Eff. (bps / Hz)	UL Sp. Eff. (bps / Hz)
So. Cal.	Wildfire	1	Uniform	1.57	0.73	3.34	1.55	3.53	1.64
Houston	Chemical Explosion	2	High Concentration	0.47	0.22	1.00	0.47	1.06	0.50
Wash., DC	Toxic Gas	2	High Concentration	0.47	0.22	1.00	0.47	1.06	0.50
Orlando	Hurricane	2	High Concentration	0.47	0.22	1.00	0.47	1.06	0.50

It is important to note that while some of these scenarios could be contained in a single sector, this does not represent the worst case scenario. Given that the cell edge throughput is roughly 30 percent of the typical or average throughput, placing the incident at the cell edge and splitting it between two sectors results in a net spectral efficiency that is 60 percent of the average or typical values. Furthermore, the scenario is more likely to provide a high interference load on the adjacent sectors, whereas, in the event of a single, isolated scenario, the traffic on surrounding sectors could be light, and therefore, signal-to-noise ratios would be higher.

The table above depicts the growing spectral efficiency discussed in the Technology Report for each incident over time. The Spectrum Task Group opted to use the year 2015 spectral efficiency to model the public safety spectrum. This is based on the expectation that the incidents discussed during the focus groups represent the applications and usage that is feasible in the year 2015. Furthermore, the group estimates the 2010 spectrum need will be equivalent to that of the year 2015. While spectral efficiency is expected to increase between 2015 and 2020, public safety expects an equivalent growth in demand during that period. This assumption is consistent with the more pessimistic estimates of the ITU for commercial spectrum allocations.[81] The Working Group felt that public safety's growth, in both users and spectral efficiency, would equal that of the commercial community between 2015 and 2020, and therefore, this pessimistic assumption represents a conservative estimate in the need for additional spectrum by the end of the decade. Further, the Working Group felt this trend would continue through the year 2022, specifically that increases in spectral efficiency between 2020 and 2022 would be offset by equivalent increases in demand during that period. Therefore, the total spectrum required in 2015 remains constant through the year 2022.

4.6.2 Application Throughput, Usage, and User Assumptions

The following table represents the assumptions regarding the application usage at the four incidents. The Working Group established baseline standards for peak throughput, session duration, and sessions per hour for each application. These values are presented in Section 3.7.13 and were used consistently for each incident. The number of users for each application was varied to represent the differences between the four incidents. The number of users for each of the applications is summarized in the table below:

[81] See REPORT ITU-R M.2078, "Estimated spectrum bandwidth requirements for the future development of IMT-2000 and IMT-Advanced," Table 25 on Page 25. The "Lower Market Setting" or lower market demand estimates of the ITU resulted in a slight decrease from 1,300 MHz to 1,280 MHz of total commercial spectrum required, while the "Higher Market Setting" increased from 1,300 to 1,720 MHz.

Table 29: Application Usage Per Incident

	Number of Users Per Application			
	DC	Orlando	Houston	California
Incident Video – High Quality (DL) (aircraft)	2	2	2	2
Incident Video – Medium Quality (DL) Traffic Camera	2	2	2	2
Incident Video – Low Quality (DL) - Situational	4	2	4	10
Incident Video – Low Quality (UL) - Situational	4	2	4	10
Incident Video – High Quality (DL) helmet/vehicle	2	1	1	2
Incident Video – High Quality (UL) helmet/vehicle	2	1	1	2
Incident Video – Medium Quality (DL) helmet/vehicle	6	3	3	6
Incident Video – Medium Quality (UL) helmet/vehicle	6	3	3	6
Incident Video – Medium Quality (UL) Video conference	1	1	1	2
Incident Video – Medium Quality (DL) Video Conference	1	1	1	2
Automatic Location (UL+DL) Vehicles	127	60	50	1000
Automatic Location (UL+DL) Personnel	253	120	150	1000
Geographic Information Systems (GIS) - Street View	15	10	5	100
GIS Detailed View	4	4	2	10
File and Message Transfer UL	25	12	15	200
File and Message Transfer DL	253	120	150	2000
Patient and Evacuee and Deceased Tracking	10	10	6	10
Biotelemetry – First Responder (UL+DL)	150	30	50	1000
Biotelemetry - Patient	10	5	2	10
Vehicle Telemetry	127	30	50	500
Third Party Sensors	4	0	4	0
Weather Tracking	2	1	2	5
PSTN Voice (Cell Phone)	20	10	10	50

These user quantities represent conservative estimates of the expected population of public safety application users. In the Washington, DC, focus group, the participants estimated that 10 percent of all users -would be streaming video at the same time and requiring high to medium quality. This would represent nearly 13 vehicles and over 25 personnel, or a total of 38 total video streams. The table above shows only 12 total video streams, less than one-third of the estimated need. The Working Group determined those initial quantities were too aggressive and there would likely be limited ability for command to view and process the content. In the event the video needs for an individual incident substantially exceed those represented in the above table, the resulting spectrum demands will increase accordingly.

4.6.3 Broadband Incident Modeling

The following table provides the results from the ITU model for the four broadband incidents. It reflects the demand in the uplink (UL) and downlink (DL) directions:

Table 30: ITU Model Results for Broadband Incidents

Incident	Study Area (sq. mi)	Spectral Efficiency Type	Serving LTE Sectors	2015 DL Spectrum (kHz)	2015 UL Spectrum (kHz)	2015 Total Unpaired Spectrum (kHz)	2015 Total Paired Spectrum (kHz)
Washington DC Gas Leak	1	Cell Edge	2	8,852	13,792	22,644	27,584
Southern California Wildfire	35	Average	1	6,681	11,622	18,303	23,244
Houston Chemical Plant Explosion	5	Cell Edge	2	6,451	8,376	14,822	16,752
Orlando Hurricane	3	Cell Edge	2	6,015	7,497	13,511	14,993

The table reflects the impact of these incidents on a broadband LTE network. Two total spectrum calculations are shown in the above table. The first total reflects the sum of uplink and downlink spectrum allocations while the second total column represents the paired value based on the worst case between uplink and downlink. In all the scenarios, the existing 5 MHz spectrum pair cannot support these incidents. The combination of the D Block spectrum would provide a paired 10 MHz allocation. Two of the four incidents exceed even this increased spectrum allocation. The Washington, DC, incident and the Southern California incident would exceed a 20 MHz allocation. If only 20 MHz is allocated to public safety, clearly quality of service and careful management of the applications and bandwidth will become critical.

The need for broadband spectrum is driven by several factors. The type of application, total area covered by an incident, spectral efficiency of the LTE network, and cell coverage radius all impact required spectrum. The Washington, DC, incident was a compact incident almost contained within one sector of the cell site. That along with the heavy need for video and Internet access drove up the need for spectrum. In contrast, the Houston incident was modeled to spread over two cell sites and benefited from the additional capacity of cell spectrum reuse.

For public safety to accept the nationwide public safety broadband network as a mission critical capable network, the network must reliably carry the traffic necessary to manage the vast majority of incidents without depending on commercial networks. The public safety community has found over the years that commercial cellular systems become overloaded or fail entirely in the geographical area of major incidents. Commercial networks cannot be depended upon to carry critical incident traffic. If the public safety users know they cannot depend on a network, either the nationwide public safety broadband network or commercial systems during large incidents, then they simply will not base their incident management plans around applications that are likely to fail. For these reasons the nationwide public safety broadband network must have sufficient capacity and spectrum to reliably carry all application data for the vast majority of incidents.

The incidents modeled for this report are a good cross-section of incidents that, with the exception of the DC incident, happen on a yearly basis. In fact the wild land fire incident on a smaller scale happens numerous times each year. It is clear from the modeling that 10 MHz of broadband spectrum for the nationwide public safety broadband network is not enough and that 20 MHz of spectrum would allow the network to carry the necessary traffic in all the but the most extreme cases such as the DC incident. Importantly, many optimistic assumptions have been made in the modeling. For example, the long-term spectrum needs are based on whether spectral efficiency gains projected by ITU are met. Additionally, the model assumes all video traffic is multicast or broadcast (without an impact to spectrum efficiency as suggested by the ITU). In consideration of these factors it will be imperative that public safety implement priority of service to manage traffic with minimal impact to incident management.

4.7 Backhaul for Data and Voice Spectrum

The implementation of the nationwide public safety broadband network will require considerable backhaul data needs. As discussed in the Technical Report, a combination of fiber and microwave transport will be required to meet the backhaul needs of the nationwide public safety broadband network. The need for microwave spectrum will compete with the commercial services needs for microwave backhaul as they build out 4G networks. The current microwave bands are heavily used and may not support this additional build out for commercial and public safety broadband backhaul needs.

One resource for public safety is the 4.9 GHz band. This band can help with the problem but not solve all the wireless backhaul requirements. Changes will be needed to the current rules for 4.9 GHz if it is to play a larger role in providing backhaul capacity. Larger dish sizes reduce beam width of point-to-point links and thereby allow more links without interference. Still where the 4.9 GHz band is heavily used for hotspots and mesh systems in urban settings, it will be difficult to expand use of the 4.9 GHz band for backhaul use. The 4.9 GHz band will be better suited for suburban and rural areas.

Another resource, but with more risk, is use of the 5 GHz unlicensed bands. Low-cost equipment is readily available for point-to-point use, but the bands are unlicensed and the risk of interference is greater compared to licensed bands. There are features available in the equipment to minimize interference somewhat mitigating this risk and agencies have successfully operated single hops with very good reliability.

The Spectrum Task Group is very concerned about the ability for the existing allocations to fully support the anticipated demand from public safety broadband systems. Additional spectrum for microwave backhaul use, while not readily identifiable, will be needed between 3 and 18 GHz to provide the needed range between LTE sites. The amount of spectrum must support up to 150 Mb/s data rates.

4.8 Interoperability Spectrum Needs

The table below lists the interoperability channels available in each band.

Table 31: Interoperability Channels by Band

Band (MHz)	Number of Frequencies or channels
25-50	4
150-174	10
220-222	0
450-470	8
809-815/854-860[82]	0
806-809/851-854[83]	5
769-775/799-805	32

The 220 MHz band is very lightly used and there is no need at this time for interoperability channels. The operations questionnaire did not highlight the need for additional interoperability channels in any specific band; however, feedback from NPSTC's Interoperability Committee indicates that field reports from COM-L training shows a need for additional channels in all bands except 220 and 700 MHz narrowband. While the table above shows inadequate interoperability channels at 800 MHz, the recent incorporation of equipment that includes both 700 and 800 MHz allocations in a single radio means the substantial number of interoperability channels at 700 MHz are available to 800 MHz users as 800 MHz devices are replaced with dual band capabilities. Therefore, the most pressing need for additional interoperability channels is in the VHF band. Given the uncertainty and timeframe of a transition of traffic from narrowband to broadband technologies, a solution for VHF interoperability is needed in the short-term.

[82] This allocation was altered by the ongoing 800 MHz reconfiguration. Some additional channels are being made available to public safety as the reconfiguration completes and total the number varies per geographical region. These additional channels are not included in the table count. See FCC 90.615.

[83] The NPSPAC band moved to the low end of the band with no change in the size of the allocation due to the 800 MHz band reconfiguration. See FCC 90.677.

5 Contributors

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The National Public Safety Telecommunications Council gratefully recognizes the hard work of the authors of this report. Joe Ross, Chair, AFST Working Group, guided the project for 2 years, assembling representatives of the public safety community who need spectrum to do their daily jobs of saving lives and property, and authoring the Technical Section of this report. NPSTC would also like to thank Televate, LLC, for its contribution of Joe's time on this project.

Barry Luke, Chair, Operations Task Group, developed questions, analyzed the data from the questionnaires, and led and analyzed the responses from the focus groups. Dave Buchanan, Chair, Spectrum Task Group, with the assistance of first responders and engineers, turned the requirements into the actual numbers reflecting spectrum needed in the next 10 years.

Special thanks are also due to all of the Working Group and Focus Group volunteers who provided thousands of hours of their time and expertise to write the Public Safety Communications Assessment 2012-2022: Technology, Operations & Spectrum Roadmap. Their work will positively impact the future of public safety telecommunications.

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